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Book of Abstracts

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Key enabling technologies for drone based multi-agent systems

Chaired by:
Dr. Ricardo Reis (Embraer), Dr. Raj Thilak Rajan (TU Delft),
Dr. Morten Larsen (AnyWi Technologies)

Analysis of the new market trends of UAVS for safe BVLOS operations

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** Harokopio University, Greece*

The deployment of Unmanned Aerial Vehicles (UAVs) is witnessing an unparalleled expansion in recent years in various application domains. These sophisticated tools are currently conquering the skies for various data intensive applications in diverse sectors. Technology advancements in sensors and communication technologies have opened the way for new applications that will further boost their, leading in turn to a growing interest among business leaders, policy makers and the public, creating more business opportunities. Beyond Visual Line Of Sight (BVLOS) operations in particular have gained significant attention in recent years, for their higher degrees of intelligence that brings several benefits. One of the greatest challenges for the greater adoption of UAV operation is safety and the resulting trust, which in turn represents the prominent driving force to reach a high technology acceptance from users. This work examines the emergence of recent market trends for BVLOS operations and their influence on the integration of safe and autonomous UAVs operations and will be the main driver in the improvement of multiple applications. In this context, a thorough review of the current market trends is provided, while the existing guidelines and regulations of UAV operations are validated through an extensive survey.

Hardware-based-security support for improved drone authentication- and communication security

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Similar to the previous Internet of Things (IoT) hype, drones are an emerging field of research on embedded systems and edge computing. Consequently, this application area will also become "the next big thing" to be attractive for hackers, as early drone-related security attacks already indicate. Therefore, the authors present new approaches, which partly enhance conventional software-based TLS authentication methods with hardware-based-security. Only when applied in a proper way – shown in this presentation – this approach can significantly harden the security of future drone communication-platforms. Finally, the authors summarize and compare even two possible approaches and applicable hardware-platforms, based on recently developed proof-of-concept demonstrators.

Designing and implementing next-generation aerial systems with Deterministic Ethernet networks

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The usage of drones for surveillance, logistics, mobility, and other highly demanding applications is pushing existing avionics systems to its limits while processing a high amount of data or proving determinism. Enabling these systems to be more automated, intelligent, and flexible brings enormous complexity into design of aerial avionics platforms which still must deliver a SWaP (Size, Weight, and Power) optimized design, high performance, and high reliability. The demonstrator designed and implemented in the European funded project ADACORSA showcases a novel drone avionics architecture proof-of-concept. TTTech has integrated this prototype based on Deterministic Ethernet backbone to realize a fail-operational drone avionics network with redundancy and defined Quality of Service for all data streams. To ensure interoperability the system uses open communication standards such as e.g., Ethernet or PCIe, and system interfaces can support mixed-criticality data communication (hard real-time also called Time-Triggered, Rate-Constrained, and normal Best Effort Ethernet) over the same wire drastically improving SWaP of the overall system. Infineon's TÜV-certified AURIX safety microcontroller platform with an innovative powered management IC and safety-certified real-time operating system PikeOS by SYSGO are deployed to guarantee functional safety up to the highest needs up to DAL A aerospace applications to deliver certifiable avionics in the future.

On UAV Terrestrial Connectivity Enhancement through Smart Selective Antennas

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Unmanned Aerial Vehicles (UAVs) are becoming widely used in many scenarios, given their advantages with respect to other kinds of aircrafts (e.g., helicopters), are already adopted in various contexts (e.g., surveillance applications, rescue operations in harsh environments, environmental monitoring, experimental delivery services, etc.), and, thanks to the constantly decreasing price of

these devices, they are going to be used for a wide plethora of uprising applications and use cases. Then, most of them will involve Beyond Visual Line of Sight (BVLOS) flights, where the UAV and the control center do not have direct visibility each other and require high data rates, wide coverage and reduced latency, and this will open to the need for the drone to rely, as per the connectivity, on existing third-party terrestrial networks. However, nowadays there are still many problems to be overcome when dealing with BVLOS-like flights and cellular connectivity for drones, as various LTE and 5G cellular networks have been designed and deployed for a terrestrial usage only, while being already able to provide low latency and high data rate communication links, in conjunction with a widespread coverage, which allows a multitude of drones-based applications to be deployed and performed. Moreover, most of the connected terminals (e.g., smartphones, cars, etc.) generally exploiting these kind of networks are located on the ground or in the first tens meters of altitude, since, on a more technical level, this means that the network topology and frequency reuse between nearby cells have been optimized to minimize (or completely avoid) the inter-cells interference on the ground-connected terminals. Instead, when dealing with flying UAVs—that can fly at an altitude between 50 m and 120 m from the ground—a drone-mounted cellular network terminal has direct visibility with multiple Base Transceiver Stations (BTSs) of the nearby cells, implying a strong inter-cell interference, as the system can receive signals also from the several cells. This destructive interference (experimentally revealed through performance measurements carried out by the research community) leads to a reasonable decrease in the radio signal quality parameters, and, as a consequence, on the network's effective performance and stability, thus threatening the safety of BVLOS missions. Moreover, experimental flights performed in an open field area located in the northern Italy returned that the more the drone height increases, the more the keys parameters indicating the LTE networks' signal quality decrease, thus reaching lower values than those observed at the ground level. With reference to a cellular terminal located on-board on a fliying drone, this behaviour can be motivated by its exposure to radio signals arriving from the multiple cells, which in turn reuse the same frequencies allocated in the cell where the UAV is flying, thus making the communication unreliable. Therefore, it is easy to understand how this inter-cell interference problem may be stronger in all those environments where a high number of cells is present (e.g., urban contexts), thus a massive amount of pico- and femto-cells in a very limited area, then presenting an intensive frequency reuse. Given these remarks, in order to speed up the deployment of BVLOS drones-oriented applications, as well as to provide a strong backup network to these devices until newer network generations (e.g., 5G or even 6G) will not be available soon, it is imperative to find a solution to minimize this problem, with the aim to easily and effectively use existing terrestrial networks. The idea suggested in this abstract is to develop and deploy a Smart Selective Antennas System (SSAS) based on a set of small and lightweight directional antennas, optimized with a proper beam width and with a spectrum able to fulfill the frequency bands used by modern networks in Europe, controlled by an advanced antenna selection algorithm based on multiple input data. More in detail, the proposed SSAS (whose illustrative scheme in an exemplified scenario is shown in the attached Figure, is composed by four directive Multiple Input Multiple Output (MIMO) antennas, each one with a 90° beam width to be located on the drone (to reach a complete 360°coverage) and connected to an advanced four-positions RF multiplexer allowing to power a single sector (e.g., just one over the four available antennas) to reach radio coverage in the desired specific direction. Then, the control algorithm takes into account different inputs, such as (i) the in-flight UAV direction and position, (ii) the nearby BTSs' position, and (iii) the UAV horizontal alignment (yaw axis data), in order to power on only the antenna which is pointing toward the nearby BTS which the on-board cellular modem is connected to. Hence, thanks to the SSAS mounted on the drone, the inter-cell interference exposure of a typical omni-directional antenna can be reduced by turning on and off the right directive antenna with respect to the UAV alignment toward the nearby connected BTS, thus improving the network reliability of the communication link with the existing network infrastructure. Finally, preliminary experimental data seem to return promising results and leave the room for further significant improvement using more advanced antennas and control algorithms, such as the adoption of additional antennas (e.g., 6 or 8 antennas) to reach a more powerful beam directivity toward the best candidate BTS selected by the on-board algorithm, as well as the miniaturization of the antennas composing the SSAS (thus opening new supported bands and, even, cellular network generation, like 5G).

An architecture for multilink drone communication

Morten Larsen*, Ricardo J. N. dos Reis, Ozren Ozelja
* *AnyWi Technologies, Netherlands*

Drone communication for command and control or to interact with cameras and other sensors in a payload can now be provided through a range of commercial offerings, going from WiFi over local radio links to various varieties of cellular connectivity and satellite links. Each offer different advantages in terms of latency, bandwidth, availability and costs, and this presentation describes a multi-layered architecture for a drone communication system that can incorporate several link technologies. The system handles availability information and quality of service data and manages the different links to achieve the overall best link connecting drone and ground stations. Early results of integration of link technologies, QoS estimators and safety and security layers will be discussed.

MBSE to support technology development in an European Research for drone technologies

Ricardo Reis*, José Ricardo Parizi, Morten Larsen
* *Embraer Portugal, Portugal*

ADACORSA is a KDT project for the development of components, software, algorithms and architectures solutions for solutions for drones. The consortium represents a constellation of non-traditional aviation partners with the common goal of being players in the same common domain - drones - but addressing different needs and capabilities, and thus not connected by the strong integration imposed by a common demonstrator. This introduces challenges regarding coherence, requirements and a common framework architecture to improve alignment and partners chances of market adoption.

This work proposes a MBSE approach to address the challenge of integration and alignment. An overall concept architecture is presented and a specific use case highlighted.

Game-Theoretic Learning for the Coordination of Drone Teams in Autonomous Cooperative Inspection

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* *CIRA (Italian Aerospace Research Centre), Italy*

Without the need for an on-board pilot, drones were usually designed to accomplish the D-cube (dull, dangerous and dirty) envelope. However, if a mission exhibits a large operative area and/or several objectives, it may entail poor performance when executed by a single drone. Multi-drone missions may overcome this issue by engaging several drones with some common objectives and by establishing a sort of multi-drone collaboration to increase mission effectiveness. An instance of such collaboration is represented by drone teams, namely networked sets of drones with a shared goal, and in which all members are assigned specialized tasks to accomplish the reference goal.

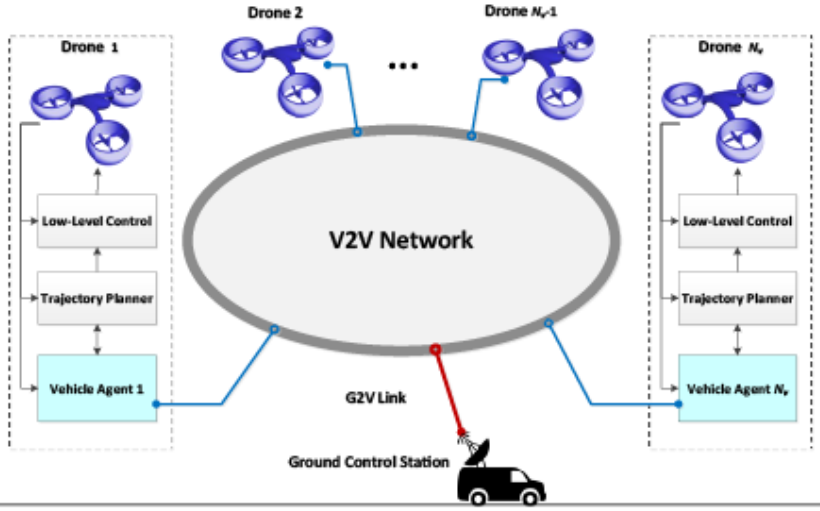
Recent advances in drone-team technology are exploited in a wide new range of both military and civil applications, revealing several market opportunities, but raising as well significant challenges. For example, a drone team may be arranged as a mobile sensor network. In this case, the drones act as mobile sensor nodes to closely perceive several targets (even changing over time) for maintaining an up-to-date picture of the situation and for balancing the load of the sensing tasks within the team. However, the autonomous cooperative behaviour is a key enabling feature for a resilient and cost-efficient drone team within mobile sensing. Indeed, this cooperative behaviour may

ensure: (i) a real-time reconfiguration and retargeting of the overall team, based on the evolution of the operating scenario, (ii) a reduction of the reliance on human operators to contain costs, (iii) faster reactions to environment changes with respect to human response.

This work proposes a dynamic and decentralized mission planner of a drone team to attain an autonomous cooperative behaviour concerning area inspection for surveillance purposes, e.g., for feared-event detection within environmental monitoring or infrastructure patrolling. The design of the planner exploits multi-agent task allocation, distributed route planning and game theory for the assignment of inspection tasks and for the processing of optimal routes in reasonable time frames and with limited communication, laying the foundation for autonomous real-time reactions to environmental changes.

Firstly, the mission planning problem is formally stated as a stochastic constrained optimization of the team's tasks and routes, by extending the operator of expected cost of ignorance to define a specific area-inspection metric. Then, a game-theoretic coordination mechanism is addressed to solve the optimization problem according to a decentralized multi-agent setting. Thus, the mechanism represents a negotiation process amongst the agents and provides a resilient behaviour by avoiding central decision points.

In detail, the coordination mechanism employs the theories of Markov games and learning in games with a two-step design process, which encompasses: (i) the game design, i.e., the specification of the interaction structure (action spaces and utility functions) of the agents, (ii) the learning design, i.e., the specification of the decision-making rules of the agents to learn the best routes, considering both the environment state and the previous choices of the other agents. For the game design, a sound methodology is applied to bring the design towards a potential game and to guarantee the learning algorithm to converge to a Nash equilibrium. For the learning design, some ad-hoc variants of best response and of log linear learning are proposed as possible learning algorithms. Moreover, the work presents several numerical results to validate the effectiveness of the proposed approach. Firstly, some metrics are assessed considering the game-theoretic nature and the complexity of the approach (e.g., price of anarchy, price of stability, communication amounts, etc.). Then, a proof of concept is reported as the implementation of the mission planner in an agent-based modelling & simulation environment to allow for model-in-the-loop testing. The Mesa framework in Python is used for the coding and the simulation of the agent-based models underlying the planner and the drone team. Lastly, a preliminary software implementation is performed for initial software-in-the-loop testing, by exploiting the DroneKit framework and the Micro Air Vehicle Link (MAVLink) protocol. The testing results refer to possible protection scenarios of real areas, and are used as source of analysis for the engineering phase.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G2V Link
Ground Control Station


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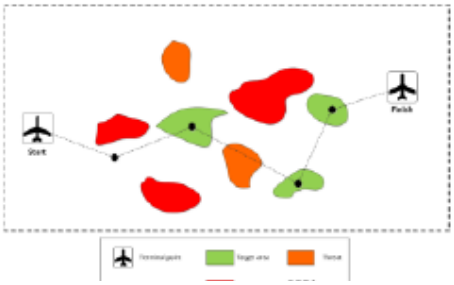
RECOGNITION
Coordinated Reallocating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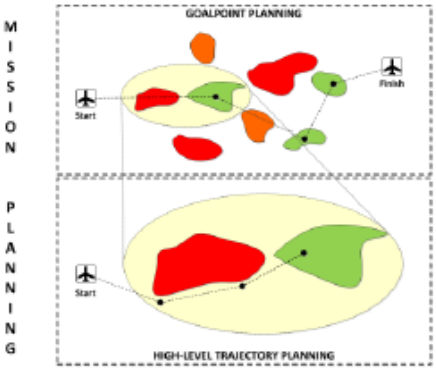
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Trajectory Planner
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Ground Control Interface
On-Ground Mission Manager
Multi-Drone Mission Settings
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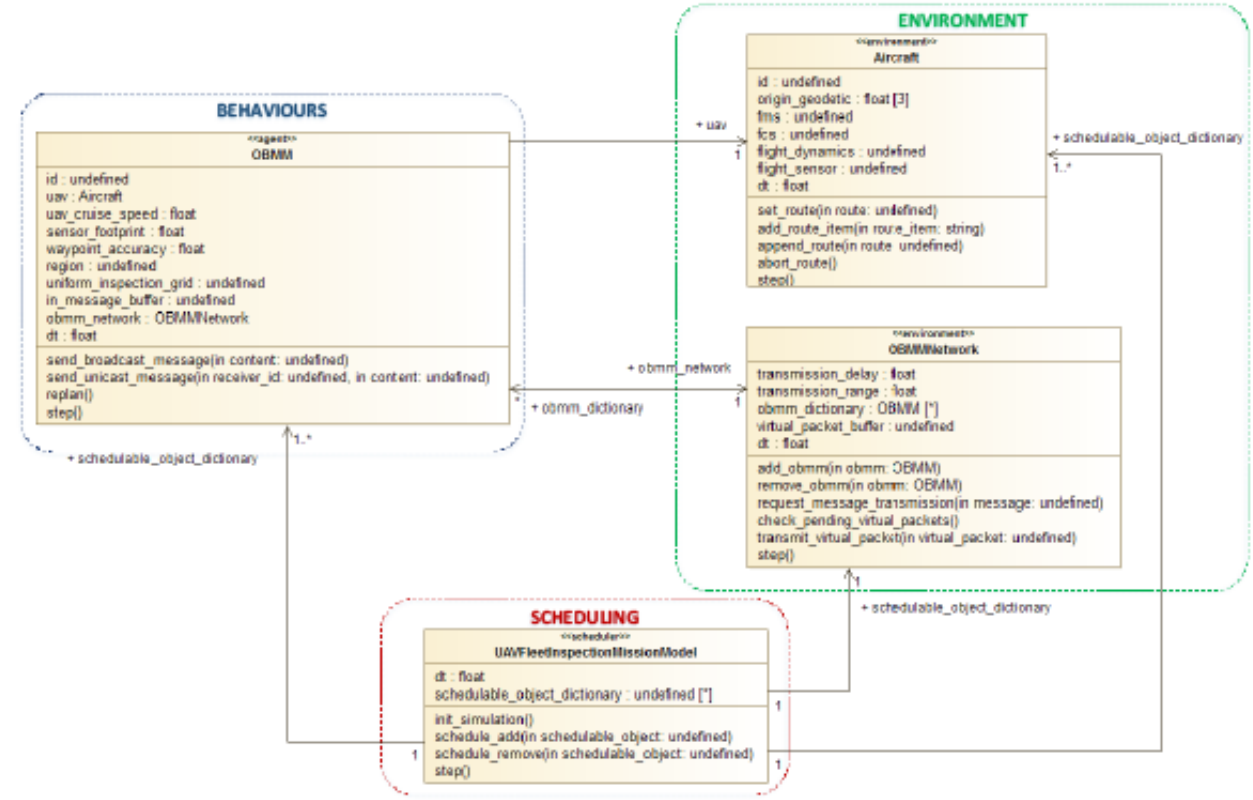
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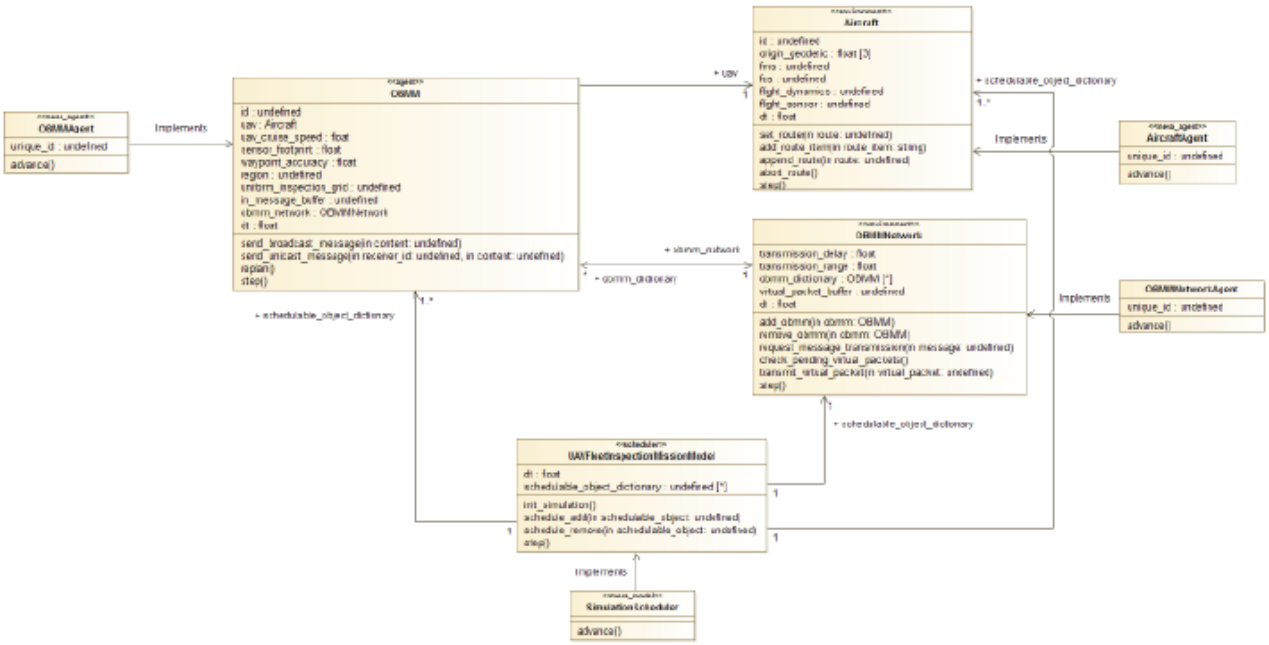
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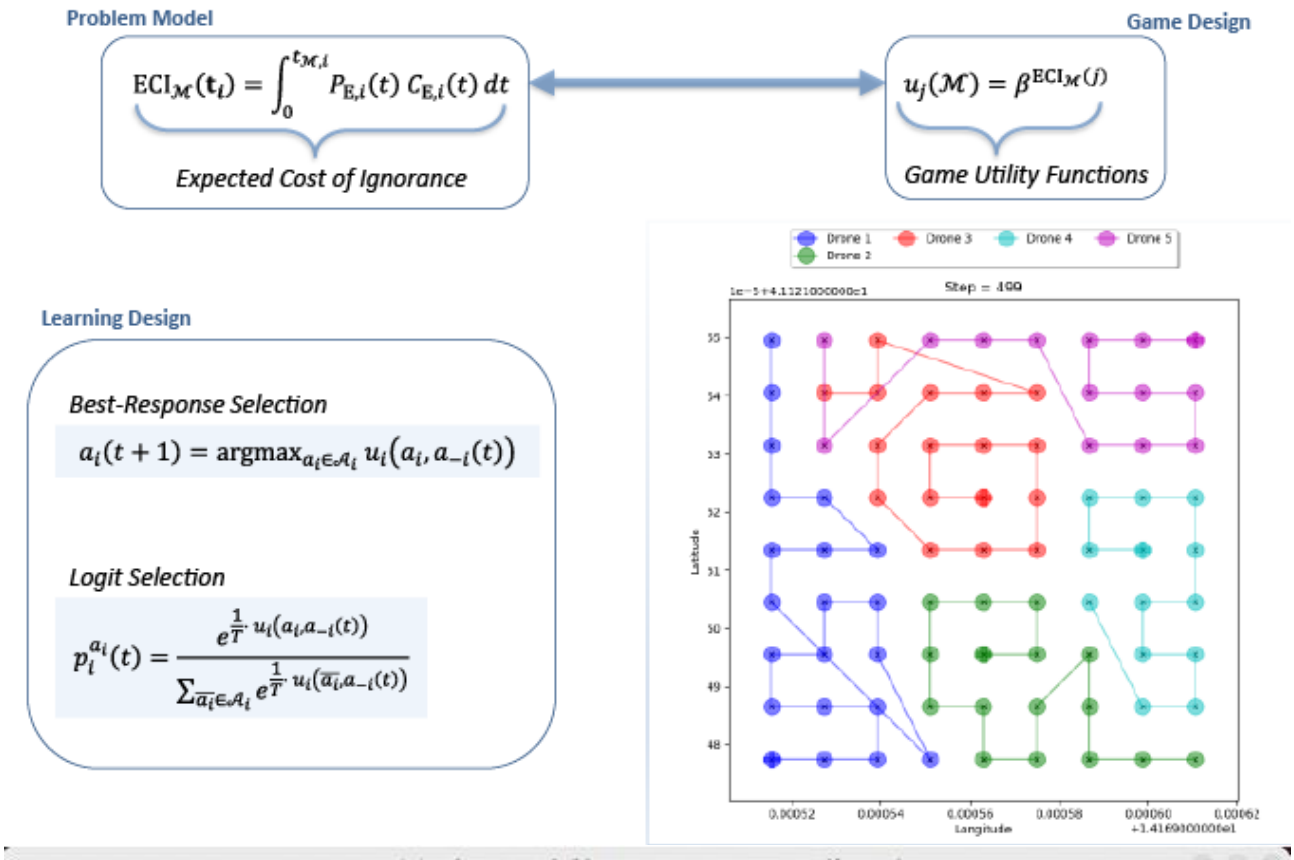

On-board Drone classification with Deep Learning models and SoC implementation

Angelo Manco, Giuseppe Di Cecio, Gabriella Gigante*

** CIRA Scpa, Italy*

The development of drone technology has been remarkable in many different application domains such as agriculture, surveillance, and delivery services. However, their growing number, jointly with their autonomy and swarming capabilities rise relevant concerns on safety and make them dramatic threats to security . To address these worries Counter-UAS Systems (CUS) are capturing the interest of research and of industry. CUS are capable of detect, identify and counter single drones in the airspace, assuring certain levels of security . Although suppression of individual drones has been addressed (at least partially), countering an hostile swarms of drones represents an emerging challenge. Very recently research has been addressing the adoption of CUS based on drones themselves.

They present some advantages such as, for example, the proximal sensing due to the extreme mobility of drones or the chance to increase the coverage of a protected area. To these purposes the"good drones" must have on-board the capability of identifying an attacking drone. Drone classification powered by Artificial Intelligence (AI) models can be considered an enabling technology for such a system. Bring this technology on-board is challenging.

Edge computing has emerged as a promising paradigm for efficient and real-time processing of data at the edge of the network, closer to the source of data generation. Detection and Identification (Classification) tasks can greatly benefit from edge computing capabilities, enabling fast and accurate decision-making without relying on centralized cloud resources

The proposed work explores the application of edge computing to drone classification. It tunes a Deep Learning model, You Only Look Once (YOLO), and and implements it on a Field Programmable Gate Array (FPGA) technology FPGAs are considered advantageous over conventional processors since they enable parallelism and can be used to create high-speed, low-power, and low-latency circuit designs and so to satisfy the stringent Size, weight and Power (SWaP) requirements of a drone-based implementation. In details, two different YOLO neural networks YOLO v3 and v8 are trained and evaluated on a large data set constructed with drones' images at small, medium and large distances. The two models are then implemented on a Xilinx System-on-Chip (SoC). In order to demonstrate the feasibility of a drone on board Images AI processing, the evaluation assesses the accuracy of classification and the computational performances such as inference speed and power consumption.

Project session: MINIMAL

Chaired by:
Dr. Carlos Xisto (Chalmers University)

Minimum environmental impact ultra-efficient cores for aircraft propulsion

Carlos Xisto*, Feijia Yin, Andrew Rolt, Isak Jonsson, Arne Seitz, Anders Lundbladh, Anna Yenokyan
** Chalmers University of Technology, Sweden*

Building a sustainable and climate neutral future for aviation is an inevitable requirement for a society with increasing mobility needs. If we are to stabilize the global temperature below the 1.5°C threshold set by the Paris Agreement, rapid action is to be taken. MINIMAL (Minimum environmental impact ultra-efficient cores for aircraft propulsion) will contribute to a radical transformation in air transport by providing disruptive ultra-efficient and low-emission technologies that will, in combination with the aviation ecosystem, sustainably reduce the climate impact of aviation. The MINIMAL project will, through a joint effort between European engine OEMs, atmospheric scientists, and lead researchers in combustion and propulsion, attack the major sources of non-CO_2 and CO_2 emissions in aeroengines. This is accomplished with the introduction of new propulsion systems based on composite cycle engine (CCE) technology, that provides unparalleled efficiency levels and

performance flexibility for climate friendly operations. The project will provide experimental (TRL 3) proof of concept of cutting-edge technology with the potential to eliminate the large sources of climate forcing, low-NOx micromix opposed piston hydrogen combustion technology, heat-management system that exploits the cooling potential of hydrogen (intercooling, piston heat recovery). Integration studies on the CCE architectures will allow to quantify the performance on future-looking application scenarios, covering typical missions from short to long ranges. The integration studies are supported by climate impact studies to investigate the interdependencies between non-CO_2 and CO_2 effects during the early stages of aero-thermal-mechanical design and converge into engine options with minimum climate impact.

This presentation will discuss the overall project background, concept, structure, and goals, setting the stage for the following technical presentations that will cover the key lessons learned in the first year of MINIMAL.

Composite Cycle Engine design for minimal climate impact - Study setup and reference systems

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** Bauhaus Luftfahrt e.V., Germany*

The Horizon Europe and UKRI funded project MINIMAL (Minimum environmental impact ultra-efficient cores for aircraft propulsion) (no. 101056863) focuses on development of minimum climate impact Composite Cycle Engine (CCE) designs. Such propulsion systems, combining piston engine core technology with advanced aero engine turbomachinery, were identified as most efficient configurations in previous projects [1-3]. This contribution will present the planned activities on aircraft integration effects and minimum climate impact design of Composite Cycle Engine configurations in work package (WP) 4 of MINIMAL. WP 4 has started by generating realistic reference aircraft platforms (including reference propulsion systems) for regional, short-to-medium and long range applications for state-of-the-art and advanced, evolutionary technology level. These platforms, using either sustainable aviation fuel (SAF) or liquid hydrogen will enable overall assessment of the CCE propulsion system potential. First insights on the chosen top level aircraft requirements as well as aircraft and propulsion system technology assumptions will be presented. Furthermore, the planned process for CCE conceptual design integration and optimisation towards minimum climate impact will be explained. Three alternative types of CCE concepts applying crankshaft-based pistons, free double pistons and opposed pistons will be presented, to be investigated in detail within MINIMAL. In addition, the interdependencies with other WPs, will be highlighted. For instance, low nitrogen oxide (NOx) emissions will be a critical requirement for future engines, so special attention is given to this, and the CCE designs are made in close cooperation with MINIMAL work package 2, which has a dedicated focus on CCE combustion processes. Also intercooling and thermal management aspects, investigated in WP 3, will be considered and, ultimately, optimized MINIMAL aircraft performance are planned to be provided to WP 1 towards the end of the MINIMAL project to analyze the climate impact sensitivity of the MINIMAL CCE architectures on fleet level.

Demonstrating low NOx for hydrogen combustion in a free-piston aero engine core in the MINIMAL project

Andrew Rolt*, Xiaoxiao Sun, Charith Wijesinghe

** Cranfield University, United Kingdom*

New energy sources and aircraft propulsion technologies need to be developed to ensure the continued viability of commercial aviation. The low specific energy of batteries means they can only

provide power for short flights, but electrolysis with renewable energy can generate green hydrogen that may be used to fuel aero engines. Hydrogen may also be combined with non-fossil carbon sources to make hydrocarbon electrofuels. Aircraft PEM fuel cell systems using hydrogen may be developed, but these still face challenges with operability, low specific power and high cooling demands. Therefore, combustion engines will also continue to be developed.

The ULTIMATE project demonstrated that composite cycle aero engines could significantly reduce fuel burn relative to engines with conventional combustors. It identified multi-cylinder free-piston engine cores as a very promising topping-cycle technology for future composite cycle engines (CCE). The MINIMAL project is developing these concepts further.

Hydrogen should become the least expensive sustainable aviation fuel. It avoids emitting carbon dioxide, carbon monoxide, hydrocarbons and soot, but its combustion can generate NOx. MINIMAL work package 2 will model hydrogen combustion with homogeneous charge compression ignition (HCCI) and it will use a single-cylinder free-opposed-piston test rig to validate the numerical models. It aims to demonstrate very low NOx emissions are possible.

Free pistons can run oil-free on low-friction air bearings, and variable compression ratio will enable compression ignition with high combustion efficiency over the wide range of aero engine operating conditions. Hydrogen can be pre-mixed with relatively cool inlet air just ahead of the inlet ports, without risking flashback, so lean combustion should be possible without the hot-spots that would generate higher levels of thermal NOx. Low residence times at the peak pressure and temperature should also help to minimise NOx production.

An opposed piston arrangement for the free-piston engine core offers further benefits. The elimination of cylinder-heads reduces heat loss, and the simple piston-operated inlet and exhaust ports create ‘uniflow’ inside the cylinders for efficient scavenging in the two-stroke topping cycle.

Exploration of heat management concepts for a hydrogen fuelled mid-range commercial aviation engine

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** Chalmers Tekniska Högskola AB, Sweden*

This contribution focuses on the development of a new intercooling concept for gas turbine engines fuelled by hydrogen. Although intercooled gas turbines have proven beneficial in stationary and marine applications, there are currently no intercooled commercial jet engines. In the ULTIMATE project, intercooling was explored as a means to achieve the required gas turbine efficiency for future aircraft, and it was shown that substantial intercooling was required for high-OPR concepts, such as the composite cycle engine (CCE). The adoption of cryogenic hydrogen (LH2) as a potentially carbon-neutral fuel for commercial aviation presents new opportunities for the development of efficient and sustainable propulsive systems. In the project ENABLEH2, intercooling was combined with cryogenic hydrogen, and installation penalties were substantially reduced. This study builds on these findings and explores new approaches utilizing both bypass air and hydrogen to increase intercooling power while minimizing installation penalties. The performance of this new concepts is planned to be evaluated by simulations and experimental data obtained from a Chalmers low-pressure compressor facility. Additionally, this study examined the suitability of piston engine configurations for use in composite cycle engine architectures from a thermal management perspective to provide insights into the potential of intercooling and composite cycle engines for future jet engine designs.

Climate model for future aircraft engine design: a novel conceptual design approach towards sustainable aviation

Feijia Yin*, Harjot S. Saluja, Turhan Eker, Arvind Gangoli Rao, Volker Grewe, Julia Schaumeier, Annika Paul

** Delft University of Technology, Netherlands*

Aviation contributes to about 3.5% of the total anthropogenic climate change, including CO_2 and non-CO_2 effects from e.g., NOx, contrails, H_2O [1]. The ICAO Post-COVID-19 forecasts indicate that aviation will recover with an average growth rate of 3.6% , which will inevitably aggravate aviation's climate impact. Furthermore, the interdependency between CO_2, NOx and contrails effects makes it challenging to tackle the overall climate impact of aviation. One potential mitigation approach is to incorporate the whole climate impact during the aircraft conceptual design optimization. To this end, a comprehensive climate model bridging the climate effects and aircraft engine design requirements is required. That is one goal within WP1 of MINIMAL project. Overall, the WP1 of MINIMAL project focuses on the climate impact study of radical engine configurations (e.g., Composite Cycle Engine (CCE) concept in MINIMAL) combining alternative fuels (e.g., Hydrogen) under different scenarios. The climate impact assessment will consider effects of CO_2, NOx, water vapor and contrails. The expected outcomes are: 1) different scenarios related to fleet developments, 2) benchmarking emission inventories for global aviation, 3) climate response model to allow climate optimized engine design.

As a first step, this research demonstrates the rationale behind the climate optimized engine concept. We apply an integrated approach combining aircraft engine performance, emissions, and climate response (average temperature response over 100 years (ATR100)) to turbofan engine configurations considering short-medium range flights. Accordingly, the variation of ATR100 with respect to engine pressure ratio, turbine inlet temperature and bypass ratio is calculated. We observed tradeoffs between CO_2 and non-CO_2 effects driven by contrails and NOx, which confirms the need of having a multi-objective optimization approach including fuel efficiency and climate impact. Within the scope of MINIMAL project, the approach will be adapted to consider global emission inventories with respect to different technology and fuel uptake under various scenarios. Accordingly, the climate impact from CO_2, NOx, H_2O, and contrails will be estimated using a state-of-the-art climate impact assessment tool, AirClim [2, 3], with a necessary adaption for non-conventional fuels. Climate response functions will be generated which will be integrated with the engine design optimization studies to design for minimum climate impact.

Acknowledgement: MINIMAL project has received funding from the Horizon Europe research and innovation programme under GA n° 101056863

Keywords: MINIMAL, fleet modelling, emission inventory, climate modelling, CO_2 vs. non-CO_2

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Advanced Manufacturing Technology for Aeronautics

Chaired by:
Dr. Jie Zhao (University of Strathclyde)

Disruptive technologies: Induction welding and Continuous Compression Molding for complex shapes

Simone Morciano*, Alessandra Passaro, Giuseppe Buccoliero, Umberto Raganato, Michele Arganese
** CETMA, Advanced Materials & Processes Consulting Department, Italy*

Thermoplastic composites are increasingly important materials in the aerospace industry due to their unique combination of properties such as high strength-to-weight ratio, impact resistance, and excellent fatigue performance. Weldability is another important advantage of thermoplastic composites that can provide several benefits in aerospace and other applications, including strong and durable joints, efficient production, enhanced design flexibility, improved weight savings, and better environmental performance. The use of thermoplastic composites can reduce production costs and increase manufacturing efficiency due to their short processing time when automated Out of Autoclave (OoA) processes (compression molding, induction welding, etc..) are used. The aim of this work is to present the potential of two highly automated OoA technologies, namely Continuous Compression Molding (CCM) and Induction Welding (IW), which when combined allow to produce complex shape structures by welding together simple components in a cost-effective way. A re-designed keel-beam structure is presented as a case study; it was manufactured welding together simple components (L-shaped corners, Ω-shaped stringers, flat skins) produced by CCM.

A STUDY OF FATIGUE THRESHOLDS ON AlSi10Mg ALUMINIUM SAMPLES PRODUCED BY LASER POWDER BED FUSION

R. Fernandes*, J.S. Jesus, L. P. Borrego, J.A.M. Ferreira, J.D.M. Costa
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Aluminum alloys are widely used in the aeronautical industry, whereby is fundamental the understanding of in-service fatigue behavior. Concerning to the fatigue design of aeronautical components, which fatigue behavior is mainly analyzed based on the crack propagation rate data, particularly around the thresholds of da/dN-ΔK curves. The fatigue thresholds of the aluminum alloy AlSi10Mg manufactured additively by laser powder bed fusion for as-build, residual stress relief and hot isostatic pressing conditions were studied in this work. The fatigue tests (R=0 and R=0.4) were carried out, at ambient temperature and in load control mode. The fatigue behavior in the threshold regime is very similar between as built and heat-treated conditions and for the different stress ratios.

The impact of data injection on predictive algorithm developed within electrical manufacturing engineering in the context of aerospace cybersecurity

Jorge-Bautista Hernández*, María Ángeles Martín Prats
** University of Seville, Spain*

Cybersecurity plays a relevant role in the new digital age in aerospace industry. Predictive algorithms are necessary to interconnect complex systems within the cyberspace. In this context, where security

protocols do not apply, challenges to maintain data privacy and security arise for the organizations. Thus, the need of cybersecurity is required. The four main categories to classify threats are interruption, fabrication, modification and interception. They all share a common thing, soften the three pillars which cybersecurity needs to guarantee. These pillars are confidentiality, availability and integrity of data. Data injection can contribute to this event by creation of false indicators which can lead to errors creation during the manufacturing engineering process. In this paper, the impact of data injection on existing dataset used on manufacturing process is shown. The design model synchronizes the following mechanisms developed within machine learning techniques which are, the risk matrix indicator to assess the probability of producing an error, the dendrogram to clusters the dataset in groups with similarities, the logistic regression to predict the potential outcomes and the confusion matrix to analyse the performance of the algorithm. The results presented in this study, which was carried out using a real dataset related to the electrical harnesses installed in a C295 military aircraft, estimate that injection of false data indicators increase the probability of errors creation in 24.22 % on the predicted outcomes required for the generation of the manufacturing process. Overall, implementing cybersecurity measures and advanced methodologies to detect and prevent cyberattacks are necessary.

Model-based approach for the automatic inclusion of production considerations in the conceptual design of aircraft structures

A M R M Bruggeman, D Bansal*, G La Rocca, T van der Laan and T van den Berg

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During the production stage of a product, many production issues are found [1], which are often related to an inadequate design [2]. However, making design changes at the production stage is a costly and time-consuming task and should therefore be prevented as much as possible. Analysing the producibility of a product during the conceptual design stage will lead to an earlier identification of production issues, which saves both time and cost. Furthermore, small changes in the design can sometimes reduce the production complexity significantly [3], which results in lower manufacturing costs and higher production rates.

However, including production considerations in the design is quite challenging, especially during early design stages when little is known about the components. Many production methods exist and each part of the system can be produced by different production process(es). Furthermore, each production method puts different constraints and requirements on the component design and vice versa. Managing all these different requirements and ensuring compatibility with all is challenging. Finally, a lot of manufacturing information has grown historically and is known by experts. This information is not necessarily well documented such that it can be integrated into the product design process [4]. This is generally tackled by bringing manufacturing experts and designers together during the initial product development discussions and critical reviews. However, the process remains informal and there are no effective means to allow the designer to make leverage of the manufacturing expert's knowledge in a systematic, model-based approach during the design process.

This paper presents a new development that focuses on formalising and modelling production information such that it can be implemented and used during early design stages. The Manufacturing Information Model (MIM) provides a standard way to connect manufacturing information to the different parts and joints in a product. Furthermore, with the MIM, both functional views as well as manufacturing views can be modelled within a single design modelling environment. By modelling the manufacturing information its effective re-use can be achieved in a systematic way at the preliminary design stage without having to rely on time-consuming discussions with manufacturing experts.

The MIM is demonstrated through the conceptual design of a wing box at GKN Fokker Aerostructures, a Tier-1 aerospace supplier. The use case shows how manufacturing data can automatically be added to a product model and how this information is automatically updated when for example the production method changes. The manufacturing information is then used to assess different manufacturing concepts for the wing box. A Design of Experiments (DoE) is conducted where the design variables include the material and production method for different parts and joints of the wing box. The results are visualized in scatter plots, indicating the impact of choosing different materials and manufacturing methods on the total cost and mass of the wing box, supporting the designer in the trade-off process.

Acknowledgments
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Gradient-based Design Optimization of Composite Structures using Double-Double Laminates

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The Double-Double (DD) family of composite laminates has been proven to be a very promising alternative for designers and manufactures in aerospace engineering. A DD laminate is characterized simply through a balanced building block, comprising four unidirectional layers with ply angles {φ, −ψ, −φ, ψ}. Assuming the homogenization due to the sufficient repetition of such a DD building block reveals continuous parameter for a laminate stacking, suitable for gradient-based numerical sensitivities. Hence, an optimization strategy is presented using the DD parameterization as design variables in order to derive an optimized thickness and stiffness distribution, which is easy to translate into a refined manufacturable design. Therefore, a gradient-based optimization process is introduced using the modular lightworks framework. The DD composite representation is implemented to a meta-model, based on panel units, where buckling and strength criteria are evaluated analytically. The finite-element-based solver B2000++ is used to provide internal panel load states. Gradients for the objective function as well as the constraints are determined with respect to the DD parameter using finite differences. The proposed method is applied to a least weight problem of a simple wing box, which is well known from literature. The newly implemented DD parameterization is compared to a laminate stacking derived from a lamination parameter-based optimization and a subsequent stacking sequence retrieval. The proposed optimization process

provides an efficient option to obtain an optimal and feasible structural design within mono and multidisciplinary aircraft development.

Manufacturing, development and control of a two-way 3D printed soft actuator actuated with SMAs

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Soft structures have been becoming relevant due to their ability to modify their properties in response to external influences, which makes them highly versatile in fields like aerospace, biomedicine, and robotics. Smart materials can work as sensors and actuators in order to drive, control, or support these structures. Shape memory alloys (SMAs) are one of the most popular smart materials used for developing soft actuators since they can change their properties when they are exposed to thermal stimuli, producing relatively large displacements and higher force-to-weight ratios compared to other smart materials that are used for actuation. By integrating smart materials into soft structures, it is possible to construct soft actuators that are lightweight and flexible. This work presents the manufacture, modeling, and control of a 3D-printed soft actuator driven by two SMAs. The soft matrix of the actuator is designed as a highly compliant structure and 3D-printed using thermoplastic polyurethane (TPU), with U-shaped SMA wires embedded during the 3D printing process. The soft actuator can deform in two directions and reach different reference positions. The prototype is able to deform in two directions in order to describe the movement a mathematical model is obtained using the system identification technique. Due to the hysteretic behavior of SMAs and their inherent nonlinearities, the control of SMA-driven samples remains challenging, therefore, we proposed a control technique that ensures robustness and precision to achieve a certain position.

CONTINUOUS ULTRASONIC WELDING OF A THERMOPLASTIC COMPOSITE FULL-SCALE FUSELAGE DEMONSTRATOR: FROM LABORATORY TESTING TO FULL-SCALE WELDING

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Thermoplastic composites, which have the unique potential to be recycled, reprocessed, and welded, are the focus of a worldwide aeronautic challenge to progress toward greener and more sustainable global transportation. Adopting more flexible and adaptive production technologies that allow for quicker manufacturing cycles, higher environmental friendliness, and increased productivity is a further challenge. Aiming to commit to the drastic projected increase in aircraft production rates, the WELDER project, focused on the next-generation MultiFunctional Fuselage Demonstrator (MFFD), has promoted the development and investigation of highly integrated and robotized manufacturing technologies that needed to be scaled up from a laboratory to an industrial environment.

Continuous ultrasonic welding, being one of these, is a promising technique for joining thermoplastic composite structures capable of meeting the required industrial needs as it is easily robotizable, fast, and reliable. For this reason, this study looked at the use of ultrasonic technology to weld a thermoplastic fuselage's first complete segment.

This research aimed to validate and further investigate the temperature effect when welding thick composite parts and understand how welding parameters such as amplitude, speed, pressure, active cooling, welding direction, as well as, material parameters, affect the weld quality. The main focus was given to the welding of larger components and a thermal camera system was used to

monitor temperature evolution not only at the surface of the adherents but also at the sonotrode tip and in correspondence with the consolidation unit. Welding investigation, including process window identification, parameter optimization, and scale-up analysis was performed at the laboratory scale using LM-PAEK/CF composites while the welds were characterized by visual inspection, microscopy analysis, and mechanical testing.

Development of the technique to increase defect detection performance in multilayered structures based on extracted features for different defect types and their comparison

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Multilayered structures are extensively used in different industrial applications, namely in aeronautical, automotive and marine industries. Structures bonded adhesively are more effective than conventional bonding methods such as bolting or riveting. They have the following advantages: overall construction weight reduction, high strength to weight ratio, homogeneous load distribution, corrosion protection and also provides composites structural integrity. However, there is a limitation of adhesive joints which is the complexity to predict bonding strength during structure's lifecycle due to the defects which can be in the adhesive. In multilayered structures bonded adhesively it is difficult to detect bonding defects with high reliability. Therefore, reliable control of the bonding quality has a great interest.

Non-destructive testing using ultrasonic waves became one of the most extensively used technique for inspecting adhesively bonded joints due to their efficiency. In this work, we focused on the ultrasonic non-destructive evaluation of adhesive integrity of multilayered structures bonded adhesively using bulk waves and data processing algorithms. The objective of the work is to develop the technique of bonding defects detection based on the ultrasonic features and compare evaluation performance of each for the different bonding defects in multilayered structures.

Experimental inspection using ultrasonic waves were performed for several adhesively bonded joints with different type of the defects in adhesive layer. Lap-joint samples of adhesively bonded materials with delaminations and brass inclusions were investigated in this work. Pulse-echo ultrasonic inspection with focused transducers were performed. Collected data was studied in order to determine ultrasonic features which can be sensitive to the bonding defects. The following ultrasonic features were extracted and analyzed: peak-to-peak amplitude, attenuation, maximum amplitude at frequency domain, frequency at the maximum amplitude, absolute energy, and others. Ultrasonic C-scans were demonstrated for every extracted feature for different samples with different types of bonding defects and compared. In addition, features were extracted and studied analyzing multiple reflections. In order to evaluate performance for each feature extracted and implemented the defect sizing was performed using measurement technique at -6dB level.

Out-of-autoclave self-heated tooling enabling temperature homogeneity and embedded graphene sensors - ESENSE

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The growing demand for composite materials in aerospace due to lightweight advantages over their metallic counterparts has given a new impetus to the development of eco-friendly, cost-effective composite manufacturing processes. Historically, aerospace composites have been manufactured using autoclave processes. Although autoclaves comprise the benchmark manufacturing technique that ensures high-quality composite components, their high costs for acquisition and operation, long

production time and inflexible manufacturing pose serious challenges to the aerospace industry. ESENSE aims to bring to market a more versatile and less costly, self-heated Out-of-Autoclave tooling solution with multiple heating zones and advanced thermal management in order to eliminate the need for costly and energy-intensive autoclaves. Two complementary niche heating technologies, namely heating foil and graphene-ink heaters are introduced and combined to optimise the heating efficiency of the tooling and achieve temperature homogeneity even in complex shapes targeting the manufacturing of thermoset composite parts. A novel graphene-based sensing system of the smart tooling is established through graphene-enhanced printed pressure sensors and strain sensors which in combination with a well-established software for monitoring and control will enable easy, reliable and fail-safe operation of the tool and ensure the component quality. Thermal and process simulations are performed for the verification of the thermal management system. The finite element (FE) material card is built using material properties extracted from characterisation tests of the tooling and part component materials. As part of this study, the concept of the project and the findings of the characterisation tests and FE analysis will be presented and discussed.

Analysis and Health Monitoring of a large-scale Wind Turbine Structure to Enhance its Performance and Reliability

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This paper presents a comprehensive study on the analysis and health monitoring of a large scale wind turbine structure, with a focus on enhancing its performance and reliability. As wind energy continues to gain prominence as a sustainable power source, the design and maintenance of large-scale wind turbines have become increasingly critical. This research addresses the challenges associated with structural integrity and health monitoring of a large-scale wind turbine, making valuable contributions to the advancement of wind turbine technology in the context of aviation and space exploration.

The study encompasses a detailed analysis of the structural behaviour of the wind turbine under varying operational conditions. Advanced Finite Element Analysis (FEA) techniques fully coupled with Computational Fluid Dynamics (CFD) are employed to accurately model the complex interactions between the structural components and external forces, such as wind loads and dynamic effects. Through comprehensive simulations, the structural performance and load-carrying capacity of the wind turbine are evaluated, providing valuable insights into its design optimization.

Moreover, a comprehensive health monitoring system is developed and integrated into the wind turbine structure. This system utilizes various sensors and data acquisition techniques to continuously monitor key parameters, including strain, vibration, temperature, and fatigue loading. The collected data can be processed and analysed using advanced signal processing and machine learning algorithms, enabling the detection of structural anomalies, early identification of potential faults, and prediction of remaining useful life.

To validate the effectiveness of the proposed methodology, a scaled prototype of the wind turbine is instrumented and subjected to lab testing. The results demonstrate the capability of the health monitoring system to detect and diagnose various structural defects, such as cracks, deformations, and component failures. This real-time monitoring approach provides crucial information for decision-making processes regarding maintenance scheduling, repair strategies, and overall turbine performance optimization.

The findings of this research contribute to the field of wind turbine technology in the context of aviation and space exploration by offering a comprehensive analysis and health monitoring approach for large-scale wind turbine structures. By ensuring the structural integrity and reliability of the wind turbine, the proposed methodology enhances its performance, reduces downtime, and

minimizes maintenance costs. This work further reinforces the viability and sustainability of wind energy as a reliable source of renewable power, opening new horizons for its integration in aviation and space applications.

A cloud infrastructure for enabling provision of the Material Testing as a Service (MTaaS)

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The concept of 'cloud manufacturing' has been well developed in recent years with great commercial interests, by linking it to IoT and Industry 4.0. Following an intensive review of 'cloud manufacturing', much effort has been dedicated in the areas of manufacturing resources, capabilities and services, as well as in developing cloud manufacturing software tools and platforms. However, managing the information flow and coordinating the interactions between the customers and the different manufacturers and suppliers of a supply chain are still significantly limited. To better allow for the customisation of material/structure requirements and achieve higher effectiveness and efficiency of the service provision by an enterprise, the concept of 'customer-centric integrated service provision platform (ISPP)' was developed acting as a single platform cloud infrastructure. This virtual enterprise integrates information and tools for 'Customer Relationship Management', 'Supply Chain Management' and 'Enterprise Resources Planning'.

Following this strategic consideration, MTaaS platform was planned to implement 'Material testing as a Service' principle to drive distributed, collaborative and innovative service provision management as well as to enable interactions with customers and supply chains. Aeronautic industry is a complex area which relies on deep collaboration from a large number of partners of different backgrounds. In this way MTaaS will be acting as a service management cloud infrastructure which integrates all relevant CRM, SCM and ERP elements for a virtual enterprise and also deals with marketing and sales, based on the business model by the partner sites.

MTaaS platform includes a front-end interface as a web portal for the customers and a back-end system for internal uses such as administrator, assigned technical experts and representatives from collaborative partners. The web-portal is accessible by a customer providing interfaces for products, services, facility uses and consultancy customisation, orders and sales management, as well as business promotion mechanisms. Besides, an internal service management system (defined as the platform back-end) is developed for registration, verification, composition, provision and monitoring of material design/testing and consulting services, as well as optimisation of the supply chains. In addition, the back-end also provides data analysis, knowledge-base and expert involvement in decision-making for service provisions. In this way a special connection among the relative partners involved and customers is established.

The effort made to create the prototype cloud infrastructure has considered the integration of all product, service and customer related information into a single platform, and it also includes necessary operation related data such as project data, inventory data and supply chain data. The developed platform can be deployed for a wide range of service provisions, product sales, facility uses as well as general consultancies, since it is scalable and reconfigurable, while data security could be secured.

Heating methods and applications in sheet metal forming – A review and outlook of future application potential in aerospace

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Warm/hot Sheet metal heating plays a vital role in shaping complex components in various industrials, including aerospace, automotive, where the demand for quality, lightweight and durable components are high. Integration of heating methods into the sheet metal forming process have demonstrated great promise in achieving superior formability and enhanced mechanical properties. To meet the evolving demands of manufacturing techniques, novel approaches are required to enhance production efficiency, precision, while concurrently reducing energy consumption and overall costs. This review aims to provide an overview of heating methods employed in sheet metal forming, examining the current practices, challenges, potential applications and opportunities for improvement.

The review begins by discussing the different types of heating methods, including furnace heating, induction heating, resistance heating, contact heating are discussed in terms of their heating mechanisms, process parameters, their effects on material behaviour during forming. Case studies are presented to showcase these heating techniques and their integration into the production line.

Furthermore, the advantages and limitations of each method are analysed, considering factors such as heating efficiency, temperature control, heating uniformity, energy consumption, etc. The impact of heating methods on the formability of advanced materials, including titanium alloys and aluminum alloys, is also explored to highlight the adaptability of heating techniques to different materials.

Looking towards the future, the review provides recommendations on the potential application and further improvement in the current practice. The integration of advanced process control strategies, such as closed-loop feedback systems and real-time temperature monitoring, holds significant promise for further enhancing the performance and reliability of hot forming processes. Additionally, the integration of predictive modelling and simulation tools can aid in optimising heating parameters and predicting material behaviour during forming, leading to more efficient and effective processes.

Digital twin and machine learning for optimising an injection moulding process and enhancing part quality

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Plastic has many specifications and features such as mouldability, ease of production in complicated geometries, lightweight, and low cost. these features made plastic parts involved in the most industrial sector on a global scale like the medical, aerospace, electric and electronics industrial sectors. The demand for moulded parts is expected to acquire a 45% rise by 2030 where the production had increased to reach 390.7 MTs in 2022 compared to 365.5 MT in 2018(1).

The quality of moulded parts is considered critical in terms of rapid production, product life cycle, and cost. So, quality monitoring and control remain a challenge during the production process, especially due to the complex geometric of moulded parts and the unique design of each mould which directly affects quality and productivity. based on the above, understanding the multitude of variables that influence part quality is extremely important.

This study aims to explore the potential of machine learning techniques that allow building a model based on the acquired process data in terms of predicting the quality of moulded products. A set of sensors are installed on the machine and mould units, while the data acquisition system is used to acquire information on different process variables and vast quantities of data are collected in real-time. Moldex3D is utilised to design and simulate the moulding process in the virtual environment. numerical simulations combined with the design-of-experiment (DOE) technique are applied to investigate the influence of process conditions and part weight and thickness on the moulded part quality. A digital representation (Digital twin) is applied to allow comparing data coming from both

the physical environment and virtual space and processing it. ML model is developed to enable continuous learning and predict part's quality and production process efficiency aspects that require labelled data.

Utilization of topology optimization and 3D DMLS printing in the general aviation aircraft design process

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This work presents the opportunities and potential benefits that can be achieved through the use of new technologies, both in terms of design and manufacturing, of a modern general aviation aircraft. The AT-P Aviation company deals with the design and production of new generation aircraft, distinguished by an above-average level of safety. The company, cooperating at many stages of the project with leading scientific units, reaches for the state-of-the-art achievements of science and technology, striving to obtain a structure that stands out on a global scale, both in terms of performance and applied technological solutions. Specialists from the Warsaw University of Technology supported the company both at the stage of conceptual and aerodynamic design, as well as in the process of detailed design of structures and mechanisms.

Topology optimization as well as generative design have proven their usefulness in the process of designing light and durable components applicable in various industries. Topology optimization (TO) is a mathematical method that optimizes the layout of materials in a defined design space, for a given set of loads, boundary conditions, and constraints to maximize system performance. One of the biggest challenges in aviation is to ensure the proper strength and rigidity of the components while minimizing its mass. Generative design and topological optimization approaches are used with promising results in the aerospace industry by both small innovative companies and the largest manufacturers.

This paper describes the process of replacing a mechanical component designed and manufactured using conventional methods with a part designed using topology optimization. The approach enabled a significant reduction in weight while maintaining adequate stiffness and strength, which was verified in a static test. The organic shapes that are usually obtained in the topology optimization process often exclude using conventional production methods such as milling, turning, etc. 3D printing technology is most often the solution for those problems. Due to the stringent strength requirements, DMLS printing technology was used, in which metal powders are the building material. When using this technology, the shape of the part is not a technological limitation anymore. The paper presents the advantages and disadvantages of using topological optimization and 3D printing in general aviation, based on an example of a selected mechanical component.

Air Traffic Management (ATM) and Airports

Chaired by:
Prof. Octavian Pleter (University Politehnica of Bucharest)

Flight trajectories optimization for warming contrail avoidance

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Aviation contributes to about 3.5% of the total anthropogenic climate change when including non-CO_2 effects (Lee et al. 2021). Among non-CO_2 effects, the contrail-cirrus radiative forcing is the largest (~2/3) with large uncertainties. The most critical affecting factor is the huge weather-induced variability of the radiative impact of individual contrails. The previous research demonstrated the potential of largely avoiding contrail formation with a limited increase of flight time (<2%) over a subset of transatlantic flights (Yin et al. 2018). Nevertheless, the large uncertainties of contrail effects impose challenges on formulating adequate mitigation measures. The Horizon Europe funded project BeCoM (https://www.becom-project.eu) aims to improve confidence in forecasting persistent contrail formation, hence enabling a large reduction in the global mean contrail radiative forcing. This is facilitated by a confidently forecast of Ice superstation regions (ISSRs), the reduced weather-dependent individual contrail radiative effects, and the successful avoidance of strongly warming contrails via trajectory optimization.

This research, as a part of BeCoM project, focuses on the climate-optimized flight trajectories for warming contrail avoidance. As the first step, we analyze the daytime and nighttime contrail climate impact of eco-efficient flight trajectories, using an air traffic simulator (AirTraf, Yamashita et al. 2020) based on a selected set of European traffic samples. By artificially eliminating the cooling contrail during the postprocessing, we observed that the mitigation potential in the daytime is mostly driven by the cooling contrail, which requires a closure analysis given the large uncertainties in weather predictions. Nevertheless, as further steps, we plan to: (1) implement the revised ISSRs conditions from BeCoM project, (2) optimize flight trajectories to avoid warming contrails, (3) analyze the potential mitigation gain of aviation's climate impact. The expected results will provide insights into how the forecast of ISSRs affects the flight routings for contrail avoidance and allow us to identify the mitigation potentials of contrail climate effects.

Implementing and testing a U-space system: lessons learnt

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Within the framework of the European Union's Horizon 2020 research and innovation program, one of the main goals in the LABYRINTH project was to develop and test path planning algorithms to calculate 4D deconflicted and optimized trajectories for drones. These algorithms were addressed to support the Strategic and Tactical Conflict Resolution services of a U-space-based Unmanned Traffic Management (UTM) system. DLR was responsible in the project for the implementation of that UTM system. The U-space ConOps provides a high-level description of the architecture, requirements and functionalities of these systems, but the implementer has certain degree of freedom in aspects like the technologies used or some policies and procedures. The current document describes those implementation decisions. The U-space prototype included, at least in a basic version, part of the services required by the ConOps for a type Z airspace volume U3 level implementation, concretely: e-identification, Tracking, Geo-awareness, Drone Aeronautical Information Management, Geo-fence provision, Operation plan preparation/optimization, Operation Plan processing, Strategic Conflict Resolution, Tactical Conflict Resolution, Emergency Management, Monitoring, Traffic Information and Legal Recording. Besides, a webapp was developed to serve as interface between operator/pilot and UTM. The system was tested in real flights with final users interested in incorporating drones to support their activities. The tests included multi-rotor and fixed-wing drones, with up to the three drones per mission. Simulations were also run to check the performance of the system under more demanding scenarios. The exercises allowed to identify needs at different levels: functionalities, procedures, information, usability, or GCS integration and roles during the mission.

ATM strategies for, and impacts of, space launches

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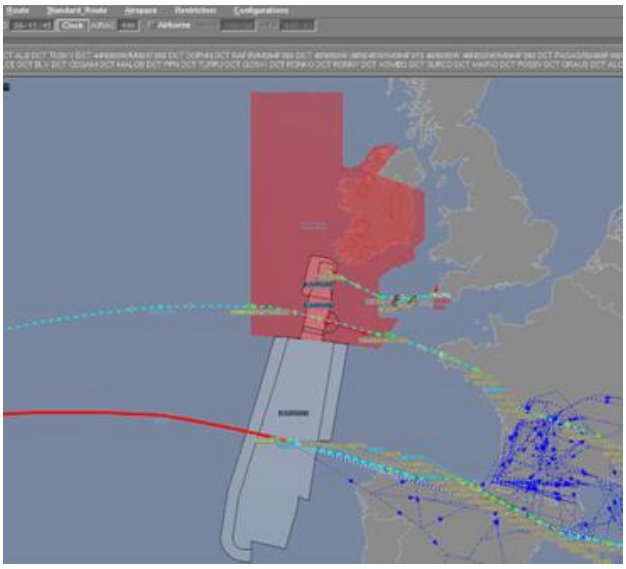
This paper explores the increasing intersection between the aviation, air traffic management (ATM) and space communities, regarding the rapid growth of national space launch ambitions and capabilities, delivering satellites into low-earth and sun-synchronous orbits. With vertical and horizontal delivery methods, and numerous locations under consideration in several continents, the industry has faced early challenges, such as failed launches and licencing timescales. This paper introduces the background and principles of space launches, before addressing the particular impacts on aviation and ATM. The strategic challenges of planning launch windows to align both with orbiting asset congestion and ATM demands, plus promulgating such information to airspace users, is discussed. In the tactical phase, the consequences of impacts on airspace users (such as the re-routing of flights) and on air navigation service providers (such as the demands of coordinating airspace closures in the context of considerable re-entry/splashdown uncertainty) are examined in some detail. In particular, the cost impacts on aviation are considered, exploring a specific case study and the challenges of designing a generic cost assessment model.



ATM towards the adoption of a passenger-centric approach

Slavica Dožić, Danica Babic, Ismini Stroumpou, Franck Dumortier, Josep Lluis Larriba Pey

Including air transport in seamless door-to-door (D2D) travelling is a new trend in the transport industry which comes along with the extension of the Mobility as a Service paradigm and single ticketing concepts, taking them to a different level. This tendency is considered in the SYN+AIR [Synergies between transport modes and Air transportation (SYN+AIR) project under grant agreement No. 894116, funded by SESAR Joint Undertaking] and SIGN-AIR [implemented Synergles, data sharing contracts and Goals between transport modes and AIR transportation (SIGN-AIR) project under grant agreement No. 101114845, funded by SESAR Joint Undertaking] projects which aim to introduce and conceptualize a new business model aligned with EU policies.

Currently, Air Traffic Management (ATM) follows a conventional Air Traffic Control with sectorization. The tendency is to change this to a flight-centric structure based on the controller's responsibility for a certain number of aircraft within a given airspace. Further, to bring the maximum benefits from covering air travel D2D and involving all stakeholders, ATM will need to shift to highly resilient and efficient network operations, passenger-centric and full collaboration with numerous actors.

To achieve all the above-mentioned, five aspects of integration need to be addressed, i.e., physical (infrastructural), network, price, information and institutional integration. With the use of Smart Contract Framework (SCF) the network, information and institutional integration could be enabled. SCF sets common goals for data sharing between Transport Service Providers (TSPs). These goals are facilitated by an extensive analysis of the relevant stakeholders' activities and the data generated per transport mode in various multimodal chains (e.g., train-airplane-bus, taxi-airplane-metro, etc.). SCF paves the way for the creation of contracts among TSPs of different transport modes by allowing the management of these agreements centrally while handling the appropriate data in a decentralized manner. More precisely, in our model, "Contracts" are agreements between TSPs that define data sharing criteria [scope, parties' obligations (i.e., revenue and responsibility sharing), contracts' time span and fulfilment criteria].

This paper aims to present the structure and the main elements of the platform that supports multimodal services through data sharing while considering applicable EU policies and regulations. All the stakeholders involved in this system will benefit: 1) TSPs will have a monitoring dashboard to manage and follow their smart contracts, 2) travellers will have a single information platform concerning all stages of the multimodal journey, 3) transport authorities and local community will have data on origin-destination matrices, moves of the population, etc. Special focus will be given to a passenger-centric vision of ATM, as an integrated part of the multimodal transport system, that should make possible a better accommodation of airlines requirements with respect to a given flight. Also, it will be explained how to provide a more collaborative decision-making environment in the case of disruptions that should lead to lessening the flight delays in the future.

Fuel consumption behaviour in aggregated air traffic metrics

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According to Our World in Data aviation accounts for 2.5% of global carbon dioxide, CO_2, emissions ,thus making decarbonisation a main topic for the aviation industry. In order to be able to gain knowledge on emissions the first step is to be able to measure them. Focusing on CO_2, which is the emission currently targeted by market-based measures tackling the carbon emissions such as CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation), the common approach is to estimate it as a linear relationship with the consumed fuel. A correlation factor between 3.15 and 3.16 has been validated by the scientific community.

Currently there exist a wide variety of models that can be used to assess the fuel consumption of a single flight, from conventional models based on physics and flight performance to more innovative ones based on avant-garde techniques such as artificial intelligence. However, the quality of the fuel consumption estimated by these models usually relies strongly on the quality of data available. In other words, the more information available of a flight, the better estimation of the consumed fuel, and therein, carbon dioxide emissions. As consumed fuel is impacted by a wide variety of features, such as aircraft type, engine family, meteorological conditions, flight path, etc, the more information available, the more accurate the estimations will be.

However, having access to such granulated data is not always trivial and, moreover, the computational cost that could be derived from assembling data coming from different agents in the aviation field (airports, airlines, manufacturers, meteorological stations), plus the processing of the data and afterwards the computation of a refined fuel consumption model will be very high. In the work presented here an extensive analysis on how consumed fuel and carbon dioxide emissions estimations could be made with a limited access to information is performed. Moreover, the aim is to be able to prove that for aggregated metrics, that being a set of flights and not a single flight, the consumed fuel can be easily estimated thus helping accounting for the dioxide carbon emissions that are produced at a global level.

Sizing of Airport Infrastructures in Support to Hydrogen-Powered Fleets

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As the interest in hydrogen as an energy source for future aircraft is boosting worldwide, numerous studies are being pursued to envisage airframes designed to accommodate innovative propulsion systems, based on fuel-cells or turboengines. The impact of such a radical transformation on the whole civil aviation system cannot be understated, starting with the radical transformation of infrastructural requirements. As a contribution to solving this problem, the present paper presents the AHRES (Airport Hydrogen Refuelling Equipment Sizing) methodology focused on the sizing of airport infrastructures in support of H2-powered commercial fleets.

AHRES application provides an estimate of the required infrastructural needs based on the knowledge of the airport's flight schedule and the characteristics of the operating aircraft. The latter are retrieved by applying the HYPERION airplane preliminary sizing tool, which outputs candidate design solutions for H2-powered aircraft, thus delivering the corresponding hydrogen quantities to be loaded on board for any mission of interest. With these data, AHRES defines an optimal solution to the sizing of the complex airport equipment, including the hydrogen generator (for on-site production), the liquefier, the storage tank, and the dispensing units. Optimality is based on minimizing the total cost, comprised of the procurement of all equipment items and the energy purchased from the grid. The output is the sizing of each item, supplemented by the optimal time scheduling of production, storage, and delivery operations. This eventually provides the cost of H2 per unit mass "at the pump", a decisive piece of information for the overall feasibility of the hydrogen revolution. Application studies are illustrated, including the reconfiguration of two existing aerodromes, a large regional airport and a major international hub. For the Athens International Airport (ICAO code: LGAV), we restricted to the needs to support a regional fleet composed of fuel-cell-powered aircraft. For a possible realistic scenario, Figure 1 shows the time histories of the hydrogen mass stored in the cryogenic tank (H2 in ST) and the delivered to the airplanes (H2 to DU), supplemented by the airport's flight schedule (Departures). The case of the Malpensa International Airport (LIMC) is also discussed, with results related to H2-burning airliners.

The Carbon Conundrum of Military Aviation: Navigating the Dilemma between Operational Efficacy and Environmental Accountability

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As the global community intensifies its efforts to combat climate change, the question of how military aviation and air traffic management should prioritize its focus between operational effectiveness and environmental sustainability is gaining increased prominence. This abstract delves into the controversial proposition that military aviation experts and advisors should place greater emphasis on refining procedures, techniques, and equipment to enhance combat capabilities against opposing forces, while potentially diverting attention away from addressing environmental issues. As an advocate of this stance, the author of this paper contends that the contribution of military aviation's carbon footprint is comparatively limited vis-à-vis other sectors or civilian aviation.

The recent commitment by NATO, where Secretary-General Jens Stoltenberg unveiled ambitious targets to achieve carbon neutrality by 2050 , lends context to this discourse. This development might underscore the alliance's acknowledgement of the imperative to address environmental concerns. Nevertheless, the author argues in favor of operational efficacy, asserting that military aviation's carbon footprint represents a tiny fraction of global emissions, diminishing its significance within the broader framework of ambitious climate objectives.

A central argument favoring a greater focus on operational efficacy lies in the necessity to uphold air and space supremacy. In a landscape where adversaries prioritize lethal capabilities over environmental considerations, another key defense policymaker emphasized the importance of reducing the air force's role in contributing to climate change . Consequently, it implies the need to allocate a significant portion of the defense budget and valuable human resources towards the adoption and implementation of green technologies within NATO allied air forces. Dedicating substantial resources to environmental issues within military aviation and air traffic management may divert attention and funding from vital defense priorities. By refining procedures, techniques, and equipment, the air force can fortify its capacity to execute missions effectively, thereby ensuring the safety and security of nations indirectly supporting broader sustainability endeavors.

The objective of the article is to initiate a discourse on the contention that military aviation experts and advisors should assign precedence to operational efficacy over environmental concerns, emanating from the relatively minor role (military) aviation plays in global greenhouse gas emissions. Then the paper describes how to aim for a rationalized balance between operational requirements and environmental responsibility which reflects the net-percentage contribution of military aviation to emissions. Finally, the article introduces a framework of methods and possible solutions from the standpoint of traffic management for achieving an equilibrium that harmonizes air force imperatives with a sustainable future.

Study on the Transition to True North in Air Navigation

Octavian Thor Pleter*, Cristian Emil Constantinescu

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The paper is an introductory study on the possible transition from Magnetic North reference to True North reference in air navigation, as envisaged by the International Association of Institutes of Navigation's AHRTAG Group. The use of the Magnetic Field of the Earth as a direction reference in aviation is explained briefly. Magnetic North is an unstable and irregular directional reference that aviation manages well, but with significant costs. The unpredictability and uncertainties of the Magnetic Field of the Earth might be exaggerated in the future, especially in the case of reversal of the magnetic poles, or incipient reversal. The paper puts forward the case for calculating the probability of such a catastrophic event, with a view to engaging further expert research in the geomagnetic phenomena. The purpose of such a probability estimate would be for the aviation decision makers to determine whether contingency planning might be required or not. Furthermore, the paper analyses the adoption of True North in maritime navigation as a possible model.

Flexible Airspace Solutions in Free Route and "New Normal" defence posture environment

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Post COVID-19 economic (air traffic) recovery and expansion of (sub)regional Free Route Airspaces are paving the way for new optimized civil flight trajectories and encouraging Air Navigation Service Providers to reconsider their sector configurations which have been squeezed mostly into Flight Information Regions.

The need for broader cross-border sectorization (static and dynamic ATS delegation) is on the horizon and these changes consequently impact on the legacy civil-military arrangements such as airspace control and air traffic management. The optimized flight trajectories and new sector configurations will also initiate discussion between civil and military stakeholders to revise military airspace structures and find solutions for an enhanced flexible use of airspace. However, the need for improving civil-

military collaboration and redesigning national airspace structures, especially military airspace reservations, is getting vital in light of the crucially changed European deterrence and defence environment. The European NATO Allies and their partners have started to address airspace requirements for NATO deterrence and assurance activities in order to support the strengthened deterrence and defence posture and ensure that trainings, exercises and missions take place utilising high-intensity, large formation warfighting capabilities in complex scenarios. The already recognized need for larger volumes of military airspaces in a legally peacetime environment could pose some constraints in Europe, given the current airspace structure and dimension of some national airspace. Obviously, solutions shall be explored with full engagement of civil and military stakeholders, and any change in airspace structure should embrace the Flexible Use of Airspace concept to minimize impact on civil aviation network.

The purpose of the article is to introduce evolution of the Free Route Airspaces and present the legacy and ad-hoc military airspaces established in the Eastern-European region. Then the paper describes the Flexible Use of Airspace principles and the reasons of extensive airspace reservations in "New Normal" defence and deterrence situation. Finally, the article introduces methods and possible solutions for modular, flexible and dynamic military airspace structures that can support both military and civil needs.

Assessing the Risk of Uncontrolled Space Debris Reentry: A Case for Airspace Management and Flight Safety

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** University POLITEHNICA of Bucharest, Romania*

In this paper, we explore the risks associated with uncontrolled space debris reentry and its implications for airspace management and flight safety. With the increasing number of satellites and other objects being launched into space, and the older existing space objects, the potential for uncontrolled reentry events poses a unique challenge for airspace management and public safety. While there have been no recorded instances of aircraft damage or human injury due to reentering space debris (but there were material damages on ground), the increasing frequency of such events necessitates a comprehensive understanding of the associated risks and appropriate mitigation strategies. We briefly examine the current methods for tracking and predicting space debris reentry, concentrating on the decision-making process for airspace closures, and the risk assessment for ground airborne safety. Our analysis aims at contributing to the ongoing dialogue on space debris management and to inform future policy and operational decisions in the context of civil aviation and public safety.

Obsolescence in Aviation Systems of Systems with Applications in ATM

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Systems-of-Systems theory is enlarging the perspective that engineers have on the objects of their work. Previously, efforts were focused at the system level, and by managing system inputs and outputs, all interactions between systems were thought to be addressed. With age, a system-of-systems designed individually at different moments in time will degrade as an overall fitness to purpose, will grow a certain degree of obsolescence. In aviation this is most evident, since systems invented and put in place 60 years ago are still operating. The assumptions made originally when the system was created became obsolete, gradually or in quantum leaps. This paper uses examples from air navigation to illustrate that the fitness for purpose for an individual system does change with the passing of time and with the changes of the environment the system is working in. The first time a

system is established as an industry standard, its first design, its first architecture is presumably best fitting the requirements, the specifications. Although these specifications of the system do not change in time, the fitness to the purpose does change and usually decays. This is only obvious at a systems-of-systems analysis, done for the system now part of a system-of-systems. The paper studies the following cases of obsolescence with impact on Air Traffic Management: Radar Altimeters, ILS Glide Slope intercept from above, Continuous Descent Approach effects on turbine engines, and evolution of SSR transponder utility.

On safe separation of aircraft flying along air corridors

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** CCTAE, IDMEC, Portugal*

Mid-Air Collision (MAC) is an aviation accident category defined as a collision while both aircraft are in flight. MAC is an extremely rare event but when it occurs, it has catastrophic consequences. To prevent aviation accidents like MACs, ICAO (International Civil Aviation Organization) has established a Target Level of Safety (TLS) stating a probability of collision not exceeding 5E-9 per flight hour. The current procedures are based on empirical separation rules that are deemed "safe enough" on the basis of extensive experience over many year worldwide. This begs several questions: (i) Is the ICAO TLS met by current separation rules? If so, what level of position accuracy is implicitly assumed?, (ii) At the current level of position accuracy can the probability of collision exceed the ICAO TLS? In this case the separation should be increased.

The present paper addresses the application of collision probabilities to address the trade-off between (i) safety or collision probability, (ii) separation or airspace capacity, and (iii) position or navigation accuracy. The scenario considered is aircraft flying on air corridors at equal velocity and in the same direction along parallel tracks. In this case, the average crossing rate is zero, because it is proportional to the difference in speed errors. This method applies both for aircraft: (i) whose relative velocity is zero, e.g., flying along air corridors with the same velocity and direction, (ii) whose relative velocity is not zero, e.g., flying along air corridors in opposite directions, or crossing or climbing and descending.

The method is used to obtain three safety metrics: (a) the maximum of the joint probability density of coincidence, (b) the one-dimensional marginal probability of coincidence, (c) the three-dimensional cumulative probability of coincidence. The theory applies to (i) altitude, and (ii) along and (iii) across track separations or any combination of them. It is illustrated by the cases of standard and reduced vertical separations. The comparison is made with the ICAO TLS standard and its analogues in Table 1.

The model of collision risk along flight corridors was applied to (i) vertical separation, since the benefits of Reduction of Vertical Separation Minima (RVSM) are very well known and documented. The model also applies to (ii) lateral separation for flights on parallel tracks at the same flight level and also to (iii) longitudinal separation for aircraft flying along the same path. A very effective method to significantly reduce collision risk is to use simultaneously two or three separations (i) in altitude, (ii) lateral, and/or (iii) along track. The methods presented can be applied to (a) all three separations individually or (b) any combination of two or (c) all three together, if they are statistically independent, the product of probabilities applies, and if not, correlation functions must be used.

Quantity	Unit	Standard	Reduced
Vertical separation	ft	$L_a = 2000$	$L_b = 1000$
r.m.s. altitude error	ft	$\overline{\sigma}_a = 180$	$\overline{\sigma}_b = 90$
One-dimensional marginal probability of coincidence with $\lambda = 1$	$(\mathrm{NM})^{-1}$	$\overline{P}_a = 1.50 \times 10^{-12}$	$\overline{P}_b = 3.00 \times 10^{-12}$
Maximum velocity to meet the ICAO TLS	kt	$V_a \leq \frac{S}{\overline{P}_a} = 3.33 \times 10^3$	$V_b \leq \frac{S}{\overline{P}_b} = 1.67 \times 10^3$
Probability of coincidence in a great circle tour of the earth	-	$\overline{R}_a \leq \overline{P}_a D \leq 3.24 \times 10^{-8}$	$\overline{R}_b \leq \overline{P}_b D \leq 6.48 \times 10^{-8}$
r.m.s. altitude error	ft	$\overline{\sigma}_{ma} = 160$	$\overline{\sigma}_{mb} = 80$
Probability density ofcoincidence with $\lambda = 3$ or $\lambda = 1/3$	$(\mathrm{NM})^{-2}$	$P_{ma} = 1.66 \times 10^{-14}$	$P_{mb} = 6.40 \times 10^{-14}$
Maximum velocity to meet the ICAO TLS (50a)	-	$V_{ma} \leq \sqrt{\frac{S_m}{P_{ma}}} = 5.48 \times 10^2$	$V_{mb} \leq \sqrt{\frac{S_m}{P_{mb}}} = 2.79 \times 10^2$
Probability of coincidence in a great circle tour of the earth	-	$X_{ma} = P_{ma} D^2 = 7.74 \times 10^{-6}$	$X_{mb} = P_{mb} D^2 = 2.99 \times 10^{-5}$
r.m.s. altitude error	ft	$\overline{\overline{\sigma}}_a = 400$	$\overline{\overline{\sigma}}_b = 200$
Cumulative probability of coincidence with $\lambda = 9$ or $\lambda = 1/9$	NM	$\overline{\overline{P}}_a = 2.17 \times 10^{-5}$	$\overline{\overline{P}}_b = 1.09 \times 10^{-5}$
Maximum velocity to meet the ICAO TLS (49b)	-	$\overline{\overline{V}}_a \leq \overline{\overline{P}}_a / \overline{\overline{S}} = 4.34 \times 10^3$	$\overline{\overline{V}}_b \leq \overline{\overline{P}}_b / \overline{\overline{S}} = 2.17 \times 10^3$

Aerodynamic Analysis and Design

Chaired by:
Prof Jerzy Zoltak (ILOT)

Cavity noise reduction with sweeping actuators

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** IAES, Algeria*

Cavity noise is a significant problem in the aviation industry, particularly in the design and operation of aircraft. Cavity noise occurs when airflow separates from a surface and creates vortices within a cavity, which then generate noise. In the case of airplanes, the cavity noise is typically generated in areas such as the landing gear bays, engine nacelles, and wing flaps. This noise can be not only annoying and uncomfortable for passengers and crew, but it can also affect the structural integrity of the aircraft. Furthermore, noise pollution is a major concern for communities surrounding airports, and the reduction of cavity noise is an important factor in mitigating this issue. Therefore, the need for effective cavity noise control solutions is crucial for the aviation industry.

Sweeping jet actuators (SJAs) have shown great potential as a solution to reducing cavity noise in the aviation industry. SJAs are devices that emit high-speed jets of air that sweeps back and forth across the surface at a high frequency, to control and manipulate the airflow around an object. In the context of cavity noise reduction, SJAs can be used to prevent the formation of vortices within a cavity by controlling the airflow and reducing turbulence.

The trailing edge of the cavity is a particularly important location for SJA application as it is where the flow separation occurs and generates most of the noise. By applying SJAs at the trailing edge, the turbulent flow can be controlled, and the noise generated by the cavity can be reduced. Sweeping jet actuators have shown great potential as a solution to cavity noise reduction, particularly in the trailing edge of the cavity. Their ability to control turbulence and reduce noise across a range of Mach numbers makes them a versatile and effective solution to this challenging problem. With further research and development, SJAs may become a standard feature in the design of aircraft and other vehicles, providing a quieter and more comfortable environment for passengers and crew.

L1 Adaptive Controller Design for a Tail Fin Controlled Fixed-Wing Unmanned Aerial Vehicle

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** ASELSAN A.Ş., Turkey*

The aim of this study is to design an L_1 adaptive controller, which is one of the robust control methods that can overcome model uncertainties, disturbances, and noise, for a fixed-wing unmanned aerial vehicle (UAV) with tail fin control. In this context, first of all, the decoupled equations of motion of the six-degrees-of-freedom system are derived for the roll, pitch, and yaw channels of the UAV. Then, the performance of the controller is demonstrated by simulation results for the linearized system representation. By adding parameter errors to the system in question, the feature of tracking the given angle commands is analyzed. It has been observed that the L_1 adaptive control structure exhibits rapid adaptation even in the presence of system uncertainties. Finally, the controller is applied to the nonlinear system and operated throughout the entire flight envelope.

A UAV is an aircraft without any human driver or passenger on board, and it can be remotely controlled, flown partially autonomously, or flown autonomously. The dynamics of a UAV constantly change during the flight of the UAV. The relatively small structure of UAVs makes them difficult to control under disturbances such as wind and noise, and the systems may become unstable. In addition, unmodeled system dynamics can also destabilize the UAV. For all these reasons, a robust control structure design that will keep the UAV stable during its flight becomes essential.

To achieve this, various autopilot strategies providing stable flight for a large flight envelope are proposed, including a gain-scheduled autopilot design, an adaptive autopilot design, an H∞-based switching control strategy, and model predictive control for attitude tracking.

Another remarkable design strategy for a flight control system is L_1 adaptive control. In recent studies, the L_1 adaptive control structure has been applied to various types of UAVs, such as tandem rotor UAV, tailless flying-wing aircraft, and ducted propeller UAV. In these works, it has been observed that the control method exhibits fast adaptation and robustness despite unknown uncertainties and external disturbances that change over time.

In this study, a complete guideline for L_1 adaptive control is presented to validate the method for a no-thrust UAV system that lacks a wind sensor. The theoretical results are successfully implemented in a full-order nonlinear model considering uncertainties and disturbances. The results reveal good tracking performance as well as satisfying robust stability for a large flight envelope.

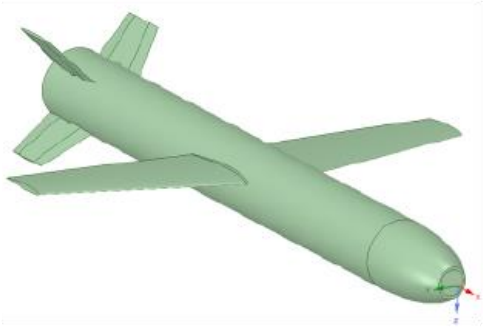

Figure 1: Model of the UAV.

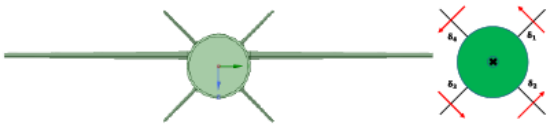

Figure 2: The tail fins of the UAV.

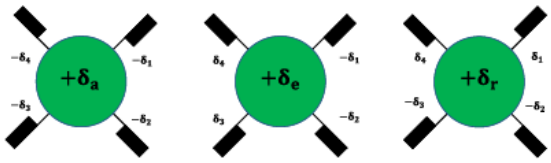

Figure 3: Positive control deflections for aileron, elevator and rudder

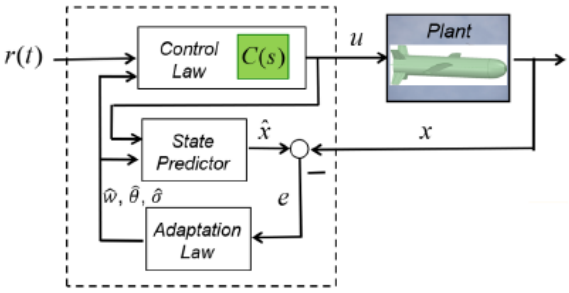

Figure 4: L_1 Adaptive Control diagram.

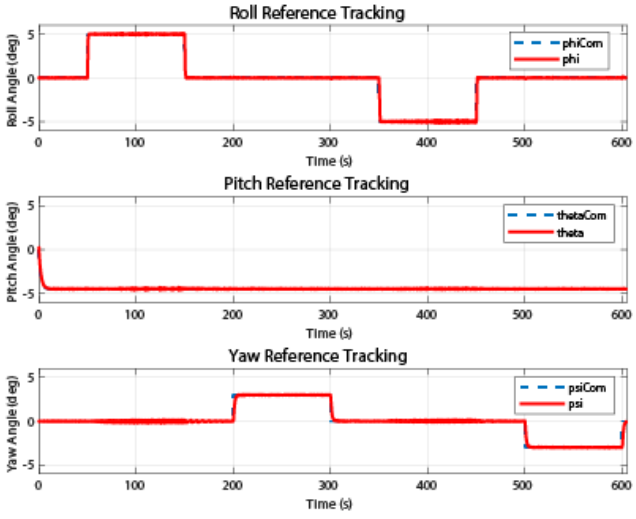

Figure 6: Reference tracking of Euler angles.

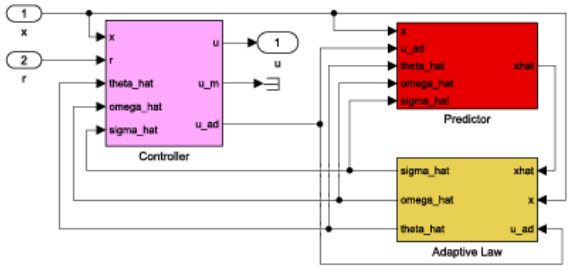

Figure 5: L_1 adaptive controller architecture in Simulink.

EXPERIMENTAL STUDIES OF INFLUENCE OF GROUND EFFECT ON AIRLINER AERODYNAMIC CHARACTERISTICS

Andrzej Krzysiak*, Robert Placek, Aleksander Olejnik and Łukasz Kiszkowiak

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Aerodynamic properties of an aircraft are defined by a set of aerodynamic forces and moments coefficients, the values of which depend on different aircraft flight phases and thus its different configurations (i.e. take off, cruise and landing configurations). The position of the aircraft relative to undisturbed flow (angle of attack, sideslip angle and roll angle), and in some cases also the flight speed habve a significant impact on the values of these coefficients. In the scientific literature on aviation, there are many publications presenting the aerodynamic coefficients as a function of angles of attack, sideslip or roll angles. In the majority, these data are related to undisturbed flow, i.e., flow unaffected by other objects or limitations. During an aircraft take-off or landing, the proximity of the ground causes that aerodynamic characteristics take slightly different values than in undisturbed flow.

The paper presents the results of experimental wind tunnel tests of the basic aerodynamic characteristics of the Tu-154M aircraft model with ground effect simulation by placing a flat plate under the aircraft model at distances of h = 0.53 m and h = 1.31 m from the fuselage axis (measured at the model angle of attack a = 00). These coefficients being influenced by the ground effect were compared with the test results of the Tu-154M aircraft model obtained in the undisturbed flow conditions.

Wind tunnel tests were carried out in the Łukasiewicz Research Network – Institute of Aviation wind tunnel T-3 (with a 5 m diameter test section) using the aircraft model at the 1:14 scale. The tests were performed at the V¥ = 40 m/s, which corresponds to the Reynolds number (related to the mean aerodynamic chord) Re = 0.75*106 and in the range of angle of attack a = -40 ÷ 200. The balance measurements allowed to determine the impact of proximity to the ground on the basic aerodynamic characteristics of the Tu-154M aircraft model.

Structural aspects of the high aspect ratio wing: DLR-F25

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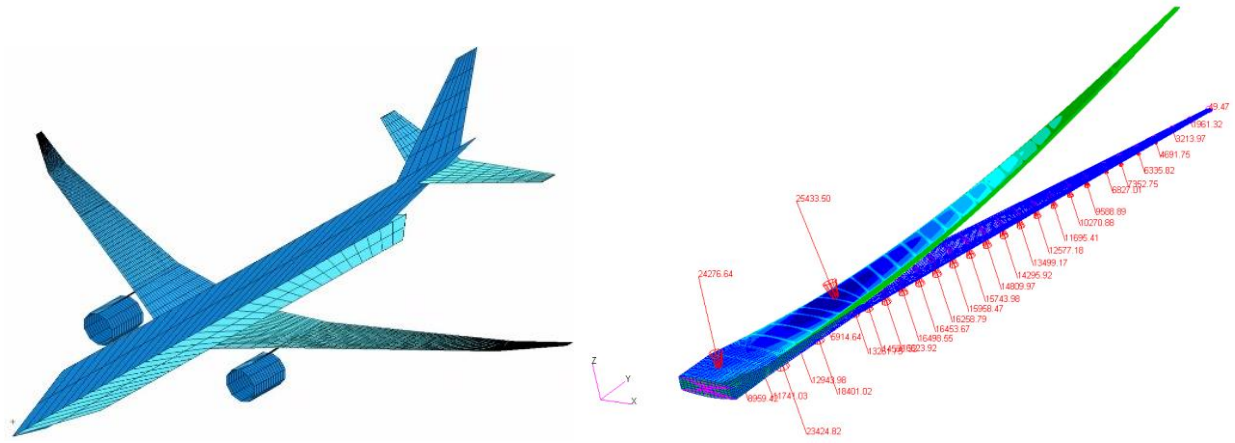
High aspect ratio wings promise better aerodynamic performance, but the wing structure design is very challenging due to the thin airfoil, shorter chord length and large span. For collaborative research purposes on ultra-efficient aircraft, a short and medium range configuration, called DLR-F25, with a comparatively high aspect ratio of 15.6 was developed at the German Aerospace Center (DLR). Nevertheless, a 15% reduction in wing mass compared to a metallic wing is required to achieve the design objectives. By taking the 36m airport parking box for typical short medium range aircraft into account (aircraft design group III), additional mechanisms are required to utilise the current infrastructure. Finally, due to shorter chord length of the high aspect ratio wing and the mandatory x-position of the main landing gear, the space for a wing mounted landing gear is no longer available and therefore a body mounted landing gear applied.

In the present work a coupled aeroelastic process for the structural design of high aspect ratio composite wings. The design process uses gradient based structural optimisation combined with automatic model generation and comprehensive load updating. For the loads analysis a flexible structural model for the complete aircraft is used. Maneuver, gust, and landing loads are calculated taking into account typical mass configuration. Fuel, passenger, and cargo mass cases plus selected center of gravity positions are considered. To achieve the mass reduction targets, composite materials are being investigated for the wing structure. Composite stiffeners are also considered and optimized in the structural design.

This framework is used to evaluate structural features of the DLR-F25 wing. The stiffened composite design is investigated as well as the effect of the wing folding mechanism mass on the wing structure and the loads. Furthermore, the positive effect of the body mounted landing gear on the wing structure is evaluated and described.



Helicopter main rotor FSI analysis using parametric blade model as an application for multidisciplinary optimization

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This work is a part of a research program which is intended at finding new approaches and design solutions for helicopter main rotor modelling using multidisciplinary optimization. It is a fourth stage of individual research programme containing such preliminary tasks as: parametric modelling of a single blade, CFD modelling of a full main rotor for different flight conditions and preliminary structural modelling of a blade.

The main goal of the work is to present the parametric modelling of rotor blade body and structure as an application for complex simulation. The paper shows the method of advanced analysis of the whole rotor and exemplary results obtained from complicated analyses.

The analytical base for combined fluid-structure analysis is presented. The parametric design method is shown to be applied for different blade planform shapes and various section airfoils. The blade CFD fluid domain is also prepared using parametric method, as well the blade inner structure.

The parameters of simulation, from the previous stages of research, as an inputs to the FSI analysis are outlined. These ones formerly obtained are combined and introduced into an FSI simulation to check their compatibility and applicability. The configuration procedure of the analysis and the boundary conditions are presented. The obtained numerical results were compared then with analytical assumptions. The simulation products which are the inputs for further analysis are shown with graphics representations. The time and memory consumption of simulation is outlined. The application of the described work into an optimisation loop is proposed.

As an output of the research, the new options for main rotor optimization are developed. Some crucial possibilities of FSI analysis were demonstrated in described simulation cases. The usage of combined parametric modelling with fluid structure interaction analysis for different flight conditions is shown in the work as a new perspective for multidisciplinary design optimization of a helicopter rotor system.

VEE-TAIL PRELIMINARY DESIGN METHODOLOGY FOR CLASS I MINI UAV

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Unmanned Air Vehicles (UAVs) are becoming increasingly popular and widely used in a variety of industries. They can be used for tasks such as agriculture, construction, delivery, surveillance, rescue operations, mapping, wildlife tracking and many more. With the advancements in technology, UAVs are becoming more autonomous and able to perform tasks with minimal human intervention, so are widely used for military and law enforcement purposes. V-tail configurations are commonly used on UAVs due to their advantages in control and stability performance, as well as their ability to reduce drag and improve overall efficiency. However, research on V-tail design and sizing is limited, particularly for Class I mini-UAVs. The objective of this paper is to identify a methodology for a V-tail sizing of a Class I Mini UAV (NATO classification), which refers to the Conceptual and Preliminary Design of the UAV. The methodology will follow the design of a V-tail from the characteristics of the conventional tail of the UAV. Once the characteristics of the conventional tail were extracted, V-tail geometric characteristics (reference area, aspect ratio, mean aerodynamic chord, tail span, dihedral angle), are computed. Therefore, the aerodynamic characteristics of the V-tail have to be extracted, first as an isolated tail, and then as an installed tail. The stability derivatives of the V-tail are then calculated. The methodology for the analytical aerodynamic characteristics and stability derivatives, is a combination of NACA Report No.823 and Marcello R. Napolitano methodologies. Paul E. Purser and John P. Campbell provide design methods for V-tail on a NACA report, which include some of the desired stability derivatives. The rest of them will be calculated with Napolitano's method. Marcello R. Napolitano gives a methodology for conventional tail sizing, thus, the equations of its methodology have to convert for a V-tail configuration. Furthermore, the aerodynamic characteristics and stability derivatives of the designed V-tail will be verified by Low Fidelity Aerodynamics simulation (XFLR5 software), and then by High Fidelity Aerodynamics by means of CFD. The results between low fidelity analytical values and XFLR5 Low Fidelity Aerodynamics values indicate a divergence lower than 20%.

Aerodynamic Concepts of Flat-Upper-Surface-Wing Light UAV

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The aim of the work was to conduct conceptual studies on the possibility of building a lightweight UAV with wings characterized by the fact that at least 75% of their upper surface is perfectly flat. In principle, such a UAV would be a flying laboratory enabling the study of various types of photovoltaic cells, including rigid ones.

The presented research focuses on the most important aerodynamic aspects, i.e. on the aerodynamic design and initial optimization of three wings dedicated to three different concepts of a small UAV shown in Figure 1. These are High-Aspect-Ratio Wing, Low-Aspect-Ratio Wing and Joined-Wing System.

The work involved two stages of aerodynamic design. The first of them concerned the design of a family of flat-top-surface airfoils. This stage was carried out based on in-house CAD software, and the aerodynamic characteristics of the airfoils were determined using the XFLR-5 software. The final result of this work was the airfoil family WS FUS X.X. All airfoils in this family have a perfectly flat upper surface in the range from 25% of the chord to the trailing edge. The WS-FUS-X.X family consists of 10 flat-upper-surface airfoils with different curvature of the camber line, starting from symmetrical airfoil WS-FUS-0.0.

As part of the second stage of the discussed research, the process of aerodynamic designing and optimization of three upper-flat-surface wing configurations was carried out. The process was based on the parametric design methodology, which was developed by the Authors and was used in many design and optimization works. A general outline of this methodology, adapted to the research

subject, is shown in Figure . The in-house software PARADES was used to build parametric models of flat-upper-surface wings in three discussed configurations. In this model, the main design parameters described a continuous distribution of aerodynamic twist of wing cross-sections (airfoils from the family WS FUS X.X) along the wing span. The aerodynamic properties of designed wings were calculated by the use of PANEL3DBL in-house software – 3D Panel Method coupled with 2D Boundary Layer analysis. The aim of optimizing each of the three flat-upper-surface wing concepts was to maximize the endurance factor (CL3/CD2, where CL-lift coefficient, CD-drag coefficient) at a given value of the lift coefficient corresponding to the weight of the entire aircraft.

In the case of high-aspect-ratio flat-upper-surface wing, a wing without aerodynamic twist, built on the basis of the WS-FUS-2.5 airfoil, was adopted as the baseline wing. Clear increase in the Endurance Factor for the optimized wing was received.

In the case of low-aspect-ratio flat-upper-surface Wing, a wing without aerodynamic twist, built on the basis of the WS-FUS-2.5 airfoil, was adopted as the baseline wing. An increase in the Endurance Factor for the optimized wing appeared significantly smaller than in the previous case.

In the case of flat-upper-surface system of joined wings, a wing without aerodynamic twist, built on the basis of the WS-FUS-2.5 airfoil, was adopted as the baseline wing. Again, a clear increase in the Endurance Factor for the optimized wing can be seen.

Study of Effect of Propeller Slipstream on a Wing with Unconventional Propulsion System

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Due to global warming concerns, the Aviation industry is trying to reduce its carbon footprint. There are three ways of doing this, (i) improve efficiency of the jet engines, (ii) use batteries and electric motors to deliver part of power requirement (hybrid propulsion) for the aircraft and (iii) use only the power from batteries to drive electric motors / propellers (electric propulsion). The scope of development of electric propulsion (EP) is immense since technology is scalable. It can be implemented for 2- seater as well as 100-seater aircraft. In EP, there is a concept of distributed propulsion (DP) or distributed electric propulsion (DEP) that is in the focus now. NASA's X-57 Maxwell, a high winged, all-electric experimental aircraft, uses this concept. It includes one electric cruise motor, placed at the end of each wing to reduce the drag from wingtip vortices. In addition, it also uses 6 smaller motors placed at the leading edge of each wing, which provide high lift during takeoff and landing, and also helps to reduce the required takeoff distance.

The present work aims at developing a CFD model (ANSYS Fluent) to evaluate aerodynamic performance of two configurations of NASA's X-57 aircraft wing, (i) wing and nacelle (clean wing) and (ii) wing, nacelle and one electric propeller under cruise condition, and compare it with the results of wind tunnel experiment performed by NASA/Armstrong X-57 research program. For the first configuration, the geometry and mesh were obtained from the Workshop on Integrated Propeller Prediction (AIAA WIPP), and CFD analysis was carried out for various angles of attack (AOA). The k-ω SST turbulence model was used under steady state condition for a freestream velocity of 27.2 m/s and CT = 0. A good match was observed for CL, CD and CP, thus validating the model for a clean wing and nacelle. For the second configuration, the propeller-mounted wing geometry, also obtained from AIAA WIPP, was used. Calculations were performed in ANSYS Fluent. The solver setup from clean wing calculations was used, with additional setting of 'Frame Motion' used for the propeller. Rotational speed of 640 rad/s for CT 0.4 was set for the wing-tip propeller. A mesh dependence study was carried out for 1.5M, 6M, 12M and 24M elements, and the 12M element mesh was found to be optimum. Further simulations were carried out for 12M element mesh. The CP was calculated at various location on the wing. On comparison with NASA X-57 wind tunnel results, it was found that in general there is a good match. Only exception is the CP values for 60" and 63"

locations, and CL and CD values at AOA of 15º and 17º.This could be attributed to these locations being under wake of the propeller. Different settings (steady, transient) and turbulence models (e.g., k-ω SST with curvature correction, generalized k-ω (GEKO)) are being used to improve these differences. Results will be compared to find the most appropriate solver settings for closest agreement with experimental data. After validation, this model can further be used to simulate aerodynamic performance of a wing with multi-propeller (DEP) configuration.

Aerodynamic Investigation of Propulsion Integration for a Low Noise Hybrid Wing-Body with Podded UHBR Turbofan Engines

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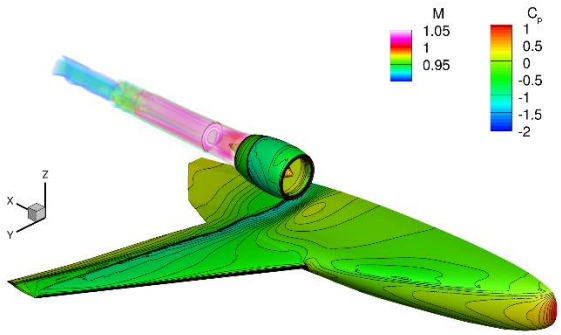
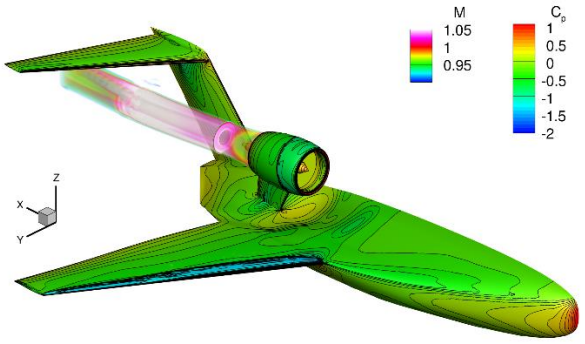
Within the framework of the SIAM project, the DLR is investigating a novel low noise aircraft concept for short- and medium range. With regard to noise impact the hybrid wing body with over the body mounted engines appears promising due to shielding effects. The installation of the engines for this type of configuration can be either realized with podded engines or buried engines. While the buried engines are thought to be the more efficient option in particular when exploiting the benefits of boundary layer ingestion, it may pose a challenge to the engine design. Moreover, it clearly removes available space from the compartment below the engines, in this case the center body. The podded installation is thought to be the more conservative approach, as it assumedly poses less challenges to the airframe and engine design while promising less aero-propulsive efficiency.

The presented work investigates the aerodynamic challenges of podded ultra-high bypass ratio (UHBR) engines installed on a low noise hybrid wing body configuration. First, sensitivity studies on the freestream Mach number, engine position, and the engine incidence angle with regard to the interference drag are discussed. Then, shape modifications of the nacelle and the center body based on 2D RANS optimizations are presented. Computations of the initial aircraft shape indicate a massive increase in total drag due to the engine integration. The results of the subsequent studies indicate that the interference drag can be reduced if the overall aircraft design either allows for a modified engine position or for a reshaping of the center body's upper surface.





System Performance of Wing and Propeller in a Periodic Distributed Propulsion Experiment

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The design space for distributed propulsion (DP) aircraft is expanded compared to twin engine designs by the propeller position relative to the wing. The DP concept relies on a beneficial and robust interaction of propulsion and wing. Additionally, a good design is optimised as a system comprised of lift and thrust generating elements. Thereby each element is not optimised by itself, but in the close coupled interaction. This interaction is presented in this work. Thrust and torque of a periodic co-rotating DP wing are measured simultaneous with all airfoil coefficients. Thereby the influence of propeller on the wing and vice versa is identified.

Three different sets of propeller geometry are studied. While two geometries are designed for minimum induced propeller loss and only vary in diameter, the third propeller set was designed to have a homogeneous induced axial velocity. We shall compare how the different strategies perform in the DP system.

The two element wing has a span of B = 2.4 m and a reference chord of c = 0.8 m, operating at Re = 2.1 x 10^6. For this study, the propellers are pitched to meet a constant C_T, J and Ma_tip.

The results focus on the take-off performance for the combined setup. In order to evaluate the different DP setups at aircraft level, their effect on a short range mission are extrapolated from the data gathered. The preliminary evaluation suggests, that a less efficient propeller with homogeneous outflow velocity outperforms a standard design when considered in the DP system.

Experimental Propeller Performance Analysis of Distributed, Single and Isolated Configurations

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Distributed propulsion (DP) configurations are a promising concept for future aircraft systems. The main objective of the presented experiment is to investigate aerodynamic interactions of such configurations in detail. This work focuses on the interaction between adjacent propellers as well as the two-way interaction of wing and propellers.

The experimental setup at the Propulsion Test Facility, TU Braunschweig, features three co-rotating propellers. These are not attached directly to the wing, but are mounted on a separate carrier. This decoupling allows the forces and moments on the wing and propeller to be considered separately. Additionally, different relative propeller positions are set up easily. In order to eliminate side wall effects, only the centre propeller and the centre wing element are the subject of investigation. The periodically repeating outboard propellers reduce the wind tunnel interference while providing a true DP setup for the instrumented centre. Two different propeller designs will be compared. While both have a diameter of 0.6m, Blade A is conventionally designed for minimum induced loss (MIL). Blade B is designed for homogeneous outflow along the blade radius. Both blades are operated at same advance ratios and thrust settings.

Additionally to the DP setup, tests for conventional propeller wing configurations (only centre propeller installed) as well as isolated propeller tests were performed. Thus, the DP effect on wing and propeller and the effect of the downstream wing on the propeller can clearly be identified. The lift gain in comparison to the clean wing at different thrust settings and operation points for both blades will be presented. In order to compare the different designs, the propeller efficiency in the distributed propulsion as well as in the single propeller and the isolated propeller configuration will be presented.

Propeller-Wing Interaction: A Simplified Method for Coupling BEM and CFD

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This paper presents a numerical procedure for studying the interaction between the wake generated by a propeller and the wing, considering a tiltrotor model framed within T-TECH Italian project [1]. A tiltrotor is an aircraft that generates lift and propulsion by way of powered rotors mounted on rotating shafts or nacelles at the ends of a fixed wing. Its design combines the VTOL capability of a helicopter with the speed and range of a conventional fixed-wing aircraft. For vertical flight, the rotation axis of the rotors is vertical to generate lift, while for airplane mode, the rotors are angled forward, generating thrust. Current studies focused on the propeller-wing interaction show a lot of complexities: performing a full CFD analysis for both components may cause problems in terms of boundary and interface settings, fidelity of results, and time-consuming simulations [2]. Moreover, since we are referring to a non-conventional configuration characterized by the presence of a big propeller compared to the dimension of the wing, the CFD approach could result very complex to set-up.

This report proposes to couple a 3D low-order unsteady Boundary Element Method (BEM) approach, to evaluate the performance of the isolated propeller, and a Reynolds-Averaged Navier-Stokes (RANS) solution for the analysis of the flow field interaction between the propeller (simulated as actuator disk, [3]) and the wing of a tiltrotor model. Starting from the geometry of the propeller, the in-house PaMS software [4] is used to evaluate the characteristics curves of the propeller based on BEM solution (i.e. (dC_T)/dr and (dC_Q)/dr). These quantities are used to perform a RANS simulation by introducing the actuator disk model according to the general momentum theory, in which the pressure drop, the swirl and tangential components of the wake are modelled. This approach allows to achieve high-fidelity results regarding the analysis of the wake interaction between the propeller and with the wing. Hence, the analyses are performed for airplane mode and hovering [5] configurations, with two CFD solvers: SU2 [6] and Ansys Fluent [7]. Data will be compared in terms of pressure coefficient distributions on the wing, velocity profiles in the wake produced by the propeller and the wing and vorticity contours.

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Propeller wake impact on transition location

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We present a numerical procedure for the evaluation of the detrimental effect of the propeller on transition location of a laminar turbo-prop wing. This work has been carried out within ESTRO Clean Sky 2 CfP project (CS2 grant n.831809), in the framework of the Innovative Aircraft Demonstrator Platforms (IADP) "Regional" of the "Clean Sky" 2 Programme, whose goal was to develop an innovative future green regional aircraft configuration based on several new technologies able to match the very demanding and challenging objectives ACARE 2020. One of the main objectives of the ESTRO project was to evaluate the effect of the propeller on the laminar flow extension since the prediction of the aerodynamic wing performances, in flight conditions, are strongly affected by the evaluation of the transition location from laminar to turbulent flow. This represents a critical key point in the correct estimation of the friction drag, leading edge separation and boundary layer thickness.

On the design of a cup anemometer performance simulator. From the wind speed to the output data

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This paper describes some important aspects of the development of a cup anemometer performance simulator. This tool aims to simulate the different phenomena which affect the different subsystems of the anemometer, in order to help the manufacturers to develop different strategies to improve the accuracy of the data obtained through post-processing or design changes. Bearing in mind that the cup anemometer is the most widely used wind speed sensor in the wind energy sector (to control wind generators and to analyze the future economic revenue of wind farms in certain locations), the relevance of the present study should be highlighted.

The software is designed in Simulink®, and is divided in 4 modules representing the different subsystems of an anemometer from the actual wind speed to the output data. The first two modules of the simulator are detailed in this paper, which consist of the Rotation Rate Module and the Pulse Generating Module. The first module outputs the anemometer's rotor angular position with time, which depends on the wind speed of the anemometer. Oscillations of the rotation rate caused by

steady state harmonic accelerations are taken into account. The Pulse Generating Module simulates the optoelectronic system of the anemometer, and creates the pulse train signal based on the rotor's angular position, taking into account the manufacturing and eccentricity errors of the system. The architecture of the modules is detailed, and related with the phenomena which is intended to simulate.

A comparison of long and short fuselage blended wing body configurations

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The Blended-Wing-Body (BWB) is a type of unconventional aircraft configuration for which several studies have shown performance improvements over conventional configuration. For this unusual configuration, one of the main issues is how to assess the coupling of the longitudinal and lateral stability. The longitudinal stability of an aeroplane is specified by a 4x4 matrix (that determines the phugoid and short-period modes) as the lateral stability is specified by a 4x4 matrix (that specifies the dutch roll and helical modes). In this work, the possibility of lateral-longitudinal coupling is considered leading to an 8x8 matrix, which includes, besides the longitudinal and lateral stability matrices, two 4x4 coupling matrices. The methodology developed applies both to strong and weak coupling, and in the latter case specifies the error in neglecting coupling effects. The application is made to two BWBs designs, and it is found that in all 18 flight configurations (Table 1) considered the terms in the coupling matrices are quite small compared with those in the longitudinal and lateral matrices.

The two BWBs designs represent different approaches (Table 2) in the sense that: (i) the long, narrow fuselage of BWB 1 is closer to a conventional design, (ii) the wide, short fuselage of BWB 2 is a more radical departure from conventional design. The main qualitative differences are: (i) for the same fineness ratio and surface area, that is equal drag, BWB 1 has a thicker fuselage with higher volume, (ii) BWB 1 also has a longer tail moment arm, allowing longitudinal trim with smaller elevator area, assuming the same elevator deflection and c.g. range, (iii) pitching motion is more noticeable to the passengers at the ends of the longer BWB 1 fuselage but it is the rolling motion which may affect most passengers at the sides of the wide BWB 2 fuselage, (iv) the longer BWB 1 fuselage has greater side area for speedy passenger evacuation. The results show that the conservative BWB 1 design appears qualitatively to be less risky.

Design	Flight Condition	Mass	Speed	Altitude	Flaps	c.g.
BWB	Case	$\times 10^3$ kg	kts	$\times 10^3$ ft	degrees	% mac
1	1a	550	176	0	15/25	25
	1b	550	176	0	15/25	35
	1c	550	200	0	15/25	25
	1d	550	200	0	15/25	35
	1e	670	$M = 0.85$	39	clean	35
	1f	670	$M = 0.85$	39	clean	39
	1g	760	$M = 0.85$	35	clean	35
	1h	760	$M = 0.85$	35	clean	39
	1i	700	300	0	clean	35
	1j	700	$M = 0.70$	30	clean	39
2	2a	550	176	0	clean	35
	2b	550	176	0	clean	39
	2c	550	200	0	clean	35
	2d	550	200	0	clean	39
	2e	670	$M = 0.85$	39	clean	35
	2f	670	$M = 0.85$	39	clean	39
	2g	760	$M = 0.85$	35	clean	35
	2h	760	$M = 0.85$	35	clean	39

Example		BWB 1	BWB 2
Fuselage	**Length Width**	**Long Narrow**	**Short Wide**
Equal Fineless	Thickness Volume	Thick High	Thin Low
Tail	Moment arm Elevator area	Long Small	Short Large
Passenger motion	Pitch Roll	Large Small	Small Large
Evacuation		Easy	Difficult
Conclusion		Conservative	Radical
Risk		Lower	Higher

Experimental investigation of blade-shaped riblets for drag reduction on UAV applications

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This study presents an experimental investigation of blade-shaped riblets for drag reduction in unmanned aerial vehicle (UAV) applications. UAVs have gained significant attention since they can perform various missions, including surveillance, reconnaissance, and package delivery. However, their aerodynamic performance, specifically the high drag associated with their exposed surfaces, remains a key challenge for enhancing their efficiency and extending flight endurance. To address this issue, riblet geometries are proposed as a potential solution, which can reduce the turbulent skin friction drag by up to 8%. The experimental investigation involves wind tunnel testing of blade-shaped riblets, with various width-to-height (s/h) ratios and constant groove cross-sectional area (Ag). The riblets are designed for application on the wing, empennage, and fuselage surfaces of a UAV. The investigations are performed on a flat plate for various flow conditions, including different freestream velocities, to evaluate the drag reduction effectiveness of the riblet configuration. The drag force is measured using a force balance system and flow visualization techniques are employed to assess the position where the boundary layer has transitioned to fully turbulent. The results demonstrate the drag-reducing effect of blade-shaped riblets and the different performance observed for the various s/h ratios. These findings highlight the potential of riblets as an effective drag-reduction technique for UAV applications, enabling increased endurance and/or enhanced payload capacity.

Performance enhancement of a Box-Wing airliner with the application of riblets

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The rapid growth of the commercial aviation sector in recent years, as well as the ambitious emission reduction targets, necessitates the investigation of novel methods to improve the aerodynamic efficiency of future airliners. With increasing passenger demand and evolving industry requirements, innovative designs, like the Box-Wing configuration, as well as flow control techniques, such as riblets, are essential to enhance efficiency, reduce fuel consumption and emissions, and meet future aviation needs. In this work, the performance enhancement of a novel Box-Wing airliner through the application of riblets is investigated through CFD modeling. The riblets are small, streamwise grooves aligned with the airflow, which when applied correctly can reduce the turbulent skin friction drag by up to 8%. The effect of riblets on the aircraft is modeled through a dedicated surrogate model, based on the cross-section area of their groove. The study aims to assess the impact of riblets on the aerodynamic characteristics, fuel efficiency, and overall performance of the aircraft, for a wide

range of operating conditions and angles of attack. The practical implications of riblet application are also discussed and concrete conclusions are drawn for future application on actual aircraft.

CFD aided investigation of a three-blade propeller in multirotor UAV applications

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In recent years, a rapid increase of multirotor UAVs in the commercial market is observed and correspondingly an increased number of motor/propeller combinations. The limited availability of data for the aerodynamic performance of the motor/propeller system often leads to their non-optimal operation at the multirotor UAV design point. Since experimental investigations are both cost- and time-demanding, the accurate numerical modelling of UAV propellers is crucial in the early design phases. In the current study, a CFD framework is employed for the performance investigation of a small scale three-blade propeller on a lightweight multirotor UAV, designed for indoors search and rescue applications. Specifically, two widely implemented methods for propeller modelling are examined, namely the Multiple Reference Frame (MRF) and the Sliding Mesh (SM). Several operating points are examined, corresponding to different propeller rotating speeds (RPM) and Reynolds numbers. The examined parameters include the produced thrust force, the required torque, as well as the propeller efficiency. Finally, the uncertainty of the computational analysis is quantified through Richardson's extrapolation method, and by comparing the CFD results with those obtained from both dedicated experimental measurements, and literature experimental data.

Design of morphing wing for aerodynamic performance considering the wing flexibility effects

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The current challenge in aircraft design is the need to reduce the environmental impact of aircraft, mainly in terms of greenhouse gas emissions. Considering classic tube-wing aircraft concepts, this aspect could be improved by adapting the aerodynamic shape of an aircraft wing to the current flight conditions, thus increasing its aerodynamic performance. The main challenge in morphing wing design lies in the design of the morphing structure in terms of structural layout and materials used.

In this paper, we present a part of the BAANG project aimed at exploiting advanced metamaterial applications for the morphing wing structure. We focus on the first step of the morphing wing design, which is the detailed design of the aerodynamic shapes of the wing for an unmanned aerial vehicle (UAV) with a maximum take-off weight of 25 kg. The wing design incorporates continuous camber changes along the span and chord. The baseline wing is rectangular, with a span of 3.8 m, and main load carrying structure is an aeroelastically tailored composite structure.

The aeroelastic tailoring was performed using Proteus optimization framework [1] developed at TU Delft. The wingbox structure was optimised for minimum weight, subject to constrains on optimal wing cruise shape, structural strength and strain (including buckling) and aeroelastic effects. Several load cases representing flight envelope and typical flight conditions of given aircraft were considered during the optimisation process. This wing design will serve as a non-morphing tailored reference model to validate the benefits of metamaterial-based morphing. Its structural layout, stiffness and structural mass distribution will be used together with properties of the metamaterial structure to simulate the elastic behaviour of the morphing wing.

Our design approach uses high-fidelity aerodynamic shape optimisation augmented with fluid-structure interaction analysis to account for the flexibility effects. It employs a gradient-based optimisation using the Sequential Least Squares Programming, SLSQP, algorithm and the CFD analysis (both within the SU2 suite [2]). The Free-Form Deformation parameterisation technique was used to explore the design space and identify optimal wing shapes. We included the effect of the wing flexibility on the aerodynamic properties using a non-linear solution of a beam stick model deformation in MSC.Nastran. The interface between fluid and structural domains is defined by Radial Basis. Our design approach uses only adjoint of the flow solver to compute the shape sensitivities of aerodynamic forces of the rigid wing. The effect of the wing flexibility is included at the end of the aerodynamic shape optimization. After the iteration of aeroelastic deformation, the optimization process is repeated using the last optimal design as an initial guess. The process is repeated until both the optimization and the aeroelastic solution converge.

The resulting shape of the morphing wing for each design flight condition will be an input to the design of the morphing structure. The structure will be based on a metamaterial – a material with engineered mechanical properties that enable the morphing action of the wing, as well as the structural health monitoring and state sensing capabilities.

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Detail and structural design of a fixed-wing BWB UAV

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The current study focuses on the development of a prototype BWB UAV for highway traffic monitoring by supporting a Cooperative Intelligent Transport System (C-ITS). This system allows the monitoring of traffic conditions at large roads and highways. Having determined the mission requirements and concluded the aerodynamic conceptual and preliminary design phases, high fidelity CFD simulations are performed, aiming to calculate the key aerodynamic and stability characteristics of the platform and to optimize its performance throughout the mission. More specifically, regarding the aerodynamic vehicle design, results concerning the calculation of stability derivatives, control surfaces sizing, trim analysis and flight envelope (V-n diagram) are presented, along with the respective methodologies. Considering the structural design of the aircraft, a combination of layout, FE simulations and parameterized design tools were employed, allowing the design and sizing of the skin and the internal structural parts. The parts are mainly made of composite and additively manufactured nylon materials. Coupled interaction loops are conducted among the aerodynamic and structural analyses to optimize the overall performance of the aerial vehicle, maximizing the aerodynamic efficiency, and reducing the structural weight. Finally, the study is concluded by the presentation of the manufactured prototype of the UAV, which satisfies all the structural,

aerodynamic, stability and performance requirements for the established highway traffic monitoring mission.

Polymeric Composites and Processes for primary and secondary aircraft structures

Chaired by:
Prof. R. Pantani & Prof. Liberata Guadagno (University of Salerno)

Polymeric Composites for Secondary Aircraft Structures: Design and Development of Hybrid Si/P–Epoxy Nanocomposites

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Epoxy resins are largely used owing to their good thermal and mechanical properties. For this reason, epoxy composites are applied in several industrial applications. The addition of flame retardants in the polymer matrix is necessary to pass specific fire safety requirements. Recently, we proposed a synthetic strategy to produce hybrid Si/P–epoxy flame retardant nanocomposites via a facile synthesis methodology, where the inorganic phase is composed of P-modified silica lamellar nanocrystals. The diffusion of phosphoric acid into silica nanodomains limited its reaction with oxirane rings and allowed for the formation of stable Si–O–P structures at safe and mild conditions. The morphology and chemical features of Si/P–epoxy nanocomposites led to the production of a large amount of continuous char and a notable reduction (up to 27.7%) in the peak of heat release rate, with only a slight detrimental impact on the mechanical performances of the final products.

Toward smart tooling for composite manufacturing by integrating 3D printed self-heating nanocomposites

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The current work presents a new strategy for optimizing nanocomposite self-heating performance processed via Fused deposition modeling (FDM). As additive manufacturing technology, also named 3D printing, FDM allows producing complex geometries and hollow structures according to a predetermined CAD model. By exploiting this advantage of the 3D printing process, Acrylonitrile-Butadiene-Styrene ABS filled with Carbon Nano-Tubes CNTs (ABS-CNTs) in a concentration higher than the electrical percolation threshold has been printed in the form of a self-heating element [1] whose electrical resistance is tunable based on its shape and geometric dimensions. Printing parameters, such as infill pattern, have been chosen in such a way as to exploit the phenomenon of CNTs orientation in the printing direction at the outlet of the nozzle to increase the electrical conductivity of the nanocomposite material after the printing process [2]. Considering the electrical properties of the nanocomposite material and the correlation between the electrical resistance and the geometry of the printed part, a scalable conductive pattern adaptable to the voltage value available in the industrial application fields has been developed. Moreover, experimental data from performed heating tests have been modeled by numerical simulations using finite element methods (FEM). The scalable and adaptive 3D-printed self-heating parts developed within this work represent

an attractive innovation in aeronautical industry processes since they can be applied as embedded heating elements in out-of-autoclave manufacturing applications [3].

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Eco-friendly composites with specific functional properties

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Composite materials play an important role for several manufacturing industry, such as automotive and aerospace [1]. Due to their strong damping capacity, high specific modulus and strength, composite materials can replace conventional component materials.

However, nowadays, the increased awareness of the environmental impact of composite materials at the end of their life has directed both academic and industrial research towards alternative solutions with almost similar performance and functionality but, at least partially, derived from renewable resources or recyclable raw materials, even for advanced applications [2].

In this scenario, natural fibers have been widely validated as a promising alternative to conventional ones as reinforcement of polymeric matrices because of their renewability, lightness, high specific mechanical properties, ease of surface modification, cost effectiveness etc [3-5].

In this contribution, thermosetting and thermoplastic polymers with different types of pristine [4] and modified [6] natural fibers (e.g. hemp, flax) based composite are realized and analyzed.

Specifically, morphological, thermal, mechanical and hydrophobic properties of green composite materials are discussed especially in order to identify potential applications.

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Design of hybrids nanocomposites based on 1D and 2D carbon nanofillers outperforming their single counterparts

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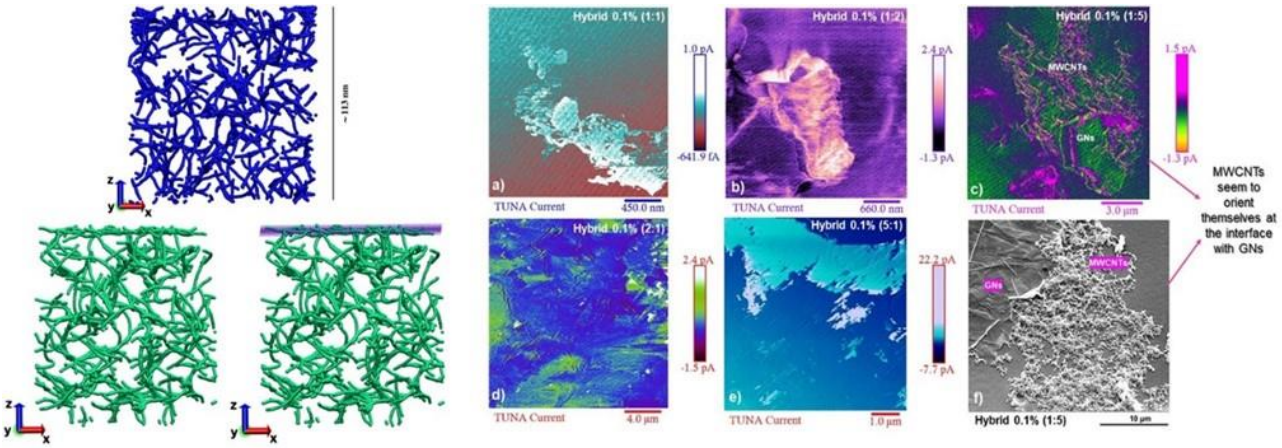
The electrical properties of epoxy hybrids filled with two-dimensional (2D) Graphene Nanosheets (GNs) and one-dimensional (1D) Multi-Wall Carbon Nanotubes (MWCNTs) were investigated by Tunneling Atomic Force Microscopy (TUNA) to understand the correlation between electrical conductivity, on a micro/nano space scale, and the arrangement of the electrically conductive paths through the sample. Two different amounts of mixed fillers, namely below 0.1 wt% and above 0.5 wt%, were dispersed by ultrasonication into a tetrafunctional epoxy matrix at five different MWCNTs:GNs mix ratios. At a low amount of nanoparticles, 0.1 wt%, the hybrid nanofiller concentration allows for detecting a very interesting synergy toward an increase in the electrical conductivity of several orders of magnitude, and a lowering of the Electrical Percolation Threshold (EPT). Both the computational and experimental results highlight that, owing to the hybrid MWCNT/GNs network formation, the hybrid nanocomposites outperform their single-nanofiller counterparts [1]. From TUNA images (see right of the figure below), MWCNTs connecting the epoxy matrix and GNs and π-π interactions between MWCNTs and GNs were clearly visible. Furthermore, computational analysis (see left of the figure below) showed that MWCNTs aggregated at the GN interface, in agreement with experimental data.



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Efficient energy-saving strategy for manufacturing aeronautical resins

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Over the past few decades, the development of epoxy-based composite materials has played a crucial role in reducing the weight of structural components used in transportation, particularly in the

aeronautic sector. However, the primary process for producing these composites - curing in autoclave - is time-consuming and energy-intensive, regardless of the part size and shape [1]. Additionally, during the curing in autoclave, the temperature gradient along the thickness part can potentially lead to the formation of microcracks and stress concentration. To address these issues and improve energy efficiency, various advanced methods have been proposed, including microwave curing, radiation curing, and electrical current heating (electro-curing) [2]. Among these, electro-curing stands out as a promising energy-saving alternative. This method involves applying an electric potential that generates heat by Joule effect directly in the bulk material, providing the necessary energy for the curing process. Typically, conductive fillers such as carbon nanotubes (CNTs) and graphene are added to the polymeric matrices to achieve the required electrical conductivity. Moreover, carbonaceous nanofillers dispersed in the resin can provide smart functionalities to thermosetting resins, such as self-sensing, anti-icing, and self-healing [3–5]. In the present research, electro-curing process was used to harden an epoxy multifunctional resin, which was obtained through the dispersion of carbon nanotubes in the epoxy matrix [6]. The electro-curing process allowed for achieving higher curing degrees and, consequently, higher glass transition temperatures than conventional methods. This energy-saving process also resulted in composites with enhanced properties.

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Self-repairing systems of composite materials with enhanced efficiency and sustainability in aeronautics

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The impact of hail on fuselages during a rainstorm, the impact of stones during landing, and that of birds in flight, can lead to microcracks, damaging the materials. It is useful, for this reason, to invest in the use of materials with self-healing properties. Self-healing systems represent a captivating frontier in science. They are smart materials as they can respond to external stimuli in order to extend their lifespan, by reducing the maintenance costs. They have caught on in a large number of areas like the automotive and construction industries. Depending on the different approaches that have been

studied to integrate self-restoring abilities in several matrices, self-healing systems can be classified in extrinsic and intrinsic.

In the last decades the scientific community has been working on the realization of intrinsic self-repairing system as they have the ability to heal multiple times in the same site since they are based on reversible interactions. In particular, our work has been focused on the use of hydrogen bond interactions.

With this contribution we want to present composites materials consisting of epoxy resin selected for aviation applications and charged with different percentages of polymers based on methacrylic monomers capable to give hydrogen bond interactions, which reversibility is the responsible of the self-healing ability of the resulting composite material.

Influence of Temperature on the Toughening Reaction of an Epoxy Resin having Auto-repair Ability

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Nowadays, self-healing polymers have obtained enormous attention due to their ability to restore material properties and extend the product's lifetime. Thermosetting polymers, particularly epoxies, are among the most studied materials due to their uses as coatings, adhesives, or structural elements [1]. Their high mechanical strength, thermal stability, and chemical resistance are due to their highly crosslinked network. These crosslinks restrict the molecular motion of the chains and, thus, limit the healing mechanisms [2]. To overcome this drawback, the epoxy precursor has been modified to confer healing capability to epoxies, adopting a successful strategy [1, 3-5]. This work proposes a formulation developed for aeronautical applications based on supramolecular chemistry, able to impart self-healing functionality to epoxy composites [6]. In particular, a bifunctional epoxy precursor was covalently modified by an elastomeric phase to improve its toughness and make the resin more suitable to host auto-repair mechanisms. The self-healing functionality was enhanced by adding molecules to establish hydrogen bond interactions with the epoxy matrix. Three compounds were employed and used as self-healing fillers, 1.3-Dimethylbarbituric acid (DBA), 2-Thiohydantoin (T), and Murexide (M).

The study performed in this work mainly focused on evaluating the influence of temperature on the functionalization process of the epoxy precursor. Two different temperatures were investigated, 120 and 160°C. The effect of the temperature was studied by Fourier trans-former infrared (FT-IR) spectroscopy and dynamic mechanical analyses (DMA), evidencing that the highest temperature of 160°C allows for a more significant amount of rubber phase bonded to the matrix. This results in better results in terms of self-healing efficiency, in particular for the sample loaded with DBA filler. The evaluation of healing efficiency, carried out by tapered double cantilever beam (TDCB) method, provided a healing efficiency of 88% for the system functionalized at 160°C. The same sample, functionalized at 120°C, manifested a healing efficiency of 52%. The performed study has allowed a further step forward in developing smart structural composites.

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Role of the aspect ratio of carbon fillers in Designing Self-Sensing and Self-Heating Structural Elements

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Research for new materials plays a crucial role in developing new technologies to be applied in different sectors, especially in producing aerospace and automotive engineering components. An accurate study of the strict relationship between a material's structure and properties is the starting point for designing new, more efficient systems. This understanding allows designing hybrid materials to satisfy new needs related to the materials' performance. The combination of polymers with a wide range of fillers, having one or more dimensions in the nanometer range, has led to the development of polymeric nanocomposites with improved properties and new potential applications [1-4]. In particular, in the aeronautic field, developing new materials for smart applications based on novel concepts involving several self-responsiveness properties would increase consumer safety, component lifespan, and performance while reducing maintenance and manufacturing costs and through-life service greenhouse gas emissions.

This work proposes based carbon fillers nanocomposites, such as multi-wall carbon nanotubes and expanded graphite, characterized by self-sensing and self-heating properties. The self-responsive functions are based on two physical phenomena: the piezoresistivity (changes in the electrical resistivity of the composites resulting from mechanically applied strains) [5, 6] and the Joule effect (heat generated by the current flow through the composite) [7, 8]. In the first case, the adopted approach allows the detection of micro-damages in the materials that a visual inspection cannot detect. In the second case, the heat generated through the joule effect allows for avoiding ice growth on the most vulnerable parts of the aircraft.

The results highlight that the choice of conductive filler plays a crucial role in optimizing smart properties: carbon nanotubes are more suitable for self-heating functionality, while 2D fillers give the epoxy matrix a more efficient self-sensing property compared to the 1D system.

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Enabling reprocessability and flame retardancy of fiber reinforced polymer composites via reactive approach

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The increasing amount of fossil-based plastic waste ending up in our environment is one of the most pressing issues of the oncoming decades. Thus, development of re-usable polymers with a prolonged useful lifetime heralds the switch for a transition towards a more circular economy.[1] A novel class of dynamic phosphonate ester bonds containing thermoset has been designed and synthesized, via a simple one-pot and two-step procedure.[2] The resulting material has been used to fabricate natural fiber reinforced polymer composites (FRPCs), which demonstrated exceptional reparability, recyclability and flame retardancy. The chemical structures and compositions of the chemical precursor and thermosets are confirmed by ^{1}H, ^{13}C, and ^{31}P NMR spectroscopy, elemental analysis, and Fourier transform infrared spectroscopy. The covalent incorporation of phosphonate moieties in the thermoset matrix introduced sufficient dynamic P-O ester bonds, and promoted the exchange of network strands under moderate heating condition, resulting in scratch reparability and recyclability. Due to the presence of phosphorus in the structure, the thermoset also exhibited excellent flame retardancy in varied fire tests. Applications of the thermoset as fire protective coating on wood samples and polymer matrix in FRPC were explored. Fire tests confirmed their excellent fire performance via intumescent mechanism.

In order to improve the recyclability of thermosetting materials, various recyclable materials have been synthesized via incorporation of wide variety of covalent exchangeable bond.[3, 4] Some of these materials containing sufficient carboxylic ester, disulfide, siloxane, imine, diketoenamine, Diels−Alder adduct, dioxaborolane bonds etc., can "flow" again like thermoplastics through network topological rearrangement by thermally triggered catalytical bond exchanges. Such network structures are fixed at product operating temperatures when the exchange reaction kinetics are frozen. Among the various dynamic covalent bonds, phosphorous ester based transesterification reaction may provide a multifaceted solution, this functionality not only offers excellent fire protection, but also has industrial relevance due to ready availability of monomers and straightforward synthesis procedure. Phosphate triester based thermosets brought new inspirations into multifunctional vitrimer material.[5] If we could replace the phosphate with phosphonate, the P-C bond will theoretically bring even better material stability and flame retardancy, as it is a chemically and thermally stable analog of a P–O bond.

A one-pot and two steps procedure (FIGURE 1a) was developed to synthesize the multi-functional transparent epoxy thermoset with varied TDPSD contents.[2] The chemical structure of the TDPSD was confirmed by 1D and 2D NMR spectroscopy. The resulting flame-retardant epoxy thermosets were analyzed by elemental analysis, ^{13}C and ^{31}P solid state NMR, and FTIR. A single ^{31}P NMR resonance at 6.5 ppm is observed for TDPSD in DMSO solution (FIGURE 1b). In the solid state ^{31}P CP MAS NMR spectrum of the modified thermoset EP-TDPSD-4P, the resonance is shifted to 25.7 ppm (FIGURE 1c) which is attributable to the formation of a P-CH2 group instead of the originally present P-H bond. This confirmed the phosphonate P-C bond formation in the thermoset network. As well studies in the bioorganic community, the replacement of the bridging oxygen in a phosphate ester with a CH2 could introduce stability and confer inertness to phosphatase cleavage. In addition to the promising reprocessability of thermosets with phosphoester linkages (P-O) reported by researchers in the vitrimer field, [5] the phosphonate linkages could increase hydrolysis stability and reduce its potential leakage during usage and recycling. In addition, the presence of phosphorus offers inherent flame retardancy.[6] The reactive P-H bond of TDPSD allows direct covalent linkage to the epoxy, which could result in optimized fire performance at lower P loadings compared to a non-reactive approach. [7] The demonstrated exceptional fire-resistance capability of the intumescent EP-TDPSDs films make them a suitable thin coating candidate for inflammable material protection, especially in the transportation and building industries. Based on the excellent fire inhibition and char foaming property in the small scale fire test discussed earlier, we applied 1 mm thickness EP-TDPSD-2.5P coating on the surface of MDF samples, and investigated their fire resistance and heat isolation properties, as demonstrated in FIGURE 2.

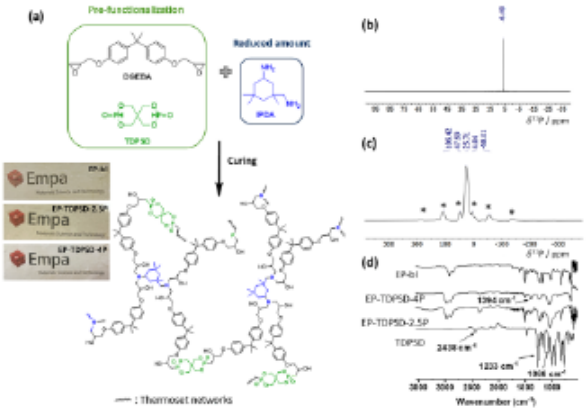

FIGURE 1. (a) One-pot, two-step synthesis procedure of reactive spirocyclic bisphosphonate TDPSD cured flame retardant epoxy resin EP-TDPSDs, with optical pictures of the 1 mm thick plates on "Empa" envelope. (b) ^{31}P NMR spectrum of spirocyclic bisphosphonate TDPSD in DMSO-d6 solution, (c) solid state ^{31}P CP MAS NMR of EP-TDPSD-4P (= spinning side bands), and (d) FTIR spectra of epoxy resin blank (EP-bl), EP-TDPSD-2.5P, EP-TDPSD-4P and TDPSD.*

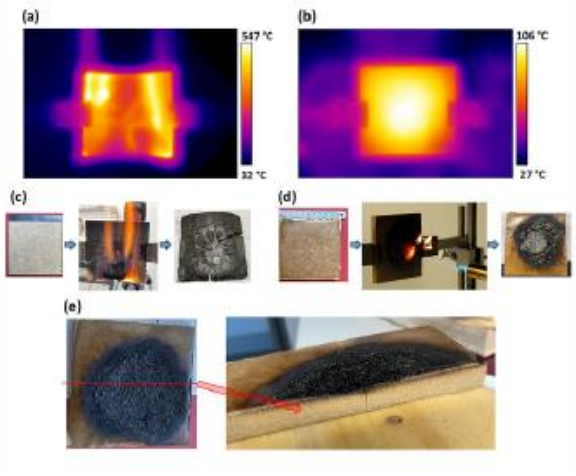

FIGURE 2. (a) blank MDF samples and (b) EP-TDPSD-2.5P coated MDF sample were measured with 5 minutes continuous ignition using Bunsen burner (butane gas), with the maximal back temperature of the wood plate measured by IR camera, optical images of (c) the untreated and (d) the coated MDF samples after 5 min ignition, (e) surface and (e) cross section of the EP-TDPSD-2.5P coated MDF plate after burning test. All samples were located with distance to the blue flame ~50 mm (flame temperature ~1100 °C).

After five minutes of continuous ignition with Bunsen burner (flame temperature more than 1100 °C), the EP-TDPSD-2.5P coated MDF plate did not catch fire on the wood matrix, with its backside temperature reaching a maximum value of 106 °C (Fig. 5b and d), while the MDF blank burned completely with backside temperature reaching almost 550 °C (Fig. 5a and c). Very intumescent char was formed during the continuous ignition. After removal of the intumescent char, the underlying MDF matrix was found to retain its integrity (Fig. 5e). It could be concluded that EP-TDPSDs has a future perspective on flame-retardant surface treatments, including the potential for industrial implementation of this material. As summarized in Table S5, the weight loss of the MDF blank is about 74%, in contrast, only 6.8% was observed for the EP-TDPSD-2.5P coated MDF plate. For EP-TDPSD-2.5P, TDPSD could improve the thermal stability and flame retardancy of the cured thermoset via combination of gas-phase and condensation phase of actions, reduces toxic nitrogen containing evolving gases production, thus we find scalable coating application on MDF to demonstrate these properties. TDPSD promote a remarkable reduction (up to 48%) in the heat release rate (HRR) values, and introduce nonflammability to the MDF plate owing to the outstanding gas-phase action and intumescent char structure through isolating heat and oxygen more efficiently. Pyrolysis evolved gas (Py-GC MS and TGA-IR), thermal and fire analysis was used to propose the combined mode (gas phase and char) of action of TDPSD in the fire performance improvement of the EP-TDPSDs epoxy thermoset system. The functional polymer EP-TDPSD-2.5P is a potential candidate for fire- and heat-resistant applications in electronic and microelectronic fields with more safety and excellent performance.

Last but not least, thermo-mechanical recycling method enabled the vitrimer thermoset reformation by applying heat and pressure, as TDPSD promoted the reparability and recyclability of the thermoset EP-TDPSD-6P. The underlying concept is laying down at the sufficient reversible P-O ester bond exchange reactions by versatile transesterification that rearrange the network topology while keeping cross-linking and functionality of the covalent links. Flax fiber reinforced composites were fabricated via compression molding to demonstrate the malleability and reprocessability of the intrinsic flame retardant vitrimer. Such intrinsic flame retardant, repairable and reprocessable thermoset material is of great potential for various applications. In future studies, we will investigate in detail the use of these thermosets in manufacturing fiber (e. g. carbon fiber, glass fiber and natural fibers) reinforced composites and its full recyclability.

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Rethinking Polymers and Polymer Composites for Sustainable Aviation Goals

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Polymers and polymer composites have been shaping modern aviation by being utilized in primary (structural) and secondary applications. For a material class with variety of properties exploited in a wide range of products, it is natural that various physical functionalities and thermomechanical properties exist. However, current aviation materials suffer dramatically from sustainability perspective. Each of these polymers are made from using toxic and hazardous chemicals, require high energy input for manufacturing and recyclability options are not available. Following Clean Aviation goals, it is vital that one must focus on the sustainability of aerospace materials as well.

Manufacturing polymers and polymer composites has been optimized over many years, and new sustainable products must enter the market to demonstrate efforts towards sustainable transformation of aviation industry. This requires studies on multiple levels: designing materials from lab scale with potential scale-up options, evaluating manufacturing of composites and examining compatibility towards aerospace applications.

In this talk, our efforts for sustainable polymers and sustainable composites formation will be summarized with few examples. Synthesis and polymerization of mevalonic lactone methacrylate, partially biobased monomer, will be elucidated to show lactone-functional thermoplastic polymers. Additionally, valerolactone-based vinyl monomer and its polymerization under fully green conditions to generate highly transparent Plexiglass-like material will be shown.

Additionally, sustainable composite materials will be exhibited. Efforts to obtain sustainable benzoxazine-based carbon fiber composites suitable for aerospace applications will be shown. Last, highly stable epoxy accelerators to reduce composite curing temperatures will be discussed.

Figure 1. Schematic illustration of the submitted talk.

Multi-fidelity evaluation of material alternatives: case study of thermoplastic composites in aerospace

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There is a clear demand for facilitated bottom-up decision-support in the early product design, material selection, and process planning phases especially in composite applications. Tools for systematic ecological and economic evaluation of each scenario throughout the entire product life-cycle are essential to enhance sustainable development.

There is an increased use of advanced thermoplastic composites in the aerospace industry due to their advantageous properties, including high strength-to-weight ratios, high fracture toughness, high thermal stability, and recyclability, and manufacturing methods enabling rapid processes with high throughput. However, to fully understand their environmental impact, the eco-efficiency of different life-cycle scenarios is to be studied in a cradle-to-gate or a gate-to-gate evaluation.

In this paper, the German Aerospace Center (DLR) implements its Eco-Efficiency Assessment Model (EEAM) to assess the manufacturing process of simplified thermoplastic secondary structures at the facilities of the Canadian National Research Council (NRC). Additional to the data collection, NRC also assesses the studied scenarios of materials and processes based on the mechanical properties of the manufactured structures. The results of this paper provide a detailed technical and eco-efficiency assessment about the compression moulding process and rough estimations about the other considered life-cycle-stages in a multi-fidelity evaluation. The results of this work would facilitate a comprehensive cradle-to-grave or a cradle-to-cradle life-cycle assessment (LCA) in the future.

A pre-screening of the solvolysis recycling process for CFRPs based on the mechanical properties of recovered fibers

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Over the past few decades, composite materials, and specifically carbon fiber reinforced plastics (CFRPs), are finding increasing use in the automotive, aerospace, and aeronautics industries. As a result, the production of CFRPs has been significantly increased, thus leading to a corresponding increase in the waste production. In the near future, landfill and incineration disposal of waste will likely be prevented due to legislation, thereby bringing forward the need to develop efficient recycling processes for CFRPs. However, recycling of CFRPs is very challenging, mainly due to the difficulty in removing the thermosetting matrix. This paper reports a pre-screening of the solvolysis recycling process for CFRPs on the basis of the mechanical properties of recovered fibers. To this end, solvolysis tests were conducted on unidirectional CFRP samples under supercritical and subcritical

conditions using acetone and water. The solvolysis tests were conducted for various conditions of temperature, pressure, and processing time. The efficiency of the recycling processes has been evaluated by means of single-fiber tension tests on the recovered fibers, which were conducted according to the ASTM C 1557-14 standard. In most cases, the decomposition efficiency of the epoxy resin in the CFRP, measured in terms of mass, ranged between 90 and 100%. Moreover, the mechanical tests showed that the recovered fibers retained more than 70% of their initial Young's modulus and tensile strength.

Low Viscosity Nano-Resins for VARI- and RTM-produced Composite Structures

Maximilian Jux, *German Aerospace Center (DLR), Germany*

Lightweight structures play a central role in mobility. Thus, research and development of materials with high specific mechanical performance have always been essential. Carbon fiber-reinforced plastics (CFRPs) represent an important and still increasing part for applications in aircrafts. However, CFRPs are prone to matrix dominated properties such as impact strength or fiber parallel compressive strength. Nanotechnology opens new possibilities to improve these properties. A key challenge is the fabrication of nanomodified CFRPs. Vacuum assisted resin infusion (VARI) or resin transfer molding (RTM) processes are often-used fabrication methods for CFRPs. These processes are realized with low-viscosity resins, but nano-scaled additives strongly increase viscosity due to their high specific surface area. An effective way to compensate the increased viscosity is to apply surface-modifications to the additives. The effect of the surface modifier depends on properties like the length of the molecular chain or availability of functional groups.

Characterizing the shape-morphing behavior of 4D-printed PLA structures

Konstantinos Stamoulis*, S.K. Georgantzinos, G.P. Kostopoulos, K.P. Stamoulis

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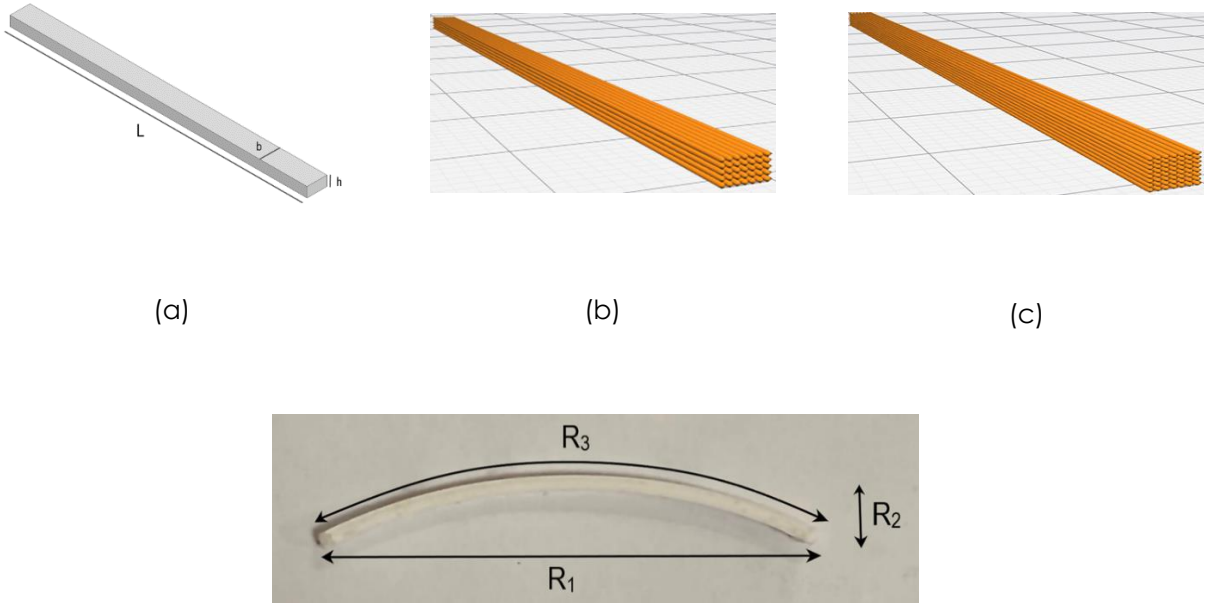
4D printing technology has gained significant attention in recent years as a promising approach to developing functional materials and structures that can adapt to different environments and stimuli. The technology involves the use of smart materials that can undergo shape transformation or self-assembly in response to external stimuli, such as temperature, humidity, or light. The potential applications of 4D printing technology in addressing aviation industrial problems have been recognized in recent years, where a pressing demand for optimization and automation, as well as a broader sustainability agenda, has driven research on various aspects of aviation systems. The aerospace industry faces significant challenges, including the need for increased safety, efficiency, and environmental sustainability. 4D-printed structures have the potential to play a crucial role in meeting these challenges by providing advanced functionalities, such as shape adaptation, self-repair, and self-sensing. Furthermore, the customization and optimization of the 4D-printed structures can lead to reduced weight and increased efficiency, contributing to the broader sustainability agenda.

The focus of this paper is on the shape-morphing behavior of 4D-printed structures, particularly beams made from polylactic acid (PLA), where the deformation is characterized by bending. The research involves using a fused deposition modeling (FDM) 3D printer to create structures with different geometries. The structures are then subjected to various stimuli, such as heat and water, to induce shape change and observe their smart behavior. To investigate the impact of the machine process parameters on the structures' shape-morphing behavior, the Taguchi design of experiments is adopted. The control parameters studied are Printing Speed, Layer Height, Flow Rate, Activation Temperature, Nozzle Temperature, and Bed Temperature, and each parameter is varied at different levels. For Printing Speed, levels range from 10 to 60 mm/s, for Layer Height levels range from 0.1 to

0.3 mm, and for Flow Rate levels range from 1.0 to 1.1. The levels for Activation Temperature range from 65 to 95 oC, for Nozzle Temperature levels range from 200 to 220 oC, and for Bed Temperature levels range from 0 to 60 oC. The experimental methods used to create and test the structures are described in detail, including the manufacturing and post-processing steps. The results of the experiments reveal that the shape-morphing behavior of the PLA structures is highly dependent on their geometric parameters, the magnitude of the stimulus applied, and the machine process parameters. The findings provide insights into the potential applications of 4D printing technology and the design principles for creating 4D-printed structures with desired shape-morphing behaviors.



(a) (b) (c)

(d)

Figure 1. PLA beam preparation and response: (a) CAD geometry, (b) sliced geometry with 0.3 mm layer height, (c) sliced geometry with 0.1 mm layer height, and (d) bending response of smart beam under thermal stimuli.

Laser shock-based paint stripping from composite substrates: Experiments and finite element simulation

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Laser shock wave applications have been widely used in metals, with the most common and popular being the laser shock peening. In composite materials, the use of such applications is still at an early stage. Laser shock stripping is a new method where a laser-induced shock wave is used for removing paint from metallic or composite substrates. In this study, the laser shock paint stripping from composite substrates has been studied by both experiments and numerical simulation. Two types of specimens were tested: a specimen covered by three layers, i.e., an epoxy primer, a structural epoxy layer and a polyurethane clear coat and a specimen covered by four layers, i.e., an epoxy primer, a structural epoxy layer, a polyurethane clear coat, and a base coat between the epoxy layer and the polyurethane layer. The specimens were shot with various laser intensities aiming to obtain the stripping threshold and the maximum stripping area as functions of the laser intensity. The diameter of the stripped area was measured by a profilometer. Electrical microscope and Fourier-transform

infrared spectroscopy (FTIR) were used to accurately detect the fully stripped area without any remaining epoxy layer. Complimentary to the tests, numerical models were developed using the LS-DYNA explicit finite element (FE) software. For the modeling of the composite substrate, a progressive damage model with strain rate parameters was used while for the epoxy an elastic-plastic-hydrodynamic material model combined with the Gruneisen equation of state. The interface between these two materials was simulated with cohesive elements of zero thickness, which implement the bi-linear traction-separation law. Validation of the models was done through comparison of the back-face velocities, measured experimentally by the VISAR system, and the stripping pattern and area. After being validated, the models were used to numerically characterize the composite/epoxy interface by correlating the stripping threshold laser intensity with the fracture toughness. The latter is a first assessment on whether the laser shock technique can be used to characterize the interfacial strength of coatings on substrates.

Synthesis of biomaterials by the sol-gel route applied to the aerospace

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Microgravity-induced bone loss during spaceflight, which is primarily attributed to an imbalance in the bone remodeling process, poses a threat to the health of astronauts. In the current study, the response to microgravity of bone cells, grown in a weightless environment, has been simulated by using a Random Positioning Machine (RPM). WST-8 assay was used to assess cell viability after 72 hours of rotation, and the results were compared to the control cell viability. Although there was no discernible difference in the viability of the two cell groups, F-actin staining revealed that the microgravity environment causes cell apoptosis and altered F-actin organization. After a period of 72 hours of rotation, the cells were seeded onto biocompatible ZrO2/PCL hybrid coatings, synthetised using a sol-gel dip-coating procedure, to see if it was possible to halt the trend of the cells toward death. After 24 hours, a WST-8 assay demonstrated that the materials can prevent cells from becoming susceptible to pro-apoptotic effects of the microgravity.

Improved fatigue life of graphene -modified carbon fiber reinforced polymers through an analytic compliance-based characterization

Konstantina Zafeiropoulou*, Christina Kostagiannakopoulou , Stavros Tsantzalis, George Sotiriadis and Vassilis Kostopoulos

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The last decades Fiber Reinforced Polymers (FRPs) are used extensively in a wide range of areas, including aerospace, automobile, aeronautics, transportation and military industries due to the combination of high strength and stiffness properties at low weight [1]. However, while carbon fiber reinforced polymers (CFRPs) have many optimal qualities, they also present some drawbacks preventing their further use as structural material in a variety of applications. It has been demonstrated that manufacturing defects, brittle nature of epoxy matrix, and a weak fiber-matrix interface seem to be the principal reasons for delamination failure of FRP composites and their low out-of-plane interlaminar fracture toughness [2]. As a result, tremendous effort has been focused on toughness improvement by enhancing the matrix material with nano-particles. The last few years, there is a considerable attention from research community in graphene based nano-particles due to their superior mechanical, thermal and electrical properties, and their high absorbability. Few publications have been cited in the open literature that investigated the mode I interlaminar fracture toughness of nano-reinforced composites with graphene nano-particles [3-5]. However, until now no study has been developed for mode I delamination under dynamic loading.

The aim of this study is to investigate the fatigue delamination growth in mode I of neat and graphene-modified carbon fiber reinforced epoxy materials. Double cantilever beam (DCB) specimens were used for the quasi-static tests and the energy release rate GI as a function of crack length was determined. For the estimation of fatigue life, the threshold energy release rate (Gth) was calculated using both 50% and 80% ratio of GImax/GI,init, whereas the delamination propagation base on Paris' law were studied too, for only 80% of the abovementioned ratio. Also, compliance calibration method (CCM) was followed after the fatigue test in order to record the relation between the compliance of materials and the delamination length. The results indicate that the introduction of graphene nano-particles in CFRPs improved their onset life by 100% and 33% for 50% and 80% ratio of GImax/GI,init respectively, while recorded 19% enhanced Gth. Furthermore, the fatigue propagation behaviour of doped CFRPs was better than the corresponding of neat CFRPs. Finally, the CCM was in good agreement with the visual observations.

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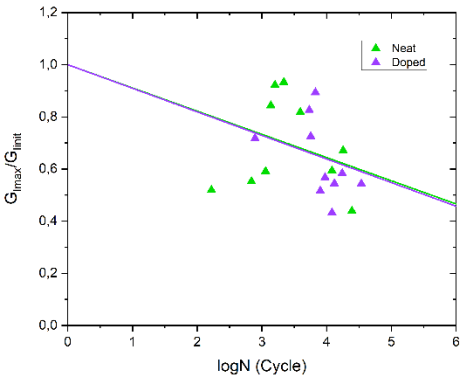

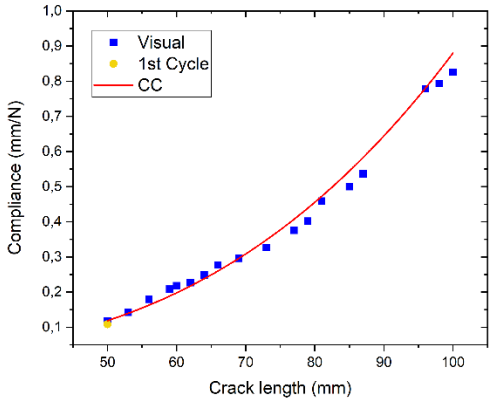

New drivetrain solutions for rotorcraft and climate-friendly aircraft

Chaired by:
Prof. Michael Weigand (TU Vien)

Intelligent Chip Detection System for Drive Train Components of Aircraft

M. Aufreiter*, D. Kagerbauer

** INMOX, Vienna, Austria*

The discussion of the effectiveness of existing chip detector systems in the EASA rulemaking task RMT.0725 was one of the drivers for us to push the development of a new solution for chip detection.

We developed a new technology for intelligent chip detection to monitor wear particles and dangerous degradation of critical powertrain components. This technology uses magnetic effects and enables both detection and automatic characterization of wear particles during operation. The new sensor system is supported by machine learning and provides data for risk assessment of wear particles and their assignment to specific component groups. Specific information about the current status of the gearbox is provided in real-time. The sensor system works at any rotational speed of components and flow velocity of wear particles as well as with any complexity of assembly. Thus, the sensor can also be implemented in oil bath-lubricated applications.

This new technology is developed with the goal to help to increase safety during operation and give operators and pilots information about failures as fast, detailed, and reliable as possible.

Rotorcraft Main Transmission with Continuous Variable Ratio – Dynamic Simulation: Modeling and Results of Simulation

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** TU Wien, Vienna, Austria*

The "VARI-SPEED II" project involves TU Munich, TU Wien, Zoerkler Gears, and Advanced Drivetrain Technologies GmbH developing a rotorcraft drivetrain that allows variable speed of a rotorcraft's main rotor. This is beneficial for different speed requirements, reduced noise, and higher efficiency. Major rotorcraft taken into account are High-Speed Rotorcraft (like Airbus RACER) and Tiltrotor/Tiltwing Aircraft (like Leonardo NextGENCTR-Next Generatoin Civil Tiltrotor). Various researchers have investigated the benefits and suitable technologies for varying main rotor speed. Calculation formulas were established to find the ratio distribution of gear stages with the lowest total mass of the drivetrain, and electric variators are potential solutions. The architecture with two compound splits before the bevel gear stage was chosen for the dynamic simulation of the drivetrain due to its favorable design considerations. In the "VARI-SPEED II" project, control of the variable speed drivetrain is crucial for achieving the desired variable main rotor speed. To achieve optimal control, a fuzzy model predictive control (FMPC) approach has been proposed. The FMPC has several advantages, including the ability to handle nonlinearities and uncertainties. Furthermore, the FMPC is real-time capable and can adapt to changing operating conditions. Modeling and results of simulation will be presented.

Safety of Rotorcraft Drivetrains – Scientific Challenges

Michael Weigand, *TU Wien, Vienna, Austria,*

Between 2009 and 2016 five severe accidents occurred in North Sea Offshore Helicopter Operation caused by problems of the Main Gearbox. Three accidents led to nearly 50 fatalities. Two accidents resp. ditchings of large rotorcraft were triggered by Loss-of-Lubrication situations.

In 2018, EASA released the Rotorcraft Safety Roadmap with the goal to reduce rotorcraft accidents by 50% by 2028, but with the aim to see clear improvements achieved by 2023.

TU Wien addresses key topics of the EASA Rotorcraft Safety Roadmap in its research and teaching, and TU Wien contributed to the EASA Rotorcraft Symposium in 2012, 2016, 2018 and 2021.

Analysis of the accidents mentioned led to research projects of EASA and the necessity of research in the following fields was identified:
- Loss-of-lubrication:
- Improvement of transmission performance under Loss-of-Lubrication Condition
- Simulation and Evaluation in early design phases of rotorcraft transmissions
- Chip detection: Realibility and necessity of chip detection tests
- Requirement of alternative means of detection of deterioation of bearings and gears
- Integrity improvement of Main Gearboxes of Rotorcraft
- Detection of abrasion & status monitoring
- Safety assessment & FMECA
- Lubricants
- Freewheel operation

The presentation shows which scientific challenges have to be handled and how they can be linked to Rule Making Tasks (RMT) of EASA, mainly RMT.0608 and RMT.0725.

How Transmissions contribute to climate-friendly propulsion systems of aircraft

Michael Weigand, *TU Wien, Vienna, Austria*

One of the major topics in aviation is the development of climate friendly or even climate neutral aircraft and propulsion systems. Focus is mainly on solutions for fixed-wing aircraft based on Battery energy, Hydrogen, Fuel cells and Sustainable Aircraft Fuels (SAF). Reserach in this area is driven actually mainly by the EU Clean Aviation Joint Undertaking. The activities are linked a.o. to FlightPath 2050 with the goal to be climate neutral in aviation in 2050.

First new system demonstrators are envisaged by the major OEM´s for 2035 meaning a perspective of entry into service earliest between 2040 and 2050.

However important contributions to reduction of emissions (fuel consumption and noise) have been reached and can further be reached by approaches like the Geared Turbofan (GTF), UltraFan and Leap (Leading Edge Aviation Propulsion). All major engine suppliers and consortiums work on the technology of geared turbofans, e.g. RISE of the CFM consortium. It has to be pointed out that these technological improvements lead also to important economical improvements resulting in a rapidly growing market share.

New disruptive solutions based on energy from batteries, hydrogen and fuel cells also need gearboxes to reduce the speed of the high-speed electric motor to the speed of the propeller or open rotor.

The presentation gives an overview how transmissions and gearboxes contribute to climate-friendly propulsion systems, taking also into account the availability (time-line till entry into service) of the different solutions.

Experimental analysis of High-Lift Propeller Positions for a Distributed Propulsion Configuration

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** Tu Braunschweig - IFAS, Germany*

In the scope of electric propulsion, distributed propulsion becomes a highlighted topic, due to the use of low-emission propellers and a beneficial wing flow. The main objective of the Clean Sky 2 Project DISPROP (Aerodynamic and aeroacoustic modeling of closely operating propellers for DIStributed PROPulsion, JTI-CS2-2020-CfP11-LPA-01-96) is to create a numerical and experimental database for a distributed propulsion setup and to improve the current aerodynamical and aeroacoustic performance. To experimentally investigate the propeller-wing aerodynamic of this configuration a 2.5D experimental setup was carried out in the closed low speed wind tunnel of the German-Dutch Wind Tunnels (DNW) in Braunschweig. Preceding to the experiments numerical studies were performed to determine the most beneficial positions and operating points for this high lift configuration. The wind tunnel model features a wing of 2.8 m span with a detachable droop nose and three 35 kW co-rotating propeller drives of 550 mm diameter using TU Delfts XProp Design. The propulsors are attached directly to the wing, enabling two different span wise, flow wise and vertical position variations plus a tilted propeller axis in reference to the wing chord to investigate the occurring effects including the nacelle effects. The adjustable flap of the wing allows different flap settings in each of the high lift operating points. Measurements include propeller thrust and torque, pressure taps on the wing behind the center propeller and the drives nacelle as well as flow visualization using tufts on the wings suction side. To avoid remaining errors due to the wall flow, the instrumentation is installed at the middle drive as well as the center part of the wing. In addition, the wind tunnel is equipped with spanwise adjustable splitter plates on which slats are mounted to prevent flow separation in the area near the walls. The paper will show and discuss the aerodynamic results of the first experimental campaign derived from both, the propeller as well as the wing instrumentation. Most of the results show a very good agreement with the numerical data in total and also with regards to local interaction effects of the propulsors with the wing aerodynamics. Due to the large scale of the experiments in combination with the large test matrix, a unique dataset is available for the full paper and presentation.

Aircraft Engine Advanced Design

Chaired by:
Dr. Christos Mourouzidis (Cranfield University)

Numerical investigation of metallic fuel addition to Ammonium Dinitramide green propellant

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** South East Technological University Carlow, Ireland, Ireland*

The hunt for "green" propellants to replace existing Ammonium Perchlorate has piqued the attention of ammonium dinitramide (ADN), as a chlorine-free oxidizer. In 1971 Zelinskiy Institute of Organic Chemistry, Moscow USSR discovered ADN, which is regarded as one of the most remarkable breakthroughs in the study of energetic materials. The former USSR employed ADN as the main oxidizer in one of its Topol-M Missile system engine stages, confirming ADN's viability as a potential oxidizer in solid propellants. Dinitramide innovations discovered by the USSR were severely restricted to the world till the year 1988. It came into the study after the rediscovery of ADN at Stanford Research Institute, USA in the year 1997 by Bottaro [1]. Since then, the ADN has been studied by various researchers. Nowadays, metallic fuels are frequently used in the operation of solid rockets to increase their performance effectiveness. The combustion cycle with solid propellants depends on the energy density, flame temperature and regression rate. Adding an energetic metallic compound is one of the several ways to improve the burn rate of the solid propellant. Metals are energetic materials which are considered burn rate modifiers and used in solid propellants for increasing specific impulse and stability in combustion. Analyses have demonstrated that metal additions improve regression rate, specific impulse, combustion efficiency, etc. This study is motivated to understand the chemical

effects of metal addition to ADN propellant by using a numerical approach. The current numerical model considers gas phases finite-rate chemical kinetics for fuel and oxidizer, respectively, based on the conservation equations for mass, species percentages and energy. To model the ADN and metallic fuels mixture a detailed coupled gas and condensed phase chemical kinetics has been obtained from [2] for Ammonium Dinitramide and for Aluminium gas phase chemistry is obtained from [4]. The developed model has been validated for further studies depending on the previous experimental [3] and modelling [3,4] work. This article summarizes the impact of adding aluminium metal and their concentrations (in the range of 20-30%) on ADN solid propellants' burning characteristics. At various pressures, an excellent correlation was achieved for the combustion of the ADN and metallic mixture which was compared with the experimental curves of temperature, and species mole fractions. The study will perform a detailed numerical analysis of solid propellant estimating the burning characteristics of propellant with the addition of aluminium metal to ADN at different compositions ratio.

Study on the Condensation Behavior of Various Fin Shapes in the Design of a Condenser in a Water-Enhanced Turbofan (WET) Engine

Majid Bhinder, Pela Katsapoxaki*, Hariharan Kallath, Jeonghoon Heo, Changmin Cao, El Hassan Ridouane

** Collins Aerospace Ireland, Ireland*

The journey to a climate-neutral aviation system through the European Green Deal is ambitious and a formidable opportunity for society and citizens. The answers proposed by Clean Aviation will probably challenge all conventions and classical approaches in bringing forth a real transformation leading to new propulsion solutions and sustainable vehicle configurations and operations.

The Clean Aviation SWITCH project aims to answer the challenge of climate-neutral Small to Medium Range (SMR) transport by developing a revolutionarily sustainable gas turbine propulsion system (the WET engine) and further boosting it with hybridization to improve energy efficiency by 25% and reduce non-CO_2 related climate impact by more than 60%. In order to ensure its technology readiness for EIS by 2035, the SWITCH project will validate the hybrid WET's key enabling technologies at TRL4 (WET) and propose a validation plan to achieve TRL6 by 2030. The core of SWITCH is the revolutionary Water-Enhanced Turbofan (WET) concept, which offers unmatched potential to enable climate-neutral aviation based on existing and future infrastructure, while also retaining the key benefits of gas turbine propulsion to meet the full range of thrust, speed, and all other mission requirements. Wet combustion allows NOx emission reduction of more than 80% and water recovery traps particles resulting in cleaner exhaust.

One of the technologies developed by Collins Aerospace is a condenser component for the WET engine. To have a high efficiency and compact condenser, a range of plate/fin geometries are being explored to provide high surface area to volume ratios and low hydrodynamic resistance. This will ensure the design targets of size, weight, overall heat transfer and pressure drop are met. High fidelity and multi-physics models coupling of fluid dynamic, heat transfer and phase change will be included in condenser design tool with consideration of condensation effects on heat transfer performance. The developed models are being validated against measurements from testing, such as measured heat transfer coefficient and pressure loss. This paper will present an overview of the condenser design tool and latest results.

Scheduling Supersonic Inlet Operation for Improved Integrated Engine Performance

S. Adamidis*, D. Del Gatto, C. Mourouzidis, S. Brown, V. Pachidis

** Cranfield University, United Kingdom*

With the imminent entry into service of the next-generation supersonic transport, extensive research endeavors have been initiated to support updates on ICAO regulations and certification processes for supersonic transport vehicles. Within this context, the EU Horizon 2020 SENECA (LTO Noise and Emissions of Supersonic Aircraft) project has been launched, aiming to comprehensively investigate the levels of noise and gaseous emissions in the vicinity of airports, as well as evaluate the global climate impact of the forthcoming supersonic civil aircraft. The fundamental objective of the project is to provide its findings to ICAO-level discussions to support the European perspective on necessary regulations for novel supersonic civil aircraft through scientific research. The present work is carried out under the umbrella of the SENECA project.

Successful inlet-engine integration is one of the most fundamental challenges in supersonic aircraft design and performance. Supersonic inlets are typically equipped with several flow control mechanisms, such as by-pass doors and slots or porous bleeds, which must be scheduled properly to ensure inlet-engine flow matching and minimise inlet-related installation losses that impact the installed thrust, the specific fuel consumption, and the produced noise levels. Specifically, installation losses should be accounted for by correcting the uninstalled engine performance through consideration of total pressure losses, boundary layer control bleed drag, spillage drag, bypass drag, and wave drag.

In the present case study, a 10-passenger twinjet Mach 1.6 business jet equipped with mixed-flow turbofan engines is assessed. However, the applied methodology can easily be extended to include fighter jet propulsion systems. A sophisticated method for handling inlet-engine flow matching using supersonic inlet operating maps is applied, integrated with thermodynamic cycle modelling. Trade-off studies are performed among the inlet operation, accounting for the inlet-engine flow matching and the corresponding drag elements. These studies are utilized to reveal the supersonic inlet design parameter sensitivities on the overall propulsion system performance. Furthermore, they are used to investigate the inlet flows scheduling for optimization of the overall propulsion system performance throughout the complete flight envelope. Finally, the capability of utilising inlet flows scheduling to avoid reaching the 'inlet buzz limit' is assessed.

Effects on non-uniform swirl on the noise of a jet exhaust

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Swirling flows occur in the exhausts of jet engines. The propagation of sound waves is considered in an axisymmetric mean flow, with uniform axial velocity and non-uniform swirl, with angular velocity increasing proportionally to the radial distance. Two simplifications are made: (i) that the maximum tangential velocity of the mean flow is small compared to the sound speed, (ii) that the Doppler shift due to rotation is much smaller than the wave frequency (including Doppler shift by the uniform axial flow) divided by the maximum angular velocity of swirl. It is shown that these conditions are not too restrictive for practical swirling flows in exhaust nozzles, and that they allow the solution of the wave equation in terms of confluent hypergeometric functions (instead of Bessel functions in the case of rigid body rotation). This type of radial dependence allows for propagating waves with decaying amplitude in the case of 'slow' swirl, and for evanescent and unstable modes in the case of 'fast' swirl. The borderline between 'slow' and 'fast' swirl is given by a rotation parameter related to the second approximation (ii) above, suggesting that the present results need to be extended to more general conditions. The theory does apply to at least the fundamental and lowest-order harmonics of sound waves in typical jet engines.

Modern method for rapid automatic propulsion system collaborative design optimisation through cloud-based microservices

Adriano Isoldi*, Christos Mourouzidis
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Engine cycle design is a pivotal part of an aero-engine design process, which is a sub-set of the larger aircraft conceptual design process. The design process begins with the definition of the requirements for a new aircraft. These are then sent, in addition to design constraints, to the engine manufacturer to carry out the preliminary engine design and thus update the engine data for the airframer. The process is repeated and continued over several iterations, with airframe and engine manufacturers exchanging updated requirements and engine data. Therefore, effective communication between design specialists is required at each iteration of the design process. However, effective communication and data exchange between different organisations or even between teams of the same organisation require time-consuming efforts to assure data integrity while protecting the Intellectual Property (IP) of the participating parties. The work presented herein explores the use of a cloud-based automatic design system for next generation propulsion systems. This modern engine design methodology proposes a radical change to the highly iterative process between engine and airframe designers within the industry, which currently lacks synergistic communication between the two specialist teams. Compared to the more traditional "email-based" communication, this method provides the capability to reduce engine conceptual design development time and thus the overall product time to market. Additionally, it allows for a highly integrated engine design solution at the early stages of the engine development. The abovementioned capabilities are feasible through the exploitation of modern day IT infrastructures and the so called "microservice software architecture". The microservice architecture is a software architecture where applications are structured as a collection of services. It removes the coupling between services, allowing them to be independently executed, and it provides flexibility on connection handling between different software tools as well as workflow orchestration for any design optimisation exercise. The individual services interact via messages to deliver outputs for a given input. Therefore, in the present context, there is no sharing of service source or the need for local installation of design tools. Furthermore, these services do not need to be hosted in the same location. The approach is therefore particularly well suited for collaborative design exercises where tools from different teams (across different geographic locations) can be independently executed and combined in the evaluation of a design's performance. It is worth to mention that the method includes considerations for protecting the IP of the collaborating parties.

Next-Generation Supersonic Aircraft Engine Design to Align with Current Subsonic Aircraft Landing & Take-Off (LTO) Cycle Noise

Dario Del Gatto*, Stylianos Adamidis, Christos Mourouzidis, Stephen Brown, Vassilios Pachidis
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With the introduction of next-generation supersonic transport vehicles on the horizon, new research activities have been started to assist revisions and updates to ICAO regulations and certification processes for supersonic transport vehicles. In light of this, the EU Horizon 2020 SENECA (LTO noiSe and EmissionNs of supErsoniC Aircraft) project has been launched to investigate in detail the levels of noise and gaseous emissions in airports' vicinity as well as the global environmental impact of next-generation supersonic civil aircraft. Additionally, the project is intended to provide its findings to ICAO level discussions to support the European perspective on necessary regulations for novel supersonic civil aircraft through scientific research. This paper is under the umbrella of the SENECA project, and it aims to provide an update on the engine design development for a 10-passenger twinjet Mach 1.6 business jet, from the perspective of noise emissions. The engine design is generated following a newly developed integrated multi-disciplinary design scheme that accounts for intake and exhaust systems

design, size, and performance. In this case and in contrast to the subsonic civil applications, engine noise emissions pose significant limitations on the design space of engines for supersonic vehicles. The noise limitation criteria regard both the Landing & Take-Off (LTO) cycle as well as the high-altitude supersonic operations. However, in the current work, the operating regime of the aircraft is limited to subsonic speeds 'over-land' and supersonic speeds 'over-water'. Thus, the ground level noise impact of the sonic boom generated at high altitude supersonic operations falls out of the scope. The noise related limitation in terms of LTO cycle that is considered to be of crucial importance in this case is the engine exhaust jet velocity. To comply with current subsonic engine perceived noise limits (EPNdB), future supersonic engines will need to produce subsonic exhaust jet velocities during the LTO cycle. Such a constraint led the engine preliminary design to increased engine size and weight, compromising the aircraft mission fuel burn capability. To overcame this, two proposed solutions are assessed in the current study to illustrate potential benefits in terms of LTO noise, while expanding the available engine design space to smaller and lighter engines. Both solutions regard variable geometry technology related to the engine exhaust system. The first regards the implementation of a convergent-divergent exhaust nozzle with variable throat and exit areas, while the second the implementation of a flow ejector at the inlet of the exhaust nozzle divergent section. An overview of the main impact of the abovementioned solutions on the engine design space, size, weight, and performance as well as overall aircraft performance is presented herein.

Experimental Investigation of the Effect of Hydrogen Enrichment on Flame Structures: Insights into Flame Characteristics and Stability

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** University of Salento, Italy*

The gas turbine industry is exploring lean premixed combustion of hydrogen-enriched fuel blends as a promising solution for reducing greenhouse gas emissions and NOx emissions. Many gas turbines currently have the capability to burn mixtures of hydrocarbons and hydrogen in varying proportions. However, efficiently mixing hydrogen and air prior to combustion is challenging, and micromixing technologies have been developed to prevent high-temperature stoichiometric reaction layers at the hydrogen injector outlet, which can lead to high NOx emission levels and thermal stress.

Hydrogen enrichment is increasingly explored as a potential method to enhance combustion processes and reduce greenhouse gas emissions. This study delves into the effects of hydrogen enrichment on flame structures, specifically focusing on maintaining a constant thermal output of 5.06 kW. Through the utilization of high-speed chemiluminescence imaging, the researchers compared two fueling conditions: pure methane/air and methane with the addition of hydrogen.

The results of the investigation demonstrate that hydrogen enrichment has notable influences on flame characteristics. The flames produced with hydrogen enrichment exhibit a slightly shorter length and a wider angle, which can be attributed to the heightened expansion occurring within the Combustion Recirculation Zone. Additionally, the emission of UV light is significantly affected, resulting in a shifted luminosity zone and reduced variance.

To gain further insights into the underlying mechanisms, the researchers employed Proper Orthogonal Decomposition (POD) and Singular Proper Orthogonal Decomposition (SPOD) analyses. These analyses unveiled coherent structures and energetic modes within the flames. The inclusion of hydrogen enrichment resulted in the emergence of smaller structures near the nozzle exit, accompanied by longitudinal oscillations and vortex shedding phenomena.

The findings of this study contribute to an enhanced understanding of hydrogen's impact on flame characteristics. By shedding light on the alterations in flame structures induced by hydrogen enrichment, this research aids in advancing the quest for improved flame stability. Furthermore, these

insights hold significance in the ongoing exploration of hydrogen as an alternative energy source with potential environmental benefits.

Scaled flight testing

Chaired by:
Prof. Andreas Strohmayer (University of Stuttgart)

Scaled Flight Testing - Concept of the modular Scaled Flight Demonstrator e-Genius-Mod from Baseline Configuration to Distributed Electric Propulsion

Dominique Paul Bergmann, *University of Stuttgart, Institute of Aircraft Design, Germany*

A sustainable future aviation industry requires new technologies to achieve the goal to reduce emissions as set in the Flightpath 2050 by the European Commission. To become more environmentally friendly new propulsion configurations were investigated in several research projects. Two of this are Wing Tip Propellers (WTP) and Distributed Electric Propulsion (DEP).

The development of such new technologies involves a major risk for the industry. To connect the upstream research and commercial development the modular Scaled Flight Demonstrator (SFD) e-Genius-Mod was developed at the University of Stuttgart. The SFD was realized to make new technologies and configuration feasible in flight.

The presentation gives a brief overview of the SFD e-Genius-Mod in his baseline configuration, the modification to investigate WTP and DEP and an insight into the flight test results.

Use of flexible architecture and automation language to ease testing of controllers and functionality of unconventional architectures

Nicola Genito*, Gianluigi Di Capua, Luca Garbarino, Gianfranco Morani, Riccardo Rocchio
** CIRA, Italy*

In Platform 1 of the Clean Sky 2 Large Passenger Aircraft - Integrated Aeronautics Demonstration Platform (LPA-IADP), WP1.6 aimed at discovering a strategy to reduce emissions of Large Passenger Aircraft. In this frame, the use of Hybrid Electric Propulsion (HEP) was identified as a possible solution and, specifically, Distributed Electrical Propulsion (DEP) was found as an important enabler for HEP future development.

To foster DEP adoption for large passenger aircraft architectures, a strategic roadmap was implemented including flight testing of a flying demonstrator called D08 "Radical Configuration Flight Test Demonstrator".

Within this plan, Italian Aerospace Research Centre (CIRA) is in charge of developing an aircraft Guidance, Navigation and Control (GNC) system to be integrated in a dedicated testing framework for supporting demonstration with the D08.

This work will benefit from the GNC system already developed by CIRA in the WP1.3.5 of the same project that was designed for supporting flight testing of the Dynamically Scaled Vehicle D03 demonstrator. This system will be updated in order to ease flight testing of an aircraft with DEP.

The D03 testing framework was developed with the objective of supporting demonstration campaign. This was achieved through the inclusion of an instruction language that allows performing complex missions and test maneuvers autonomously increasing repeatability in flight-testing.

Differently from current commercial autopilots that offer full turnkey solutions for remote piloting of unmanned aircraft but with limited possibility of being customized for new aircraft configurations, the proposed autopilot solution has been specifically designed for increasing experimental flexibility.

This paper describes how the proposed autopilot supports innovative configuration of the aircraft by easing integration of custom advanced control laws architectures and strategies. Moreover, it will be explained how this procedure was facilitated thanks to the modularity of the SW architecture and providing a specifically development framework allowing the users to integrate their modules following a sequence of simple steps.

These two characteristics, repeatability and modularity, can be also combined thanks to the flexibility of the GNC SW and to the automation instruction language mentioned earlier that allows selecting the custom control modules instead of the available standard ones for performing an automated sequence of experimental maneuvers.

Last but not least, to support demonstration of unconventional aircraft configurations the Ground Remote Pilot Station (GRPS) embeds the aircraft real time simulator for verification and validation that, together with the above descripted functionalities, allow fast-time testing in few steps of the custom developed control laws, as of the whole SW, and, in addition, to train a remote pilot to operate this E-demonstrator.

Such GNC, together with the development framework, will ease the design of control laws architectures and strategies and automated flight tests of unconventional DEP demonstrators. Thanks to this platform, the flight campaign of the D08 can be executed reaching the goal of demonstrating feasibility of HEP in large platform aircraft attempting to reduce their impact on the environment.

Approach to a preliminary design and scaling methodology of flexible kites for airborne wind energy applications in the maritime sector

Achim Kuhn*, Klaus Heudorfer, Andreas Strohmayer

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As far as climate goals are concerned, renewable energy sources play an important role. Concepts and systems in the field of Airborne Wind Energy (AWE) provide the potential to harvest the enormous available energy of high-altitude wind resources. A well-known AWE concept is a tethered kite that flies dynamic maneuvers at heights not reachable by other wind energy systems, providing high traction forces, which are converted into green electricity by generators on the ground. For maximization of the energy yield, the kite design must account for the high loads encountered, while providing the desired flight characteristics and flight performance during operation. The design of such tethered AWE kites requires appropriate methods that take into account the flexible characteristics and in-flight deformation during operation, in contrast to the fixed-wing design in classic aviation.

In this work, an approach for a preliminary design and scaling methodology of flexible kites in the field of AWE is developed. In general, the following points are considered:

- Flight behavior due to kite properties (Airfoil, geometry, material, rope attachment points, etc.)

- Rope load transmission and control inputs (Controllability and change in the shape of the flexible structure)

- Material and lightweight aspects

- Scalability

For this purpose, the methodology is structured in several sections, which allow an iterative design with an increasing level of detail. The requirements and boundary conditions are chosen based on a use case in the maritime sector. Furthermore, a design point is derived on this basis and an initial sizing is done to determine the relevant geometric parameters. Finally, the initial results of the developed methodology are evaluated and compared with flight test results.

Preliminary design of a multirotor UAV for indoor search and rescue applications

Chris Pliakos*, Stathis Vlachos, Chris Bliamis, Kyros Yakinthos

** Laboratory of Fluid Mechanics and Turbomachinery, Aristotle University of Thessaloniki, Greece, Greece*

Multirotor UAVs have become an essential tool in a wider range of applications, including among others disaster management, and search and rescue (SAR) operations. Typically, these systems operate outdoors, with their guidance and positioning being based primarily on GPS. This work is focused on the design and optimization of a multirotor UAV specifically tailored for indoor SAR applications, where GPS signal is unavailable, and obstacles are prevalent. The design incorporates a lightweight frame structure, in order to increase the UAV's payload capability. This is necessary, since the UAV requires multiple obstacle recognition and avoidance sensors, as well as thermal and optical cameras, to successfully accomplish its mission objectives in a GPS-denied environment. Towards this goal, various trade studies were conducted including different motor/propeller configurations and airframe FEM analyses. The aerodynamic performance of the UAV is evaluated using dedicated CFD analyses that also incorporate the effect of propellers. Additionally, the adequate cooling of the UAV's electronic systems is also considered for different operating conditions (e.g., low-velocity cruise, hovering etc). Lastly, a prototype of the designed configuration is produced using additive manufacturing methods and initial flight tests of the UAV are performed.

Artificial Intelligence & Regulatory Compliance

Filippo Tomasello, Elisa Spiller, Simona Turco *

** Deep Blue, Italy*

Governments and industry are investing in development of applications based on Artificial Intelligence (AI) and Machine Learning (ML). However, especially in aviation, to make such application become a reality on the filed or in the cockpit, involved organisation would need to demonstrate to the competent aviation authorities that these systems are sufficiently safe, secure and socially acceptable. There might be two beliefs in the community:

a) there are no rules on AI/ML for aviation applications, because these two techncologies are very innovative and of course regulations are lagging behind, and

b) in any case, it is not necessary to pay attention to regulations during development, because compliance would become an issue only at the highest Technical Readiness Levels (TRL) which comes downstream of research and development.

Unfortunately both beliefs are wrong.

In fact, the project Human AI teaming Knowledge and Understanding for aviation safety (HAIKU https://cordis.europa.eu/project/id/101075332) funded by the European Commission has

demonstrated that several EU/EASA rules, being performance-based and technology-agnostic, are already applicable to AI systems.

Furthermore, HAIKU has identified which requirements should be complied with from beginning of a development project. Otherwise, it would be extremely hard for the final user of the system to reconstruct all the documentation to obtain approval by the competent authority.

Enhancement of multirotor UAV conceptual design through Machine Learning algorithms

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Designing an efficient and optimized multirotor UAV requires laborious trade-off analyses, involving numerous design variables and mission requirement parameters, especially during the early conceptual design phase. The large number of unknown parameters, as well as the associated design effort often leads to non-optimal designs, for the sake of time efficiency. This work presents the implementation of a machine learning (ML) framework to assist and expedite the conceptual design phase of multirotor UAVs. The framework utilizes information from a comprehensive database of commercial lightweight multirotor UAVs. The database contains an extensive collection of crucial sizing parameters, performance metrics, and features associated with foldability and indoor guidance (e.g., obstacle avoidance sensors). These attributes specifically pertain to multirotor UAVs weighing less than 2kg, which exhibit diverse design and performance characteristics. The proposed ML framework employs multiple regression models (e.g. k-nearest neighbors regression, Multi-layer perceptron regression) to predict the sizing parameters during a multirotor UAV's conceptual design phase. This enables designers to make quick informed decisions, while also significantly reducing computational time and effort. Finally, the ML framework's predictive capability is validated by comparing the predicted values with real-world data from an "unseen" test dataset.

Life Cycle Assessment in aviation

Chaired by:
Mrs. Ligeia Paletti (NLR)

On the definition, assessment and enhancement of circularity in different industrial sectors: A literature survey

Christina Vogiantzi*, Konstantinos Tserpes

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Circularity has emerged recently as a critical strategy for promoting sustainability and reducing waste across diverse industrial sectors. This paper provides an overview of circularity in the aerospace, the wind energy, the automotive, the sports equipment and the transportation industries using data from the literature and the EC funded research project "RECREATE". The survey reviews the various definitions and approaches and metrics used to assess circularity in these industries, including closed-loop systems, recycling, and life cycle assessment. It also explores the challenges, opportunities, and the available tools for enhancing circularity, such as eco-design, circular business models and digital tools. The survey highlights the importance of a holistic and systematic approach to circularity, involving all stakeholders along the value chain. Additionally, it investigates the role of policy frameworks and regulations in advancing circularity in these industries. Overall, this work aims to

contribute to a deeper understanding of circularity and provides insights for future research to promote a more sustainable and circular economy.

Towards Sustainable Aviation: Addressing Gaps and Future Perspectives in Life Cycle Assessment

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Life Cycle Assessment (LCA) is an increasingly vital tool for assessing the environmental impact of aircraft, which is a growing concern for the aviation industry. While significant progress has been made in recent years, there are still critical gaps in understanding the environmental impact of aviation. In particular, there is a lack of a proper aircraft-specific inventory, which limits accurate LCA calculations. In addition, there is no common understanding of how to link LCA results to flight impacts at high altitudes.

This presentation provides a comprehensive overview of these gaps, including their causes, consequences, and possible solutions. In particular, we highlight the importance of developing an aircraft-specific database, which is being addressed within the ALICIA project at the German Aerospace Center (DLR e.V.). Finally, we provide an outlook on the future development of LCA for aviation, including the need for further research and development in this area.

Estimating Maintenance Costs of New Aircraft Concepts under Consideration of Uncertainties: A Feasibility Study

Jennifer Wehrspohn*, Ahmad Ali Pohya, Kai Wicke, Gerko Wende

** German Aerospace Center (DLR), Germany*

The urgent need for green air mobility has led to the development of new and innovative aircraft concepts aimed at reducing environmental impact. However, for these concepts to be truly successful, it is crucial not only to focus on minimising their environmental footprint, but also to establish a viable business case for operators. To achieve this, a thorough analysis of life cycle costs, including maintenance costs, is essential. While there has been significant progress in the introduction of new technologies, such as fuel cell systems on aircraft, the study of their maintenance costs is often neglected or little researched. Therefore, the objective of this study is to systematically estimate the share of maintenance costs in the life cycle of hybrid electric aircraft concepts using fuel cell systems as a replacement for the Auxiliary Power Unit (APU).

In order to do this, an analysis will be carried out comparing conventional aircraft systems with those incorporating fuel cell systems. The analysis will include a detailed technical examination of the two systems to identify key differences and categorise them. Expert knowledge is then gathered to assess the expected life and maintenance activities associated with the identified system changes.

In the early stages of product development, when information may be scarce, probabilistic approaches cannot be used due to the assumption of the central limit theorem. To mitigate this, the Dempster-Shafer Theory of Evidence can be used to overcome this limitation. Expert opinion, empirical data and other available information can at this point help to achieve a meaningful and comprehensive assessment of maintenance costs. We want to investigate the effectiveness of evidence theoretic approaches by combining evidences gathered by expert interviews so that the uncertainties surrounding maintenance costs can be effectively addressed, resulting in more robust and reliable cost estimates.

Furthermore, a global sensitivity analysis is performed to quantify the impact of uncertainties of input variables on the estimated maintenance costs. This analysis helps to identify the key drivers of cost variation and to understand how changes in different parameters affect the overall maintenance cost estimate. By systematically varying input variables and observing their effects, critical factors can be identified to guide further investigation and refine design decisions.

This feasibility study serves as a demonstration of early maintenance cost estimation during the product development process, using a novel framework which combines evidence theory and global sensitivity analysis. The results of this study contribute to the establishment of a comprehensive knowledge of maintenance costs and associated boundary conditions. More importantly, this information can be effectively fed back into the development process, facilitating informed decision making and increasing the potential for successful integration of fuel cell systems or other emerging technologies into future aircraft concepts. With a solid understanding of maintenance costs, stakeholders can make informed decisions that balance environmental sustainability and economic viability in the pursuit of green air mobility.

Life cycle impact of travelling with planes, trains and automobiles

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** Netherlands Aerospace Centre NLR, Netherlands*

The study consists of a comparative life cycle impact assessment of the greenhouse gas (GHG) emissions involved with travelling from Amersfoort, The Netherlands, to one of five explementary destinations in Europe by passenger aircraft, train or passenger car.

The work highlights how the emissions are distributed over different life cycle groups and phases for specific, modern vehicles instead of (sometimes outdated) fleet averages. For the aircraft, the work includes emission calculations for trajectory-based non-CO_2 emissions made specifically for this study. This gives a better insight in the impact of non-CO_2 emissions of short haul flights compared to the majority of studies that use a fixed factor to account for non-CO_2. For the other modalities, the assessment is based on literature values. With a sensitivity analysis, the impact of the most important assumptions in this study is demonstrated. Finally, the work includes an outlook into the climate impact of future aircraft with more sustainable powertrains for which little LCA data is available.

The study shows the life cycle GHG emissions for trips made to the five explementary destinations, made by a passenger aircraft, train and passenger car, expressed as kg CO2eq per passenger, per trip, per vehicle kilometre travelled and per passenger kilometre travelled. For all destinations the train is the mode of transport with the least GHG emissions per passenger per trip. Aircraft and electric passenger car are closely tied for second place with longer distances favouring the aircraft and shorter distances favouring the passenger car. The petrol passenger car is the least sustainable mode of transport in all scenarios. An assessment of future aircraft operating on a sustainable aviation fuel and hydrogen demonstrates the potential of these technologies in reducing the GHG emissions of air transport.

Challenges in the Life Cycle Assessment (LCA) of fibre reinforced polymers using the example of a composite aircraft interior shell.

Jens Bachmann, *DLR, Germany*

Lightweight structures made of fibre reinforced polymers (FRP) already play an important role in the reduction of fuel consumption in the aviation sector. Life Cycle Assessment (LCA) is a tool to support decision making by giving information on different categories of potential environmental impacts.

While nowadays the aircraft use phase is by far predominant in the majority of the environmental impact categories considered in LCA, both production and end-of-life must not be disregarded in order to ensure the smallest possible ecological footprint.

In this presentation, a preliminary LCA from a business class seat shell demonstrator in the SuCoHS* EU project will show potential reductions of environmental impacts by choice of materials and manufacturing method (AFP, Automated Fibre Placement) compared to the state-of-the-art sandwich structure. Based on this example, today's challenges in the LCA FRP and aviation in general are addressed and needs for future developments are identified.

*) SuCoHS (Sustainable and cost efficient high-performance composite structures demanding temperature and fire resistance). This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 769178.

Proposed LCA approach to estimate the Environmental Impact due to High Altitude Platform Systems

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The anthropic activities, starting from the early industrial development phases, are pointed-out as concurrent causes affecting the environmental conditions of planet Earth as well as people life quality. Evidences of these influences have been observed even in the more remote territories like North and Australis poles. Every day news report about extreme meteorological events affecting vast geographical areas with heavy loss in terms of victims and damages to infrastructures. In these potential risk scenarios, it is extremely important to support emergency management with timely and accurate geo-spatial information and also to restore minimal communication services.

In these severe conditions a relevant role may be played by High-Altitude Platform Systems (HAPS) operating at high altitudes, ranging from 17 to 22 kilometres, typically in the stratosphere, extending coverage for large areas and improving connectivity in remote or underserved areas, bridging the digital divide and providing connectivity to rural or isolated regions, carrying remote sensing instruments, such as imaging sensors or atmospheric sensors, to gather data about the Earth's surface, weather patterns, or atmospheric conditions.

To analyse their sustainability, the proposed work presents the implementation of a Life Cycle Impact Assessment (LCIA) for two distinct "lighter than air" configurations: an "innovative blimp airship" (IBA) and a classical blimp airship (CBA) as baseline. Both IBA and CBA airships have been considered as unmanned vehicles. The goal of this activity is to support the characterization and validation of the environmental contribution due to innovative technologies, concepts and industrial processes adopted for the development of such HAPS configurations. For this assessment SimaPro tool has been used. The applied methodology has adopted the ISO standards: ISO-14040:2006 and ISO-14044:2018 as guidelines to estimate the collectable benefits due to the adoption of innovative eco-design solutions. Specifically, the following phases will be analysed: Raw Material Acquisition, Manufacturing/Assembly, Operation and Disposal, while for the other life cycle steps only general consideration will be done.

Hydrogen in Aviation

Chaired by:
Mr. Hugues FELIX
(European Climate, Infrastructure and Environment Executive Agency - CINEA)

OVERLEAF / H2ELIOS: Hydrogen-Powered Aviation LH2 Storage

Emma Lope*, Jorge Martinez
** Aciturri, Spain*

The use of hydrogen in aviation, among other challenges, highlights the need to develop liquid hydrogen storage that optimizes the volume needed in the aircraft.

The validation of new storage solutions requires regularization and standardization of tests to ensure safety in flight as well as on ground. To do this, it is necessary to identify specific test centers to carry out tests in a cryogenic environment with specialized personnel.

Aciturri is in full development of 4 projects related to the storage of hydrogen, both liquid and gas. Therefore, based on this experience, it will be share the current state of the different challenges facing the aeronautical sector for the integration of hydrogen.

HOPE: hydrogen optimized multi-fuel propulsion system for clean and silent aircraft

Feijia Yin*, Arvind Gangoli Rao, Roberto Merino Martinez, Alexander Heidebrecht, Moritz Kolb, Arne Seitz, Xin Zhao, Ling Lim, Lorenzo Mazzei, Rita Ponza, Ernesto Benini

** Delft University of Technology, Netherlands*

The aviation industry has been growing rapidly until the COVID-19 pandemic. The ICAO Post-COVID-19 forecasts indicate that aviation will recover with an average growth rate of 3.6%1. Air traffic growth inevitably causes an increase in aviation's combustion and noise emissions, hence aggravating aviation's environmental and societal impact locally and globally. The recently funded Horizon Europe project HOPE focuses on the development of a multi-fuel propulsion system to minimize the environmental impact of future aviation. This abstract introduces the rationale of the HOPE concept, the innovative aspects of the aircraft engine system, and its potential in reducing the environmental impact.

HOPE will deliver an integrated aircraft propulsion system comprising two multi-fuel ultra-high bypass ratio (UHBR) turbofan engines, a fuel cell based auxiliary propulsion and power unit (FC-APPU) driving an aft boundary layer ingestion (BLI) propulsor based on existing tube-wing aircraft configuration (see Figure). The expected advantages of HOPE system are the following aspects:

• Minimize the combustion and noise emissions during landing and takeoff cycle (LTO cycle), by switching to hydrogen-fueled electric-only operations in situations where emissions and noise matter most, without compromising efficiency in cruise;

• Being compliant with operational profiles, e.g. continuous descending approach, to abate LTO noise;

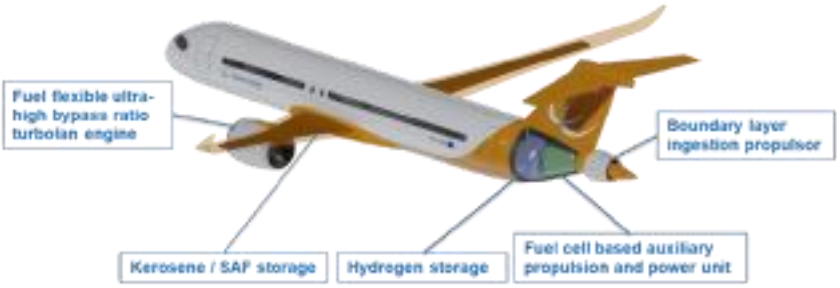
• Modify an existing aircraft configuration, allowing substantially shortened development time;

• De-risk the use of hydrogen in aircraft configurations by introducing hydrogen technology as an "add-on";

• Smooth aviation's energy transition through the assessment and exploitation of several greener propulsion technologies at different maturity levels. The emission goals consist of LTO NOx: -50%, CO: -50%, soot: -80%, perceived noise: -20% (i.e. ~3 Db per operation), and climate impact: -30% (including the effects from NOx, CO2 and contrails), compared to state-of-the-art technology (e.g., A320neo).

Acknowledgement: HOPE project has received funding from the Horizon Europe research and innovation programme under GA n° 101096275 and UKRI Horizon Europe Guarantee n° 10068673

Keywords: Multi-fuel combustion, Hydrogen optimized aircraft propulsion, environmental impact



Sustainable UAM concepts

Chaired by:
Mr. Hugues FELIX
(European Climate, Infrastructure and Environment Executive Agency - CINEA)

FF2020: Sustainable Urban Drone Operations

Filippo Tomasello, Arthur Dallau, Pasquale Junior Capasso, Sara Molinari *

** EuroUSC Italia ltd, Italy*

All experts in the world agree that to really develop in a societal acceptable way, operations of Unmanned Aircraft Systems (UAS, so called drones) above populated areas need to be safe, secure, environmental friendly (e.g. noise) and lawful (e.g. liability, privacy, compliant with urban land use). However, for both commercial organisations and entities carrying flights in the public interest, these operations need to be economically sustainable. Two examples can be : (1) urgent transport of medical equipment (e.g. defibrillator), not on a routinary basis, but on call, when and where needed, and (2) security or plant safety applications in which a drone sits in its 'nest', fed by a battery charger, but ready to take off and collect imagery of other sensory information, when triggered by security personnel or by automatic alerts (e.g. a camera spotting an individual penetrating a perimeter). Clearly these applications must be available 24/7, but they will be used seldom. Deploying one remote pilot for each 'sleeping' drone 24/7 would lead to enormous service costs, difficult to be sustained by any organisation. The drone hence needs to be completely autonomous, meaning that a remote pilot would no longer be necessary. 'Drones in the box' already exist today and therefore technically these solutions are feasible. Organisation of the operations, however, goes beyond technical feasibility. According to the Automation Concept under development by the Joint Authorities for Rulemaking on Unmanned Systems (JARUS), this is level 5 of automation, in which there is neither involvement of remote pilot in the aircraft functions (on ground and in flight), nor human awareness of dynamic operational parameters. In other words, the 24/7 operations, to be economically sustainable, should completely eliminate the remote pilot. Nevertheless, a UAS operator (i.e. the legal entity organising the operations, being accountable for them and obtaining the necessary approvals) would still exist. And a professional job profile would still be necessary, to possibly trigger the flight, receive the collected information and act upon or, should it be necessary, activate the emergency response plan. This professional would neither need to be trained nor licenced as remote pilot. But the position should be 24/7. In the two mentioned examples, security personnel may be in service 24/7 to protect certain installations (e.g. hospitals) or to provide medical emergency services (e-g- 118 in Italy). These operations would therefore become economically

sustainable if these personnel were trained by the operator for this part-time on demand duty. Project Flying Forward 2020 (FF 2020) funded by the European Agency CINEA, has named this function 'Fleet Manager' and intends to standardise it through ISO, for global harmonisation.

UAS Safety

Chaired by:
Mr. Hugues FELIX
(European Climate, Infrastructure and Environment Executive Agency - CINEA)

Labyrinth: towards a safe, automatic and coordinated UAV air traffic. Lessons from operation.

Fernando Quevedo*, Blanca López, Javier Muñoz, Luis Moreno, Concepción A. Monje., Santiago Garrido

** Universidad Carlos III Madrid, Spain*

Unmanned aerial vehicles (UAVs) have gathered significant attention in research, gradually expanding their range of applications. However, due to regulatory limitations, the utilization of drones remains restricted despite their increasing availability to the general public.

Addressing this issue, the LABYRINTH project, conceived under the SESAR initiative, aims to create an automatic and safe U-SPACE (a new framework designed to integrate drone operations at low level airspace), enabling any possible drone application. This system will serve as a reference point to accelerate regulatory frameworks and future implementations.

Nevertheless, this project does not come without its own challenges. High in-flight coordination in close areas for segregated operators and Ground Control Station (GCS), is a challenge. To tackle this, two core systems have been created: an Unmanned Traffic Manager (UTM) and a global planner. The latter was developed using state-of-the-art techniques (fast marching square, 4D deconfliction, flight levels) which were successfully intertwined, creating spatially and temporally congruent trajectories between drones.

Although the system provides a significant advance, still areas of improvement have been detected from the different real test use cases. Drone takeoffs demand careful consideration, particularly regarding proximity to obstacles. Time windows for path execution often prove too narrow, producing a cascading effect to other drones and possibly overloading the system. Emergency contingencies must be provided in the plan, to avoid loss of communication.

Digitalization of Manufacturing, sustainable manufacturing and MRO

Chaired by:
Mr. Hugues FELIX
(European Climate, Infrastructure and Environment Executive Agency - CINEA)

SUSTAINAir: Joining of similar and dissimilar aircraft materials for new and recycled composites and metals

Senne Sterk*, Ruben Nahuis

* *Royal Netherlands Aerospace Centre NLR, Netherlands*

Within the Horizon 2020 project SUSTAINair one of the research topics is joining of similar and dissimilar aircraft materials for new (1st life) and recycled (2nd life) composites and metals. SUSTAINair applies circular economy principles to the design, manufacturing, operations and end-of-life phases of aircraft. The aim is to increase resource efficiency and aircraft performance while reducing waste and material costs throughout the aircraft life cycle, what is known as circular aviation. In total 11 partners are involved each working and collaborating on the different topics.

On the topic of joining 7 partners research the differences in overall quality of the different joints and joining techniques, applied on the selected material combinations. The aspects include joining for production of assemblies as well as repair of metal-to-metal, metal-to-composite and composite-to-composite (thermoset and thermoplastic) material combinations for 1st and 2nd life materials. Materials under consideration are novel aluminium alloys, Titanium, EPDM and carbon fibre reinforced epoxy, PPS and LM-PAEK. The joining techniques researched are laser welding, friction stir welding and MIG for the metals, induction and conduction welding for thermoplastics and co-curing and bonding for thermosets. The metal samples are novel Al-alloys made through high pressure die casting (HPDC) as well as standard Ti6Al4V samples. Also hybrid joints between the metals and the thermoplastic and thermoset samples are investigated. Interface strength is improved by addition of small pins through 3D printing or WAAM/LDED and by a laser pretreatment. The pins interlock with the composite counterpart and thereby improving strength and durability.

The joints will be evaluated in terms of – for example – strength and structural integrity, using mainly single lap-joints and L-type test articles. Subobjectives are the setup of a database with test results for the several joining techniques, material combinations and sensors, both for new and recycled material. Performance is measured in terms of static and dynamic strength. The outcome of this research will be highlighted in the presentation and paper.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006952.

SUSTAINAir: Damage Diagnostics to support Maintenance, Repair and Overhaul for SUSTAINability increase of Airframe and Engine Parts

Christoph Kralovec, *Johannes Keppler Universität Linz, Austria*

Modern airframe and engine parts need to meet manyfold requirements. Extreme light-weighting combined with the integration of novel functions, like e.g. morphing aerodynamic surfaces, enable novel aircraft design solutions that are more efficient, and thus, more sustainable during flight operation. Typical for these designs is a multi-material mix which requires multi-material joints. Considering, today's circular aviation this results in apparently contradictory joining requirements as, (i) highest strength, durability and reliability are needed, and (ii) highest repair capabilities and recycling rates have to be enabled, the latter by detachable joints and composite materials.

The Horizon 2020 project "SUSTAINability increase of lightweight, multifunctional and intelligent airframe and engine parts" with its 11 partners from industry and academia addresses the aspects of circular design by researching numerous key enabling technologies for tomorrow's multi-material joints. Among these, the project work package "Damage Diagnostics" researches novel sensor technologies and their application for structural health monitoring of a joint to reduce manufacturing and operational uncertainties on the integrity. This shall enable the transformation from today's scheduled maintenance to tomorrow's condition-based and predictive maintenance, thereby, avoiding operational downtimes and supporting repair and overhaul by early damage identification. The research includes, (i) the fundamental understanding of joint damage initiation and propagation, (ii) the development and tailoring of sensors and their structural integration, and (iii) the

identification and evaluation of measurable damage effects and the development of reliable damage diagnostics in operational conditions.

Within the SUSTAINair project, a co-cured pinned hybrid titanium-composite single-lap-shear (SLS) joint is used as a case example. Static and cyclic tension tests are used to analyze the damaging behavior of the considered hybrid SLS joint. The results are consistent with results from similar joints described in the literature and clearly show its robustness and damage tolerance. Novel extremely thin, flexible and lightweight piezoelectric sensors based on piezoelectric nanofibers are investigated, further enhanced, tested and tailored to enable the integration of a sensor network to the case example. And lastly, a multi-method damage diagnostic concept for pinned hybrid joints that applies piezoelectric sensors and electric contacting of the structure itself for sensing, and uses various active and passive damage evaluation methods is presented and experimentally demonstrated by the considered hybrid SLS joint.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006952.

DOMMINIO: Next generation multifunctional materials and composites by assessing integrated carbon nanotube sensors for strain monitoring of thermoplastic laminates

Moisés Zarzoso*, Anastasiia Mikhalchan, Carlos González, Juan José Vilatela, Ricardo Loasada, Pablo Romero , Alexandru Ionel and Cesar Banu

** IMDEA Materials Institute/Universidad Politécnica de Madrid, Spain*

The current approach for maintaining civil aviation aircraft involves scheduled maintenance inspections performed on the ground, where Non-Destructive Inspections (NDI) are conducted to identify any structural damage. This type of inspection requires direct access to the component, which makes the process more expensive or even unfeasible for internal components. In the case of composite material structures, this process is further complicated by the complex behaviour of this type of material under damage.

In this context, the Structural Health Monitoring (SHM) of composite airframe parts plays a crucial role in evaluating their performance and integrity. Since the SHM system utilizes sensors installed within the structure, there is no need to remove surrounding internal components for inspection.

Currently investigated SHM systems are based on several types of sensors, such as strain gauges, accelerometers, and ultrasonic sensors. Unfortunately, most of the strategies consist of attached sensors, which lack the robustness of an embedded system.

The DOMMINIO Project[1] proposes a fully integrated Structural Health Monitoring (SHM) strategy for thermoplastic composite structural components using novel sensors based on carbon nanotube (CNT) filaments[2]. These filaments, thanks to the piezoelectric behaviour of CNT, enable the detection of damage effects on the composite. Along with the sensor system composed of these CNT filaments, the strategy includes a cloud-based digital twin capable of integrating the information received by the sensors into a system that assesses the remaining structural integrity of the component.

Local air quality, Noise, Green Airports

Chaired by:
Mr. Hugues FELIX
(European Climate, Infrastructure and Environment Executive Agency - CINEA)

MYTHOS: Medium-Range Hybrid Low-Pollution Flexi-Fuel/Hydrogen Sustainable Engine

Francesca di Mare*, J. Donndorf, F. Lo Presti, D. Quagliarella, R. Donelli, G. Saccone, G. Andreutti, A.D. French, M. Minervino, S. Russo, N. Natale, B. Mele, U. Merola, N. Viola, D. Ferretto, R. Fusaro, O. Gori, S. Graziani, G. Piccirillo, C. Fureby, X. Bai, M. Richter,P.
** Dream Innovation Srl, Italy*

MYTHOS answers HORIZON-CL5-2022-D5-01-12 Call (i.e. Towards a silent and ultra-low local air pollution aircrafts) and proposes to develop a demonstrated innovative and disruptive design methodology for future short/medium range civil engines capable of using a wide range of liquid and gaseous fuels including SAFs thus aiming at fulfilling the objective of decarbonize civil aviation as foreseen by the ACARE SRIA Goals by 2050. To achieve these ambitious goals, the MYTHOS consortium develops and adopts a multidisciplinary multi-fidelity modelling approach for the characterization of the relevant engine components deploying the full power of the method of machine learning. The latter will lead through hidden-physics discovery to advance data-driven reduced models which will be embedded in a holistic tool for the prediction of the environmental footprint of the civil aviation of all speeds. The methodological concept of the MYTHOS project consists of six main steps. The first step (Step 1) is to define a realistic reference framework in terms of working conditions and design points in which the flexible-fuel engine technology based on bio-fuel and hydrogen have to work. Step 2 requires the definition of a model hierarchy for the engine critical components. In this phase, particular attention must be paid to the search for a good balance between the accuracy of the models and the computational effort required to ensure that both the constructive and structural aspects and the estimate of the polluting levels of the multi-fuel engine guarantee both acceptable computational costs and well-defined margins of uncertainty. In Step 3 the experimental validation of the of multi-fidelity simulations using SAF and H2 will take place. The new validated toolchain will reoptimize some selected points extracted from the Pareto front. The experimental campaign is also preparatory to Step 4, dedicated to using advanced machine learning and data mining techniques to build a data fusion process aimed at optimizing the critical parameters of the new models that characterize the forecast quality in the regimes of interest. Step 5 focuses on constructing advanced ROMs for the engine components and verifying these ROMs against both high-fidelity numerical and experimental results obtained in Step2 and Step 3. Finally, Step 6 encompasses the integration of engine components ROMs in a holistic framework that allows the performance assessment and feasibility analysis of flexifuel solutions for aeronautical propulsion.

STARGATE: MONITORING AND MODELLING OF ULTRAFINE PARTICLES AT BRUSSELS AIRPORT: UPDATE FROM THE STARGATE PROJECT

Stijn Vranckx*, Jan Peters, Gert Geentjens
** VITO, Belgium*

Ultrafine particles (UFPs) are the finest category of particles in ambient air, and a constituent of the particulate matter (PM). The concentration of UFP at and near airports has already been studied at a number of airports worldwide, and particle numbers close to airports are significantly higher than locations distant or upwind from airports and could affect the local air quality. There are currently no limit values for ambient UFP levels, but recommendations are being made to extent the UFP

monitoring actions, especially at locations where concentrations are expected to be high, by WHO and the European Commission.

In the Stargate project, the introduction of an innovative monitoring and modelling system for UFP is implemented at Brussels Airport. Experience and lessons-learned are shared with Stargate fellow airports and other dissemination events such as this workshop.

A UFP monitoring system composed as a network of fixed and continuously operated UFP measurement instruments was installed at dedicated sites for two months. These sites are situated in the local municipality near the airport, between 500 m and 1500 m from the end of the main departing runway. Complementary to the stationary monitoring at fixed sites, short temporary campaigns (hours) with portable instruments have been conducted at dedicated sites and with mobile monitoring.

Average UFP-concentrations range between 17 000 and 35 000 pt/cm³ in the local municipality, depending on the site. Averages are in the range of UFP-concentrations measured at traffic locations in urban environments, but peak concentrations can be much higher near the airport. There is a clear gradient in function of distance. The UFP concentrations show high temporal dynamics. Large day-by-day differences in UFP concentrations occur. Typically, the UFP concentrations show three periods of increased concentrations over the day, during the morning, around noon and in the evening. UFP concentrations are much lower during the night (i.e. between 1 and 6 am).

A clear relationship was observed between UFP concentrations and UFP size. Increased UFP concentrations are attributed to small sized UFP (<20 nm).

Wind direction is the most important meteorological variable influencing the UFP concentrations, by its influence on airport operations and the down or upwind situation of the community, relative to the airport.

A bottom-up modelling system composed of an emission and a dispersion module has been developed. Starting from flight data and the EMEP emissions database, the emission module estimates hourly UFP emissions for the LTO-cycle. These emissions are thereafter used as input for a Gaussian dispersion model (IFDM), to model hourly and annual mean UFP concentrations in the vicinity of Brussels Airport. The resulting UFP concentrations maps are validated using the UFP measurements of the monitoring system.

The model chain has been applied both for a recent representative year (2019) and for a future year (2030), and additionally, the modelling system has been applied for other pollutants of concern (e.g. NO2, particulate matter),. Finally, a nitrogen deposition module has been added as well.

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Project session: GENESIS

Chaired by:
Prof. Fabrizio Nicolosi (University of Naples "Federico II") &
Ms. Sonell Shroff (Clean Aviation JU)

Advancements in Battery and Fuel Cell Technologies and design of future energy storage system for Hybrid-Electric Aircrafts

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With 2% of the world's total carbon emissions, the aviation industry is a significant emitter, but predictions show that its effect could increase two-fold by 2050, amplifying its role in the current climate crisis [1]. Hybrid and "all-electric aircraft" are considered the most promising solutions to achieve more environmentally friendly air travels. However, shifting the mobility paradigm from fossil fuel to electric propulsion system poses several challenges to a large extent attributed to the low energy density of storage systems. Therefore, their developments depend significantly on new and disruptive technologies, which requires identifying and overcoming existing gaps in research [2].

Battery and fuel cell-based hybrid systems offer meaningful potential for environmentally sustainable aircraft energy. However, research is still in its infancy, and implementation in actual aircraft, especially for regional class aircraft, is minimal.

This study presents a conceptual design of a hybrid electric regional aircraft that meets TLAR (Target Level Aircraft Requirements) over different time frames (2030, 2040, and 2050+). A technological forecast is performed to estimate the expected performances regarding weight, volume, stored energy, and power density based on past experiences and current development trends. Subsequently, a bottom-up technology analysis defined the characteristics of the hybrid system during various flight phases. The study results highlight the required level of hybridization in the energy system and the limitations that need to be overcome to enable electric airplanes to take off.

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Electric power, propulsion and supply strategy of hybrid-electric regional aircraft systems

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Sustainability, particularly the reduction of emissions, are significant challenges for aviation that are currently being addressed. The Clean Sky 2 project GENESIS addresses the environmental sustainability of hybrid-electric 50-passenger aircraft systems (PAX) from a life cycle perspective to support the development of a technology roadmap for the transition to sustainable and competitive electric aircraft systems [1].

This paper has emerged from the GENESIS research and describes different options for power electronics, electric motors and an airport power supply to operate a hybrid electric aircraft. Possible solutions and estimates for 2030, 2040 and 2050 are proposed. This paper presents the required components of power electronics, electric motors and ground power supply technology for the operation of a regional hybrid-electric aircraft.

The electrical power distribution system of the whole aircraft, the HV DC voltage and the power electronic converters have been analysed. These converters are presented, calculated, designed

and specified. Special attention is paid to the power density and efficiency of the converters. The comprehensive band gap materials, silicon carbide (SiC) and gallium nitride (GaN), are discussed for the design of the converters [2, 3].

Electric propulsion systems are considered another way to achieve the ambitious greenhouse gas emissions and noise targets of the European Union's Flightpath 2050. Therefore, a design for the technical architecture of an electric motor for a propulsion system in this hybrid-electric regional aircraft is proposed. The project partners have defined the performance requirements for the thrust of the propulsion system. The electric drive motor for the propellers was calculated and simulated. The engine is specified in this paper, together with the possible construction materials [4, 5].

Finally, this GENESIS research paper explains different ground power supply options at a regional airport. Possible solutions for airport infrastructure in 2030, 2040 and 2050 are proposed. This analysis includes an estimate of the future energy demand per day, month and year. It gives an overview of the energy demand of a regional airport divided into individual time horizons [6–8].

Design of Sustainable and Innovative Regional Aircraft for Three Time Horizons

F. Nicolosi*, V. Marciello, M. Di Stasio, M. Ruocco

** University of Naples Federico II, Italy*

Nowadays, although aviation is responsible for only 12% of transport-related CO_2 emissions, research cannot hesitate to address the unique technological challenges of the sector. In this sense, it is of fundamental importance to evaluate the feasibility of promising hybrid-electric concepts, without neglecting their compliance with market needs. This is one of the main objectives of the EU-funded GENESIS Project (European Union topic JTI-CS2-2020-CFP11-THT-13, Sustainability of Hybrid-Electric Aircraft System Architectures). The project explores a wide range of propulsion solutions that aim for the complete decarbonization of aviation by 2050. Several innovative configurations have been designed with respect to three different time horizons (short-term, 2025-2035, medium-term, 2035-2045, and long-term, 2045-2050+), focusing on a 50-seats regional turboprop aircraft. The outcomes relating to all time horizons will be presented, as the result of the integration of industrial experience within a complete aircraft design chain. The design process has been based on the simulation of the flight mission and on compliance with the assigned top-level aircraft requirements. A design of experiment has been performed to identify the best combination of degrees of hybridization and geometric parameters. Starting from a conventional reference aircraft similar to the ATR42-500, several hybridization solutions were explored. In the short-term, a serial/parallel partial hybrid architecture has been considered, coupling internal combustion engines (ICEs) with 100% biomass fuel usage and lithium-ion batteries, leading to a block fuel reduction of up -23.6% for a 200 nmi typical mission with respect to a conventional aircraft with the same entry into service year. For the medium-term, the same concept has been improved by means of advanced ICEs and lithium-sulfur batteries, increasing the fuel saving to -45.1%. However, it is in the medium-term that the transition towards solutions with zero-emissions will take place. This vision is represented by a configuration that is entirely based on lithium-sulphur batteries, pressurized tanks and PEM fuel cells, with energy savings up to -60.2%. Finally, in the long term, two different configurations are presented: one with lithium-air batteries, cryogenic hydrogen tanks and improved PEM fuel cells, with slightly higher energy savings and improved performance, the other one based on lithium-air batteries, cryogenic hydrogen tanks and SOFC, with energy savings up to -69.6%. All the configurations analyzed feature distributed electric propulsion.

Technology Roadmap for a Transition to Sustainable and Competitive Electric Aircraft Systems

Valerio Marciello*, Manuela Ruocco, Vincenzo Cusati, Mario Di Stasio, Fabrizio Nicolosi
** University of Naples Federico II, Italy*

Nowadays, the growing demand for air transport and the increasing sensitivity to environmental issues creates the need to promptly implement a revolution in today's aviation paradigm. For this reason, researchers need to evaluate the feasibility of promising hybrid-electric concepts, without neglecting their compliance with market needs. One of the main objectives of the EU-funded GENESIS Project (European Union topic JTI-CS2-2020-CFP11-THT-13, Sustainability of Hybrid-Electric Aircraft System Architectures) is to explore a wide range of propulsion solutions that chart a roadmap towards the complete decarbonization of aviation by 2050. Three different time horizons are investigated within the project (short-term, 2025-2035, medium-term, 2035-2045, and long-term, 2045-2050+), focusing on a 50-seats regional turboprop aircraft.

All aircraft concepts designed within the project, each implementing innovative technology solutions, have been further analyzed from a life-cycle perspective. Several possible scenarios have been considered, to evaluate the expected effects in terms of environmental impact and costs. In this way, the estimated advantage resulting from the analysis of direct polluting emissions has been re-evaluated, by also including the effect of the production and disposal phases, as well as the need for new infrastructures and safety standards. In order to recombine all these aspects, detailed comparative analyses have been carried out, involving both hybrid-electric and conventional aircraft, and including several aspects such as flight performance, fuel emissions, costs, maintenance, operational capabilities and constraints, and life cycle environmental impact of the technologies considered. A critical eye has been kept, considering the risk that the project vision will not materialize if the technologies fail to reach the level of maturity required for application in the aeronautical field. In this sense, the main technical and socio-economic challenges have been examined, identifying potential show-stoppers.

The result of this analysis has supported the development of a technology roadmap for a transition to sustainable and competitive electric aircraft systems, identifying environmental hotspots to integrate in future eco-design strategies, and gathering recommendations to different stakeholders in the aeronautics sector.

Comprehensive Prospective Life Cycle Assessment of Hybrid-Electric Aircraft Systems: Scenarios, Impacts, and Recommendations

Alexis Laurent*, Nils Thonemann, Karen Saavedra Rubio, Eleonore Pierrat, Katarzyna Dudka, Julie Elleby, Anna Lia S. Tromer Dragsdahl
** Technical University of Denmark, Denmark*

The results of a full-fledged prospective life cycle assessment (LCA) that encompasses the entire life cycle of hybrid-electric aircraft systems is the cornerstone of this presentation. It is one of the main outputs from the Clean Sky 2 project GENESIS, aiming at developing a technology roadmap for a sustainable transition towards hybrid-electric regional aircraft. The prospective LCA considers different scenarios based on various powertrain technologies (e.g., combining battery and fuel cell technologies) and evaluates the environmental impacts of these scenarios while accounting for temporal differentiation and potential upscaling and learning effects.

The study integrates foreground system processes (i.e., activities specific to the aircraft systems) with consideration of temporal perspectives spanning the periods of 2025-2035 (short-term), 2035-2045 (mid-term), and 2045-2050+ (long-term). Background systems, like energy generation systems, are

also adapted to the extent possible, including factors such as electricity grid mixes, waste management, technology efficiencies, and environmental regulations. The prospective life cycle assessment adheres to ISO standards and encompasses a wide range of environmental impacts, including climate change, toxic impacts on human health and ecosystems from chemical releases, metal/fossil resource use, water use, and land use.

The results enable comparisons between scenarios and technology alternatives, highlighting potential environmental burden-shifting. Furthermore, within each scenario, the assessment identifies environmental hotspots, representing sources of significant environmental impacts in the life cycle of aircraft systems. These findings lead to recommendations, particularly in the realm of ecodesign for future electric aircraft and contribute to the development of a technology roadmap for transition towards environmentally-sustainable hybrid-electric aircraft systems.

Development of Life Cycle Inventory Datasets for Holistic Environmental Impact Assessment of Hybrid-Electric Regional Aircraft

Katarzyna Dudka*, Nils Thonemann, Karen Saavedra Rubio, Eleonore Pierrat, Julie Elleby, Alexis Laurent

** Technical University of Denmark, Denmark*

Life cycle assessments (LCAs) are crucial in evaluating the environmental impacts of products and systems. Accurate life cycle inventory (LCI) datasets are essential for comprehensive assessments. In the Clean Sky 2 GENESIS project, investigating technological feasibility and environmental sustainability of hybrid-electric regional aircraft, LCI datasets were developed for all elements of the life cycle of the aircraft system. These datasets thus encompass the aircraft itself, the on-ground airport infrastructure, and the fuel supply chain. The study focused on three different time horizons (short-term, mid-term, and long-term) and prioritized various technologies, including battery technologies, fuel cells, hydrogen technologies, gas turbines, power electronics, electric drives, and on-ground infrastructure.

A framework was established for the collection of LCI data and for the building of LCI blocks, which represent one or more unit processes at an appropriate technological aggregation level, such as the component level. An LCI data collection template was used to facilitate the procedure and ensure harmonization and compatibility across the different LCI datasets. Eventually, the LCI datasets were verified, and the LCI blocks were finalized before their assembly and integration into the LCI modeling.

The finalized LCI datasets for all time horizons will be showcased in this presentation. These datasets can serve as valuable resources for conducting comprehensive life cycle assessments of hybrid-electric regional aircraft systems. The inclusion of multiple technologies and the integration of the entire life cycle, including on-ground airport infrastructure and fuels, ensures a holistic evaluation of the system's environmental impacts. These findings contribute to developing sustainable aviation solutions and facilitate informed decision-making in the aviation industry.

ecoDESIGN and Engineering for Sustainability

Chaired by:
Mr. Rainer Schweppe (Fraunhofer ICT)

ecoDESIGN in Next Generation Aircraft Fuselage

Marta Solares-Canal*, Laura Costa Lopez, Ralf Herrmann, Carl-Christoph Höhne, Peter Bransch
** Airbus, Spain*

Sustainability and competitiveness of next generation large scale aircraft structures will strongly depend on their environmental footprint along the full life cycle. This particularly includes design, materials processes and resources, manufacturing and production, lifetime services as well as recycling and end-of-life for disruptive concepts and innovation.

This presentation provides an overview about the implementation of ecoDESIGN in the Multi Functional Fuselage Demonstrator as part of the Clean Sky 2 and introduces adapted LCA methodology and an approach to environmental results. Detailed presentations on contributing projects will be presented separately as part of the EASN Conference Session on ecoDESIGN and Sustainable Productivity.

ecoDESIGN in Advance Rear End demonstrator

Marta Solares-Canal, Laura Costa Lopez, Enrique Guinaldo, Carl-Christoph Höhne*, Peter Bransch
** Fraunhofer Institute for Chemical Technology ICT, Germany*

Sustainability and competitiveness of next generation large scale aircraft structures will strongly depend on their environmental footprint along the full life cycle. This particularly includes design, materials processes and resources, manufacturing and production, lifetime services as well as recycling and end-of-life for disruptive concepts and innovation.

This presentation provides an overview about the implementation of ecoDESIGN in the Advanced Rear End Demonstrator as part of the Clean Sky 2 and introduces adapted references and an approach to environmental results.

Life Cycle Assessment of Engine Blisk-Manufacturing for dif-ferent Machining Scenarios

Kilian Fricke*, Thomas Bergs, Philipp Ganser, Sascha Gierlings
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The aviation industry has been growing continuously over the past decades. To ensure sustainability and competitiveness for aviation industry, a full understanding of the environmental impacts is re-quired, not only during use phase but along the entire life cycle including Materials, Processes and Resources, Manufacturing and Production, Lifetime Services as well as Reuse, End-of-Life and Re-cycling. Core engine components, for example integral rotors (Blisks), are comprised of high value metallic alloys that require complex and resource consuming manufacturing processes.

The presentation deals with the methodology and approach for a full size Blisk Life-Cycle-Assessment based on ISO 14040/44. While previously published EASN-papers focused on the "Goal & Scope Definition", the "Life-Cycle-Inventory", as well as preliminary LCIA results for a Blisk-manufacturing process chain. This presentation includes a more detailed analysis of process varia-tions and compares alternate scenarios of machining operations from an ecological perspective.

The work is part of the Clean Sky 2 ecoDESIGN Transversal activity and Engines ITD.

How to approach a Life Cycle Assessment of aircraft engines and engine sub-systems? A methodologic proposition based on "notional engine" model

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Life Cycle Assessment (LCA), based on ISO 14040/44, actually stands as the reference methodology to assess systems' environmental impact along their lifecycle. Result's analysis notably may lead to the system ecodesign improvement. Nevertheless, LCA requires a huge amount of data input to supply relevant results and the exercise becomes very intense regarding complex system's assessment, such as an aircraft engine.

Literature provides a few Aircraft Engine's LCA, which perimeter and assumptions have been very simplified. They lead to macroscopic results that can be controversial when dealing with ecodesign application. Engines ITD, within Clean Sky 2, provides different engine's parts LCA. Regarding Engine LCA state of the art, a question is raised about the opportunity of using such studies: how can results from specific part could be used and extrapolated to a larger scale component?

Our study proposes to set up a methodology to use Part LCA in order to achieve a notional Engine LCA. The study step will notably address the following key elements:

- How do we link part LCA functional unit to Engine Functional unit, in order to ag-gregate results?

- How do we assess the part's engine representativity and coverage in order to define a repartition key from part's LCA results to a global engine view?

Our proposal will be illustrated by a case study lying on Blisk LCA results.

[This work is a follow up study on last year's presentation at EASN 2022.]

Critical review of life cycle assessments of aviation systems

Alexis Laurent*, Lea Rupcic, Karen Saavedra-Rubio, Nils Thonemann, Chizoba Oguga, Eleonore Pierrat
* *Technical University of Denmark*

In the context of ever-growing air transportation demand, sustainable aviation is an upcoming research topic. Numerous life cycle assessment (LCA) studies have been published to assess the potential of specific technologies to tackle aviation climate change impacts. However, a compilation of the existing literature on multiple environmental impacts passing the aviation sector is missing. What learnings can be derived from this pool of LCA knowledge and what recommendations can be drawn for further LCA practice in aviation sector? We address these questions in our presentation to line up a guidance for aviation stakeholders in their assessment of environmental sustainability. We reviewed the main findings and LCA practice of 61 peer-reviewed environmental studies and life cycle assessments (LCA) applied to aviation.

Taking a sector-wide approach we categorise the different aircraft system life cycle between (i) the aircraft itself, (ii) the airports, and (iii) the fuels, each taken in a life cycle perspective. In past LCA studies, focus has been on alternative aviation fuels and propulsion systems, with 38% of all reviewed studies, followed by aircraft (33%), airports (26%), and sector-scale studies (3%). Climate change was investigated in 85% of all studies, nonetheless, 60% of the studies also included other indicators, such as human health damage. Moreover, the environmental impacts of some parts of the aviation systems are understudied, such as the aircraft manufacturing, maintenance, and end-of-life.

Therefore, further impact reduction could be achieved by investigating resource use (e.g., water, land, metals), circularity, and toxicity impacts.

Based on the reviewed literature, several methodological improvements could increase the robustness of LCA applied to aviation. The recommendation to LCA practitioners and industrial stakeholders include defining clearly the system boundary and the functional unit of the LCA study, increasing the transparency of the life cycle inventory data, and assessing multiple environmental impact indicators systematically. Guidance is provided in the presentation in this regard. Furthermore, research needs are also highlighted, including the need for specific life cycle impact assessment method development, like the development of altitude-differentiated characterization factors for non-CO_2 emissions (contrails) and characterization factors for noise annoyance.

Enhancing Sustainability in Laser Powder Bed Fusion: Optimization of Process Parameters for 17-4 PH Steel

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Additive Manufacturing (AM), commonly known as 3D printing, has emerged as a transformative technology in the aviation industry, offering new possibilities for design, production, and sustainability [1]. In this context, Laser Powder Bed Fusion (LPBF) is a key additive manufacturing technique known for its ability to produce intricate geometries with high precision. However, in order to establish a sustainable process, it is crucial to minimize the environmental impact and manufacturing costs associated with the manufacturing process, while also ensuring the quality of the printed parts [2].

This study utilizes genetic algorithms and suitable regression models to optimize the LPBF process parameters for 17-4 PH steel, considering sustainability criteria. To enhance circularity in the printed parts and promote sustainable practices, the printing process utilizes recycled powders. The proposed approach entails conducting real experiments to gather data on key process variables, including laser power, scan speed and layer thickness, to examine their impact on the mechanical performance of the printed parts. A combined approach of genetic algorithms and appropriate regression models is employed to refine the process parameters, taking into account sustainability criteria encompassing technological, ecological, and economic metrics. Sustainability is expressed through a Sustainability Index derived from a Multi-Criteria Decision Making (MCDM) method combining the Analytic Hierarchy Process (AHP) and a Weighted Sum model [3]. The optimized process parameters are validated through additional experiments, ensuring sustainability is maximized while maintaining acceptable levels of part quality, environmental impact, and costs.

This research provides valuable insights into the trade-offs between the different aspects of a sustainable process, helping identify optimal process parameters for achieving a sustainable LPBF. The findings contribute to the advancement of sustainable additive manufacturing practices and the transition to an environmentally conscious manufacturing industry. Furthermore, the work discusses the potential for the reuse of recycled powders in the LPBF process.

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ecoDESIGN for Airframes

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Clean Sky 2 Airframe ITD ecoDESIGN Demonstrators include novel composite, novel metallic as well as hybrid materials and structures across a variety of different airframe types and sizes –for wings, fuselage, and control surfaces.

For this demonstrators Eco-Design in the Airframe ITD is developing environmentally sound technologies and associated Life Cycle Inventory (LCI) data to perform Life Cycle Analysis (LCA) within the transversal CS2 activity ecoDESIGN (ECO TA) to quantify the benefit brought by the newly developed technologies.

Eco-Design in AIR ITD is focusing on lower environmental impacts during the production of A/C parts, the maintenance phase and end-of-life of the a/c.

In the presentation several test cases were introduced and the overall status of the improvements is summarized.

Design, Manufacturing, and Testing of a Metallic Fuselage Panel Incorporating New Alloys and Environmentally Friendly Technologies

Alexandra Karanika*, Alexandra Karanika, Evangelos Carelas, Egoitz Aldanondo, Alexander Abramoivich, Marc Van Der Geest, Peter Visser
* *Hellenic Aerospace Industry, Greece*

Within the ecoTECH project, a new fuselage section was designed based on an existing business jet panel, aiming to incorporate innovative technologies and environmentally friendly approaches. The Metallic Fuselage Panel Demonstrator developed in this project integrates the most promising technologies previously developed in the areas of manufacturing methods, including mechanical milling and friction stir welding, as well as surface treatments such as sol-gel and Thin film sulphuric acid anodizing, along with a Chrome-free primer applied on a new Al-Li alloy structure.

Two types of full-scale testing were performed to mature the newly developed technologies and assess the performance of the demonstrator. The first was a Static Full-Scale Test Demonstrator, designed and manufactured to undergo static full-scale testing. This testing evaluated the structural integrity and performance of the panel under various load conditions, including compression, shear, pressure, tension, and combinations of these forces.

The second type of testing conducted was the Endurance. Similar to the static test demonstrator, this demonstrator was subjected to fatigue to assess its durability and long-term performance by simulating representative flight loading spectrum of a business jet aircraft and providing valuable insights into the panel's ability to withstand prolonged operational conditions.

The successful completion of these phases in the ecoTECH project represents a significant milestone, demonstrating the effective integration of innovative manufacturing methods and environmentally friendly surface treatments for new aluminum alloys in the development of innovative environmentally friendly technologies. The project's outcomes contribute to the advancement of sustainable and efficient technologies in the aerospace industry, providing a foundation for the future development of aircraft structures with improved performance, durability, and reduced environmental impact.

The work performed within the frame of the European Research Projects of Clean Sky 2 ecoTECH (GAM agreement number 945521) and the CfP DEMONSTRATE

The recycling of different carbon fibre grades from aeronautic composite waste

Alexandre FAURE*, Olivier MANTAUX, Arnaud GILLET, Constance AMARE
** Université de Bordeaux, France*

While the use of composite materials is increasing in the aeronautic industry, the composite waste quantity generated is following the same trend. It is therefore essential to recycle carbon fibre (rCF) composites from different deposits. These deposits include diverse carbon fibre grades in various shapes: I) Composite offcuts II) End of life composites III) Carbon fibre fabric offcuts IV) Carbon fibre tow ends.

In the vision held by Manifica, to manufacture high performance rCF composites, a substantial question is raised in this document, is the blend of these different grades of carbon fibre possible? In other words, is the sorting of this waste required to manufacture high mechanical performance rCF composites.

To understand the influence of the carbon fibre grades, different type of carbon fibres commonly used in the aeronautic industry are either blended or sorted. Composites are manufactured using these batch and mechanically tested to be compared.

According to the results obtained, a suitable sorting strategy will be adopted to manufacture composites made of recycled carbon fibre collected from distinct deposits.

Systems / Prognostics / Safety

Chaired by:
Prof. Matteo Dalla Vedova (Politecnico di Torino)

Automated generation of aircraft on-board system architectures and filtering through certification specification requirements

Carlos Cabaleiro*, Marco Fioriti, Luca Boggero
** German Aerospace Center (DLR) & Politecnico di Torino, Germany*

The aviation industry is developing new aircraft concepts in order to face the challenge of becoming more environmentally friendly in the near future. These new aircraft concepts (e.g., hybrid-electric propulsion or hydrogen propulsion) are leveraging new technologies that lead to innovative on-board system architectures (e.g., more-electric or all-electric [1]). On-board systems represent an important part of an aircraft having a noticeable impact on mass and fuel consumption, among others. New innovative systems might increase the performance of the new generation of aircraft. Aircraft on-board system architectures are defined by the different subsystems, components and connections among them, as well as their respective redundancies. Differences in performance among architectures are typically assessed during preliminary design of on-board systems. This allows to have a first insight to decide whether the new architectures are promising or not. However, other domains such as certification and safety analysis should also be considered in order to verify if the architectures are actually viable or not [2]. The big amount of possible combinations usually creates

a vast number of design variables. This creates a huge architectural design space that requires automation in order to be properly explored. Automation applies to all the tools and connections among them. Including certification aspects in early design stages of on-board systems serves for two main purposes. The first one is that certification can be used as a filter. This allows to discard some architectures right after they are generated if they are not compliant with the certification specifications. These discarded architectures do not need to be sized and calculated, saving computational time. The second purpose is that certification now drives the design and this can potentially lead to new optimal solutions. The proposed methodology will show the link between on-board system architectures generation and certification rules. It is represented in figure 1. A huge number of architectures will be automatically generated [3] and then filtered following a set of rules extracted from the certification specifications.

CS25 [4] will be used for the application cases but other certification specifications could be used following the same methodology. As an example, some of these rules are qualitative and others quantitative. One quantitative rule states that the safety of a system must be assessed and provides a minimum value of reliability that must be ensured. In order to estimate this, the reliability block diagram technique is used [5] and automated [6]. Examples of qualitative rules are those compelling the existence of back-up systems for the power generation or those restricting single component failure leading to a whole system failure.

Results will show an application case regarding the modelling of one or more aircraft on-board systems. However, the methodology can also be expanded to space systems or other fields. Several architectures (i.e., millions) will be automatically generated and then automatically filtered by the certification specification rules. The remaining architectures are preliminary certified and can later be assessed in terms of performance, maintenance, manufacturing, or other domains. The advantages of this study are mainly the capability to assess multiple on-board system architectures automatically and to verify certification requirements during early design stages. This achieves a preliminary certification of innovative on-board system architectures and allows certification aspects to also drive the design process.

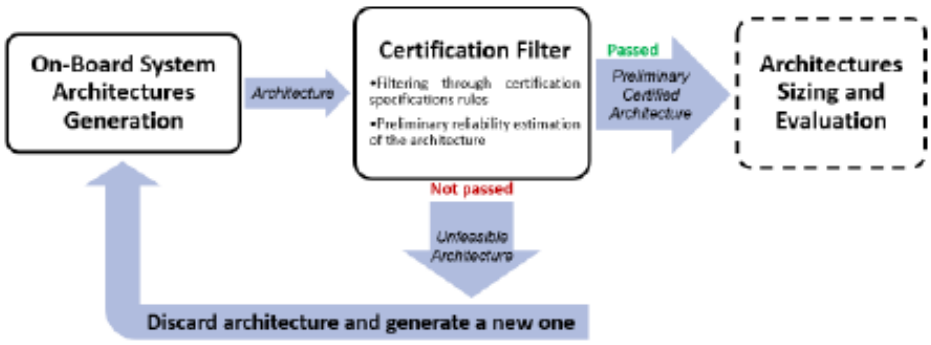

Figure 1: **Methodology schema for architectures filtering through CS25 requirements**

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Experimental investigation of the high-temperature loop heat pipe performances in harsh environmental conditions

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A new generation of turbojet engines with ultra-high bypass ratio (UHBR) will surpass existing engines in technical, operational and environmental performances. At the same time, the UHBR engine components and systems will operate in a harsher environment due to the increased compression ratio and gas temperature in front of the turbine. For example, an air bleed system will require a separate thermal management system to remove the heat from the sensitive elements of the valves and ensure their long-term operability and reliability.

Nowadays, the best candidate for thermal management of valves is loop heat pipe (LHP), a passive two-phase heat transfer system in which the working fluid movement happens due to the effect of capillary forces. However, an operating range of the state-of-the-art LHPs based on water, ammonia, ethanol, pentane, and other traditional working fluids is limited. The maximum surrounding temperature does not exceed 100°C, while the heat sink temperature is usually below 50°C. Also, for normal operation of LHP, it is necessary to minimize the extra heat inflow from environment to the LHP's evaporator and to the liquid line.

Thus, the aim of the research is to experimentally prove the LHPs performances and to investigate the influence of the thermal insulation of LHP parts on LHP performances at high environmental temperatures (surrounding temperature is up to 300°C, heat sink temperature is up to 120oC).

The LHP with toluene as a working fluid is used. The vacuum thermal insulation was proposed for the minimization of the extra heat inflow to the evaporator and liquid line. An experimental setup consisting of a box containing the LHP, a heat supply system, a heat dissipation system, a measurement and control systems. The temperature in the box was maintained in the range of 20…300°C. The maximal heat load was about 130 W. The heat dissipation system simulated the conditions of heat transfer at the heat sink level. Temperature sensors (thermocouples) were placed on the LHP and their readings were recorded by the measurement system. The thermal power supplied to the LHP's evaporator was also measured. The temperature measurement error was ±0.5oC, and the thermal power measurement error was 1.2% of the heat load level.

Experiments were conducted in the following sequence: the temperatures in the box and at the heat sink location also as the heat load were set. After reaching a steady-state, the temperature distribution at various points in the LHP was recorded. Using this data, the performances of LHP with and without thermal insulation were elaborated.

Research was made in the frame of Clean Sky 2 project EVAL, Grant Agreement #886615

Aero Engine Derate: A Fleet Comparative Study for Improved Flight and Maintenance Operations

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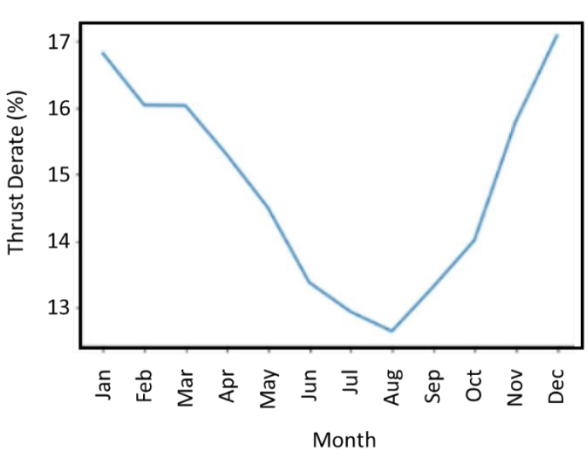
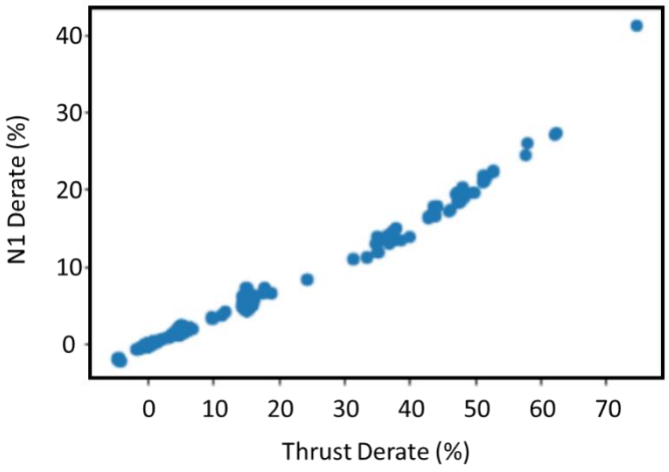
Commercial aircraft do not take-off and climb at their full thrust capacity when it is not necessary. This process is known as derate. Derate is applied in all situations where an aircraft can take off safely with a lower amount of thrust, given the existence of favourable ambient conditions. This practice preserves the engine from higher thermal and mechanical loads, eventually expanding the remaining useful life of various parts. Moreover, lower take-off thrust means lower fuel consumption and fewer gaseous emissions such as CO_2, as well as other pollutants associated with high combustion temperatures (e.g., NOx).

The estimation of the level of engine derate that has been applied fleet-wide over a period of time is a topic of significant importance for numerous reasons. For most engine types, derate values are recorded once per flight phase by the on-board data management system developed by the Original Equipment Manufacturer (OEM). However, these measurements can deviate from the actual mean value of derate, as derate is applied continuously during take-off and climb. This paper suggest a data-driven method for the determination of the actual value of derate in engine and also provides results with the use of actual on-wing data coming from a major aircraft operator. The aircraft type considered is analysed for take-off conditions and is equipped with a two-spool engine. Data extracted by the Quick Access Recorder (QAR) were used and compared with the aforementioned snapshot data. As the parameters recorded by the QAR are limited, the rotational speed of the low pressure spool (N1) is used as a thrust indicator, corrected for the effects of ambient temperature.

Results show that the analysis of the continuous data can differ from the nominal value of the snapshot ones, with a maximum deviation of 0.2%. This amount might seem negligible, but the non-linear nature of thermal deterioration (e.g., creep) in parts such as the turbine blades means that equipment might be maintained either earlier or later than the optimal point in time, resulting in additional costs. Moreover, seasonality pattens in derate have been identified, correlating the operational and weather characteristics.





Cardiodynamic adjustments in skilled civil aircraft pilots while unexpected emergency conditions appeared during a simulated flight within a homemade Airbus A300 cockpit

Albeto Concu*, Salvatore Melis, Riccardo Marcello, Antonio Héctor Dell'Osa, Andrea Fois, Antonio De Pau, Filippo Tocco, Damiano Mattana, Paolo Usai, Carmen Serra and Andrea Manuello Bertetto

** Laboratorio de Electrónica Aplicada y Biomedicina - Universidad Nacional de Tierra del Fuego, Argentina*

To highlight which cardiodynamic adjustments take place in civil aircraft pilots when unexpected mechanical accidents occur while they are in flight, in 8 skilled pilots we detected the mean blood arterial pressure (MAP) and heart rate (HR) while a unexpected failing of one engine occurred when they were engaged in a simulated flight with a homemade Airbus A300 cockpit. Comparing these two cardiovascular variables in a simulated flight test, just as when the accident happened, together with the values assessed in a simulated control flight without accidents, by the non parametric Wilcoxon test for paired data it has been found a significant increase of MAP's median (+ 20.3%, P = 0.008) without significant increase in HR one. However, in several tested pilots this sudden MAP increase tended to progressively recover baseline values while simulating the flight despite the event triggering this functional response was still present.

We concluded that the cardiovascular apparatus of skilled aircraft civil pilots adapts in such a way of sudden respond to unexpected emergency conditions by adjusting mean arterial blood pressure for adequate blood flow to limb muscles, and this happens without a concomitant tachycardia response in order to maintain an optimal mechanical/metabolic efficiency of the heart.

Simulation of an Aerospace Electrohydraulic Servomechanism, with different Coulomb Friction models

Parid Alimhillaj*, Luis Lamani, Matteo D.L. DALLA VEDOVA

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Modern flight control system design necessitates using highly detailed models to analyze individual components or subsystems, on the other hand, more fundamental and synthetic models with adequate accuracy are required for preliminary design, monitoring or diagnostic issues.

In this paper we will be focusing in, electro-hydraulic servomechanisms for aeronautical use, given the importance that these systems have nowadays especially for primary flight commands which are depicted as position servo command with high degree of accuracy.

The great variety of configurations and applications, their complexity and the criticality that characterizes this servomechanisms, deemed appropriate to devote particular attention to their modeling and the development of numerical simulation systems models that are versatile and reliable (flexible and easily applicable to different real systems but capable of providing realistic simulations). In particular, in this work are presented two innovative Coulomb friction models which are applied through MATLAB/Simulink block diagram structure to the model of the electrohydraulic servomechanism. The two friction models are foreseen to overcome the problematic of standard models for the friction, giving more realistic results, increasing the accuracy of the simulations.

Numerical simulation of servovalves for electrohydraulic systems: a novel simplified fluid dynamic model sensitive to hydraulic capacity

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Modern flight control system design necessitates using highly detailed models to analyse individual components or subsystems, on the other hand, more fundamental and synthetic models with adequate accuracy are required for preliminary design, monitoring, diagnostics, or prognostic issues. As regards this second category of models, in literature are available several simplified numerical solutions able to simulate, with different levels of accuracy and details, the fluid dynamic behaviours of a given valve geometry. Typically, the aforementioned simplified models calculate the differential pressure regulated by the valve as a function of its spool opening and the flow rate disposed of by the valve itself. In some specific applications (e.g. asymmetric hydraulic jacks, regenerative actuators, or transmissions where the effect of fluid compressibility is not negligible), models with differential pressure output are inadequate. In these cases, new simplified fluid dynamic models must be used to calculate the flow rate delivered by the valve as a function of the spool displacement and the differential pressure. Thus, this paper proposes a new synthetic fluid-dynamic valve model (i.e. a lumped parameters model with a semi-empirical formulation) accounting for the effects of spool position, hydraulic capacity, variable supply pressure and leakage between the output ports that connect the valve to the motor element. The advantages and disadvantages of the suggested model are evaluated, by comparison with other simplified numerical algorithms available in the literature, analysing the corresponding fluid-dynamic characteristics and comparing the dynamic behaviours of numerical models simulating a typical flight control servomechanism. Furthermore, it is validated with a high-fidelity digital twin that replicates valve behaviour while accounting for spool shape, hydraulic capacity, fluid characteristics, and local internal fluid-dynamics (laminar or turbulent regime, cavitation, etc.).

Preliminary Analysis and Optimization via CFD of a Liquid Hydrogen Pressure Regulating Piston Valve

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Due to their high reliability and precision, piston valves are frequently used for pressure regulating applications. Particularly in the aerospace industry, where cryogenic fluids such as liquid hydrogen are frequently used, the design and operation of piston valves become crucial.

The current state of advancement of this technology in the cryogenic field is still in its early stages, owing to the difficulties in designing such complex systems in harsh environments. This justifies the need for further in-depth studies and analysis using CFDs tools and predictive models.

In order to ensure an optimal and efficient use of a piston pressure regulating valve in cryogenic environment, it is necessary to understand the strengths and limitations of this technology in an extreme thermal and mechanical condition.

The presented work concentrates therefore on a preliminary analysis and optimization of a piston valve operating in liquid hydrogen flow field, for pressure regulating applications. Particular focus will be dedicated to the overall dynamics of the main body of the piston, in terms of robustness and controllability of the desired response of the system. The dynamics of the piston within an extremely low-viscous flow, as well as the thermodynamic and fluid dynamic aspects of the valve system, will be discussed.

Simulations of the flow field will be performed through CFD tool, crossing the results with the dynamics of the simulated system response through and implemented Simulink model. The obtained results will be then critically analyzed in order to suggest possible optimization of the valve in the locations where the system is most affected from a thermal and mechanical standpoint.

Preliminary definition of a PHM scheme for electro-mechanical brakes of short-range aircraft

Andrea De Martin*, Riccardo Achille, Massimo Sorli
** Politecnico di Torino, Italy*

The evolution towards "more electric" aircraft has seen a decisive push in the last decade, due to the growing environmental concerns and the development of new market segments (Urban Air Mobility). Such push interested both the propulsion components and the aircraft systems, with the latter seeing a progressive trend in replacing the traditional solutions based on hydraulic power with electrical or electro-mechanical devices. Although more attention is usually devised towards the flight control actuation, an interesting and fast-developing application field for electro-mechanical systems is that of the aeronautical brakes. Electro-mechanical brakes, or E-Brakes hereby onwards, would present several advantages over their hydraulic counterparts, mainly related to the avoidance of leakage issues and the simplification of the system architecture. Moreover, although it is expected a weight increase of the brake, the elimination of the hydraulic lanes would still come with an overall weight reduction. The more difficult heat dissipation, associated with the thermal issues that usually constitute one of the most significant sizing constraints for electro-mechanical actuators, limits so far their application (or proposal of application) to light-weight vehicles. Within this context, the development of PHM solutions would align with the need for an on-line monitoring of a relatively unproven component, in addition to the usual advantages associated with the application of prognostic techniques to aeronautical equipment (lower risk of unanticipated failures, reduced downtimes, improved fleet management and so forth). This paper deals with the preliminary stages of the development of such PHM system for an E-Brake to be employed on a future executive class aircraft, where the brake is actuated through four electro-mechanical actuators. The paper will open with the introduction to the case study under analysis and provide an in-depth description of the simulation model employed to investigate the E-Brake behaviour under different operating conditions. The high-fidelity model of the E-Brake and of its interactions with the aircraft, its wheels and the runway is then presented in detail and used to perform several simulations of landing cycles considering realistic operational scenarios where both the environmental conditions (runway conditions, external temperature) and aircraft parameters (mass at landing, tires type and inflation pressure) are varied according to probability distributions obtained from operative data. Simulation results are then used to foster a preliminary feature selection process, where physics-based indexes are compared and evaluated. Simulated degradation histories are then used to test the application of data-driven fault detection algorithm and the possible application of particle-filtering routines for prognosis.

Passive Pressure Reducer (PPR) through Multiple Annular Chambers for Aerospace and Aeronautical Systems

Arash Safaei*, Matteo D.L. Dalla Vedova, Paolo Maggiore
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Both in the aeronautical and aerospace fields, valves and active components along the fuel distribution system are fundamental. However, most of these components are very complex, expensive, and subject to failure. Redundancy in aerospace and aviation systems leads to a more reliable and robust design, but at the same allows potential optimization and implementation of dedicated components that can lighten and simplify the whole distribution fuel system, still guaranteeing the required performance. Furthermore, due to the importance of fluid properties within the distribution line, the technology employed shall be reliable and efficient, even in harsh environments. For this reason, the introduction of a passive component capable of reducing significantly the pressure of the working fluid has been studied. The Passive Pressure Reducer (PPR) analyzed in this work does not require power, movable parts, springs, or other typical components

installed inside the valves currently used in aerospace and aeronautical systems. Integrating this component into specific locations within the fuel distribution line makes it possible to mitigate the action of specific components (valves, pumps, evaporators). In some cases, pressure-reducing valves can be excluded.

As the fluid flows around and past the multiple annular chambers of the PPR, turbulent eddies will form. As a result of the interference of these chambers with the axial fluid flow, the fluid's pressure will decrease, and energy will be lost. The PPR performance analysis is carried out through CFD simulations to understand better the pressure drop through each chamber and the global pressure jump through the component. The shape and size of the annular chambers affect the flow in terms of pressure and temperature, so it is crucial to design these chambers appropriately to achieve the desired output.

Reducing Ground Impact Hazards of a Solar UAV Through Modeling and Analysis

Francesco-Antonio D'Amico*, Tommaso De Maria, Giovanni Pitarresi, Matteo D. L. Dalla Vedova, Paolo Maggiore

** Leonardo, Italy*

The research described was conducted by a student team dedicated to finding sustainable and long-endurance systems and outlines an innovative solar panel UAV aircraft solution. Our prototype demonstrated the feasibility of the concept, while the second aircraft, currently in the design phase, aims to improve performance further and allow for extended self-powered flight time. The sustainable approach of our project addresses the growing need to reduce the environmental impact of transportation technologies. The main objective of this study is to address the requirements of the Specific Category - Civil Drones regulation, promulgated by EASA, regarding the risk associated with the impact of the aircraft on the ground in case of an in-flight failure. To address this issue, we conducted an in-depth analysis of possible failure scenarios and their consequences on the safety of the aircraft and people on the ground. Furthermore, the team developed models for risk assessment to evaluate the risk associated with solar panel UAV operation.

To mitigate the risk of impact, we considered using a parachute, the effectiveness of which was analyzed using a dynamic model implemented in Simulink. The analysis allowed us to evaluate the semi-controlled descent of the aircraft with the parachute attached, providing valuable information to optimize the safety system further.

In conclusion, our study significantly contributes to ensuring the safety of our model in flight and on the ground through ground-impact risk management while promoting the development of sustainable and innovative solutions in the aviation field.

Space Technologies

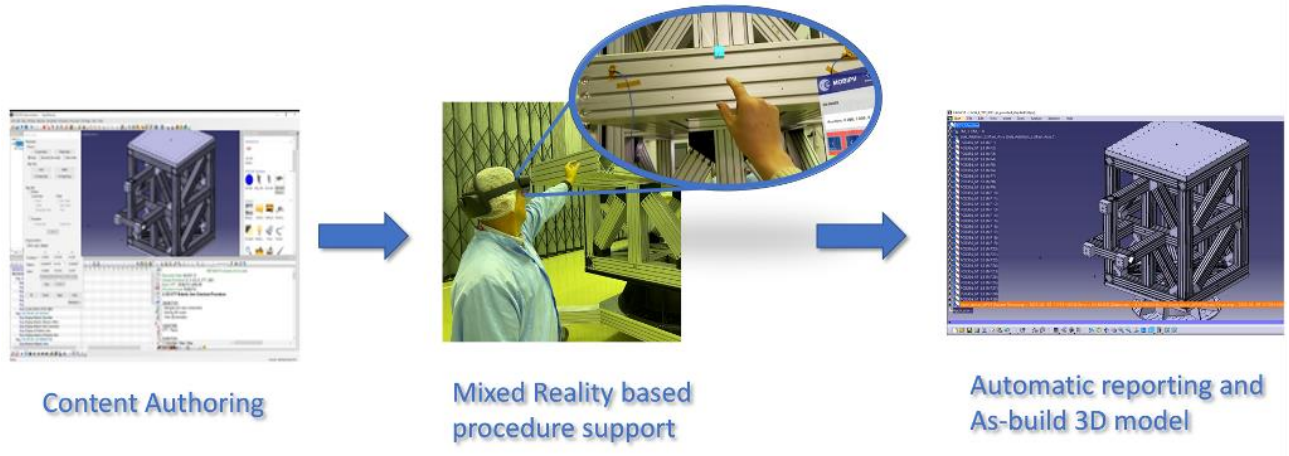
Chaired by:
Dr. Athanasios Dafnis (RWTH Aachen)

Mixed Reality for Assembly, Integration and Testing in Space Domain

Kaj Helin*, Gianluca Casarosa (ESA-ESTEC), Jaakko Karjalainen (VTT), Paul Kiernan (SKYTEK), Timo Kuula (VTT)

** VTT Technical Research Centre of Finland Ltd, Finland*

This abstract introduces the Mixed Reality (MR) system which has been developed for assembly, integration, testing and verification (AIT/V) in the space domain. It has been developed in two European Space Agency's (ESA) projects called: (1) "AROGAN - Augmented reality based orbit and ground applications" and (2) "VirWAIT - Virtual Workplace for AIT & PA Training and Operations Support". The Microsoft HoloLens 2 mixed reality platform was integrated as novel user interface to the ESA Mobile Procedure Viewer system called mobiPV. Developed system was tested in two use cases: 1) MR supported installation of thermocouples on an Heat Plate used as GSE for the Solar wind Magnetosphere Ionosphere Link Explorer – SMILE, and 2) MR supported phase 2 sensor installation on TEDY (TEst DummY) for a vibration test campaign on the Hydra facility. The NR system was also preliminary tested for the configuration of the JUpiter ICy moons Explorer's (Juice) Network Data Interface Unit (NDIU) in preparation to the Thermal Vacuum test campaign held at ESTEC. The first evaluations have been performed remotely via online tools due to COVID-19. All the test and reviews have been performed during 2021 and 2022. The users' overall reaction to the system was positive. The system usability scale (SUS) scores were quite high in both test phases indicating already acceptable system usability. All the individual scores from the final user review reached the range of acceptable usability. It should be noted that the main test users were actual operators performing their real work task. The results of the study suggest that the developed MR-system has potential to become a useful tool for AIV/AIT applications. The MR-system can significantly speed up the current work and provide motivating novel tool for the operators and engineers.



On the use of cup anemometers as wind speed sensors in stratospheric balloon missions

Daniel Alfonso-Corcuera*, Mikel Ogueta-Gutiérrez, Santiago Pindado, David González-Bárcena, Ángel Luis Porras-Hermoso, Sergio Marín-Coca, Juan Zamorano, Ángel Perez

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Stratospheric balloon missions have emerged as a cost-effective alternative to space missions for scientific research and technology development. These missions enable the collection of critical data from the Earth's upper atmosphere while reducing financial and logistical burdens associated with traditional space missions. One key challenge for in these missions is accurately measuring the relative wind speed in the tropopause and the stratosphere. This paper explores the viability of using cup anemometers as wind speed sensors in stratospheric balloon missions, offering an easy-to-calibrate, low-cost, and accurate solution.

The present paper provides a short overview of stratospheric balloon missions and their relevance in atmospheric research, and outlines the challenges and limitations of existing wind speed sensing technologies. The cup anemometer is also described, detailing its working principle, advantages, and limitations, and propose a methodology for incorporating the instrument into stratospheric balloon missions.

To validate the proposed methodology, a stratospheric balloon mission (the Tasec-Lab experiment, onboard a B2Space balloon launched in 2021), was equipped with a cup anemometer whose performance was analyzed. The results prove that cup anemometers can provide accurate and reliable relative wind speed measurements in the tropopause and the stratosphere. Furthermore, the low power consumption and the ease of development and calibration of cup anemometers make them an attractive option for stratospheric balloon missions.

Experimental characterization of a launcher's fairing separation shock and its influence on RF antennas' supporting structures

Carmen Fonseca*, Daniel Alonso, Alain Souza

** RFA Portugal Lda., Portugal*

Fairing separation is a critical event during a rocket's launch as it generates mechanical shocks that can cause partial or total failure of onboard equipment. This study details the experimental results on the fairing separation shock of the launcher RFA ONE and its influence on the supporting structures of RF antennas. To characterize the separation devices' shock, accelerometers were used at multiple points of neighboring structures during fairing separation tests. Moreover, the propagation of the shock on different material structures, such as aluminum, carbon fiber, and Viton® elastomer sealant, was investigated. The results showed that the presence of Viton® sealant increased shock transmissibility. Further investigation was conducted to study the influence of applied torque on the separation locks on the shock levels. The study revealed that higher torques lead to increased shock acceleration magnitudes. Finally, the paper provides recommendations for reducing the shock levels. The experimental results and recommendations presented in this paper provide valuable insights for launcher designers and manufacturers to ensure the safety and reliability of shock sensitive components during flight.

Analysis of Film Cooling for a 3kN LOX/butane Demonstrator Engine

Zoe Ashford, *Cranfield University, United Kingdom*

Regenerative cooling has been the primary cooling method for every modern launch vehicle engine, except for the Viking: a film-cooled (with ablative throat) N2O4 / UH25 engine used on the first stage of the Ariane rockets 2-4. Despite this, film-cooling as a stand-alone cooling method has traditionally been considered insufficient for the high combustion temperatures and long burn times associated with launcher engines.

For small launch vehicles, the regenerative cooling pipework can comprise a significant proportion of the overall engine mass, by contrast, a film-cooling injection manifold may be much lighter. Therefore, this report explored the feasibility of a solely film-cooled engine at the demonstrator scale (3 kN). A wide range of liquid oxygen (LOX)/butane engines were modelled and from this a relationship was determined to predict chamber wall temperature for a given oxidiser-to-fuel ratio (O/F), chamber pressure, and amount of film cooling. Notably, this equation was found to apply to both a 3 kN and a 30 kN engine. Numerical modelling of engine specific impulse (Isp) using this equation then found the conditions yielding optimal engine performance. From these, the engine detailed design was conducted.

Qualification test campaign of RFA one fairing engineering model

Pedro Meireles*, James Hooton, Luis Colaço, Daniel Alonso, Luis Pinheiro
** RFA, Portugal*

The fairing is an important element of the rocket as it protects the payload from the external environment during the most aggressive phases of the flight. A test campaign was developed with the aim of qualifying the fairing structure of the RFA One. This test is intended to simulate the quasi-static loads of the most critical phase during flight. A FEA model was developed to identify the most critical phase of flight and to identify the quasi-static reactions that replicate the flight loads. Based on these reactions, the loads and test levels were defined. The test results were compared with the FEA data in order to correlate and improve the model. The static test was successfully performed at acceptance and qualification Level 2. The load and strain results indicate that the DLL was achieved and exceeded by a factor of 1.11, while the fairing maintained its functionality and key performance. This paper presents the most relevant results of the test, discusses the results compared with the FEA model and summarizes some lessons drawn from the test campaign.

Development of a Multidisciplinary Framework for Next-Generation Launch Vehicles Design

Girolamo Musso*, Iara Figueiras, Héléna Goubel, Alain de Souza, Frederico Afonso, Fernando Lau
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The space sector is currently entering a new era, where small satellites are increasingly being used in all the standard satellite applications. This era is characterized by the commercialization and development of the industry, even among countries and institutions with no previous experience, and by increasing economical and environmental concerns regarding rocket launches, so far overshadowed.

A multidisciplinary framework to design and optimize space vehicles will be proposed. It will emphasize the importance of considering the entire value chain along the design phase, from materials and manufacturing processes to end-of-life disposal. Further emphasis will be given to reusable launch systems, which can significantly reduce the environmental impact of launches and lower the cost of space access. By combining technological innovation and environmental sustainability, a more resilient and responsible space industry can be created.

The main scope of the framework will be to couple all the disciplines relevant to the space vehicle design in a modular way. This will allow the users to create custom discipline blocks, allowing as well for the inclusion of cost, manufacturing and sustainability considerations. The main focus of this document will be the "trajectory and control" discipline block and its coupling with the aerodynamics, structures and propulsion blocks.

Optimization techniques will be used to optimize the design and aid the designer in the trade-off studies. To demonstrate the possible use of this framework, a design concept for a reusable conventional microsatellite launch vehicle will be proposed and studied.

Overall, this multidisciplinary framework aims to provide a comprehensive approach to designing next-generation launch vehicles that meet the demands of a rapidly changing market while also minimizing their environmental impact.

On the Design of Next-Generation Launch Vehicles: A Multidisciplinary Framework for a Reusable Vehicle for Multipurpose Missions

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The commercial space launch sector is currently undergoing a significant shift, with increasing competition and demand for launch services, as well as growing concerns about the environmental impact of rocket launches. To address these challenges, within the New Space Portugal project scope, a multidisciplinary framework for designing and optimizing new launch vehicles is proposed.

Creating a more resilient and responsible space industry can be achieved as emphasized by the framework. It underscores the significance of taking into account the complete value chain throughout the design of launch vehicles, encompassing materials, manufacturing processes, and end-of-life disposal. Moreover, particular attention is given to reusable launch systems, which have the potential to considerably diminish the environmental consequences of launches and decrease the expense of accessing space.

Significant emphasis has been placed on the Propulsion aspect of the framework, along with the inclusion of LCA (Life Cycle Assessment) considerations. Optimization techniques will be employed to enhance the design and assist designers in conducting trade-off studies. As an illustration of the framework's potential application, the objective is to develop design concepts for a versatile Reusable vehicle capable of executing multipurpose missions, including the ability to alter orbits and perform on-orbit servicing, with partial or complete reusability.

In essence, this comprehensive, multidisciplinary framework aims to address the evolving demands of the market by designing next-generation launch vehicles that not only meet these demands but also minimize their environmental impact.

Design and testing of an HDPE - N2O hybrid rocket engine

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Hybrid propellant rocket engines have gained considerable attention with the potential of combining solid and liquid propellants and inheriting the advantages of both configurations. The ability to control thrust levels and provide throttling makes it better than solid-propellant engines, while the simplicity of its design is an advantage over liquid-propellant engines. Enhanced safety

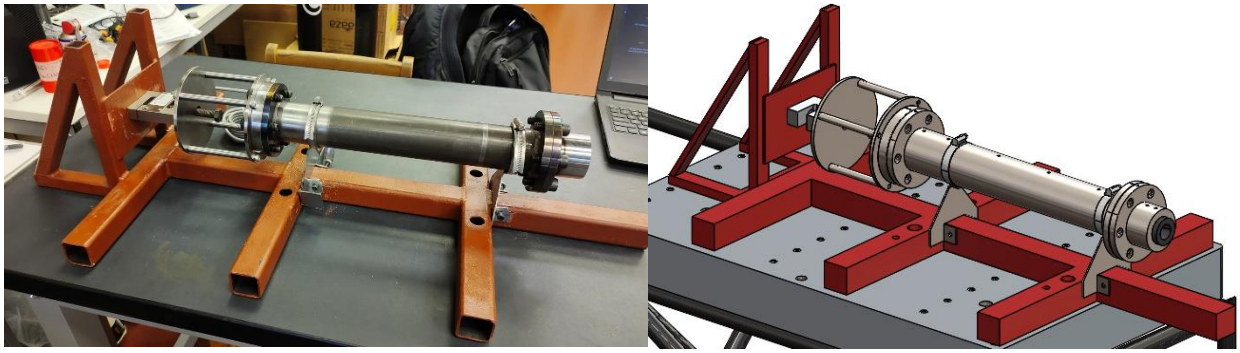
features, lower cost and better performance controllability, have brought much interest to hybrid propellant rocket engines.

Hybrid engines are well-suited for small to medium-sized launch vehicles, testing, and research purposes. Hybrid engines are recently finding their applications for multiple rocket launching service providers to be used for sub-orbital flights for commercial space travels and scientific research of the sub-orbital environment. Hybrid engines have specific applications, such as long-duration missions and in-space propulsion systems, where they are a better option than solid propellant and bi-propellant liquid propellant systems. This work focuses on developing, designing and testing a 300 N thrust class hybrid rocket engine.

The research objectives targeted for the current work are assessing the impact of the Pre and Post combustion chamber lengths selection on the overall motor performance, assisted by CFD simulations, and developing an actual laid-back test engine, providing exploration scopes for design, manufacturing, integration of different sub-systems, and hot test firings.

The designed rocket engine comprises a small combustion chamber with axial support from the L-shaped engine mount at the back and planar supports positioning the chamber horizontally to the ground. The project highlights the initial design trade study on the fuel and oxidizer choices and details on the chamber ignition and purging. The ignition process by spark ignition method will be achieved remotely by igniting a fuse that passes into the combustion chamber through the nozzle. Gaseous nitrogen (N2) will be used as the purging gas. The feed line system incorporates multiple safety features, such as valve isolation between the tanks and the chamber, as well as a detailed description of the safety measures adopted in the design of the feed system. The engine shall employ data acquisition systems: thermocouples over the combustion chamber length and nozzle, pressure transducers for internal combustion chamber pressure measurement, and a sensitive load cell measuring the thrust values for the entire test firing duration.

In this work, the primary outcomes of this experiment will be shown with the aid of real-time sensors and high-definition cameras. The obtained results shall provide information on the thrust levels from the load cell, temperature gradients from the thermocouples, pressure readings from the pressure transducers, plume properties from the high-def camera, and post inspections portraying the effect of hybrid propellant rocket engine firing on the structure and components.



Combustion Performance of zero-carbon fuels in a Shaped Micro-Combustor for aerospace propulsion applications.

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Microcombustor applications are being investigated in aerospace propulsion field, electricity and heat production.

The research effort towards the microcombustor field has recently increased due to the demand for high-performance systems in microelectromechanical and micro power generation for portable generation devices, unmanned aerial vehicles, micro-satellite thrusters, and micro chemical reactors and sensors. To address rising concerns about pollutants from fossil sources, zero-carbon fuels such as hydrogen and ammonia have been considered as an alternative in microcombustion processes.

In a microcombustor, the surface area-to-volume ratio is much higher compared to conventional combustion systems, resulting in faster heat transfer rates and more intense combustion reactions. As a result, the combustion of hydrogen and ammonia can occur more quickly and with greater efficiency in a microcombustor.

However, achieving efficient mixing of fuel and oxidizer in a microcombustor can be challenging due to its small size, particularly for highly reactive fuels like hydrogen and ammonia.

The unique properties of microcombustors can lead to differences in the combustion behaviour of hydrogen and ammonia compared to larger-scale combustion systems. Therefore, studying the performance of these fuels in microcombustors is important for developing clean energy technologies.

To explore the thermal performance and pollutant emission characteristics of premixed ammonia/air and hydrogen/air combustion in micro-scale combustors, a numerical investigation was conducted on a Y shaped micro-combustor.

Development of a highly reconfigurable and modular computer system for suborbital rockets and micro launchers

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This article presents the development of a modular on-board computer system for a suborbital rocket in accordance with the in-house developed OBC-K architecture. The computer is made of independent modules, each one responsible for performing a dedicated task. This architecture is a great answer to the needs of an ever-changing market and specific demands of different customers. The ability to easily reconfigure the system or add new functionality without the need to make any changes to the existing solutions is a great advantage that streamlines the development process.

The computer has been flight proven during last year's ILR-33 AMBER 2K test flight. Moreover, environmental tests have been performed to assess the operation of the computer in harsh environments, such as wide operating temperature range, vibration or humidity. Throughout the whole process, the computer has proved to be a highly reliable and robust system well suited to the conditions of suborbital space flight.

Besides the launch and tests campaigns, the work involved the definition of the OBC-K standard and the development of multiple different boards compliant with it. The final product includes control, memory, navigation or power modules capable of handling multiple tasks aboard the vehicle. The development and integration of new modules is very straightforward thanks to the standardized interface. Multiple OBC-K devices can be linked, providing the benefits of a distributed architecture.

The article focuses on the current state of the OBC-K standard, the developed boards and tests as well as lessons learned throughout the whole process. Different configurations are discussed, proving the merits of the proposed architecture. Plans for future developments are briefly presented and discussed.

Design of a LEO engine control unit for a space-constrained environment

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The growing demand for satellite imaging and space communication has spurred numerous new small and nano satellite constellation projects. Many of those need some form of propulsion for orbit and attitude control. Mass and size constraints make a one-size-fits-all approach almost impracticable, and even specific solutions can often be challenging to develop.

The goal of the SAT-ECU project is to develop an engine control unit (ECU) for a Low Earth Orbit small satellite with a planned lifetime of 2 years. Its key functionalities include measuring the propellant pressure and temperature, tracking the propulsion system health and controlling the actuators. The main challenge of the project is to fit the system in the limited space available, while still providing all the necessary functionalities and ensuring robustness.

This paper describes the design of an engine control unit for a Low Earth Orbit small satellite. Key requirements are presented, along with the system architecture developed from them. The SAT-ECU design is described, with focus given to issues created by the small size of the device. The approach to system reliability is discussed and an overview of lessons learned so far is provided.

Electric propulsion system for Nano Satellites

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The number of small satellites is increasing significantly over the years. It has been estimated that 15.000 satellites are going to be send to space between 2021 and 2030. About 90 % of them are going to be small satellites.[1] Those can be produced fast and cost efficient, which opens up new possibilities for research projects or commercial ones. To reduce weight and volume is always relevant for space missions which is where an electric propulsion system can play an important role.

In the DLR project DEEP an electric propulsion system is build up to demonstrate the potential for new nano satellites. Compared to chemical ones, this system can improve fuel efficiency and mass savings even further. The base of the system is an electrode plasma heater, which allows the use of alternative and cheap propellants such as argon. By using intermittent operation of the propulsion, the thermal control of it will improve. Beside all the positive aspects of using electric propulsion there is one drawback coming from the intermittent operation: a high electric current stressing especially the energy source of small satellites. A way out of this situation is the use of a so called supercapacitor, an energy storage able to provide high electric currents. Adding a second energy source brings with it an increase in the overall system mass and volume. To reduce the additional mass, we will introduce structure integrated supercapacitors. They can relieve the energy system of satellites by providing the electric energy for the ignition and simultaneously act as structural part of the propulsion itself, which helps decreasing the overall system weight.

In this talk the project DEEP is being presented with the focus on the electric energy system. First integration strategies and the system architecture of the energy storage will be shown to present the way of a novel propulsion system from the lab to an in orbit demonstrator.

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Hybrid Rocket Performance Modelling using Siemens AMESim

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Hybrid rocket engines use both liquid or gaseous oxidizers, and solid fuels to generate thrust. These engines offer several advantages: compared to solids, they are safer since combustion can be stopped anytime by controlling the oxidizer flow rate. Additionally, they have higher specific impulse. Compared to liquid rocket engines, hybrids have better controllability because there is only one propellant feeding line to control and regulate the thrust. Hybrid rocket engines, however, have significant drawbacks. They are less efficient than liquid rocket engines and they also have more sophisticated feed systems than solid rocket engines, which can make them more challenging to design and run. Due to their potential use in space travel, satellite launches, and other space exploration missions, hybrid rocket engines have recently attracted renewed interest. The design and performance of hybrid rockets are constantly being improved by engineers to address their problems and capitalise on their special qualities.

Prior to conducting rocket engine tests, model development is essential. Before spending money on expensive and potentially risky testing procedures, it enables engineers to simulate and analyse the engine's behaviour under various conditions to find design flaws and areas for improvement. This approach helps to reduce the cost and time involved with testing by limiting the number of physical tests needed. Hence, model development is a key phase in the rocket engine design and development process that saves time, money, and increases safety.

In this paper, we propose a comprehensive modelling and validation for designing hybrid rocket engine that includes feed system, combustion chamber and nozzle analysis. The model is developed in SIEMENS AMESim and validated by comparing it with available literature data. The validation process ensures the accuracy and reliability of the model. Siemens AMESim is a versatile and powerful system simulation software tool used in numerous sectors to design, simulate, and evaluate complex dynamic systems. In addition to pre-built models and a variety of modelling and simulation methodologies, it offers an intuitive user interface. Engineers may build and improve control systems for their systems using Siemens AMESim, which offers sophisticated modelling and simulation capabilities.

To highlight the usefulness of the suggested methodology, we give different case studies for different types of oxidisers used in hybrid rocket engines. Models are developed based on specific requirements and they are validated using available literature data. The proposed modelling and validation framework provides a comprehensive approach to designing and validating hybrid rocket engines.

Radiation protection methods for a suborbital aircraft

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The aim of SALTO'S work is to study possible radiation protection system to shield Elysium aircraft during a suborbital flight. Deep research on space radiation, their intensity and penetrating power was carried out, into compare such values with the recommended dose for the human body.

First of all, a sandwich panel was designed as passive solution (more traditional and reliable), designed to both shield the structure and withstand the flight loads. In this way, it was possible to have a solution with no weight penalty on the vehicle. The selected materials are hydrogen-rich materials, as electron-rich materials are the best choice for space radiation shielding. The external

faces of the sandwich panel are a layer of a composite material with epoxy resin as matrix and long carbon fibres, while the core is a hydrogen-rich benzoxazine composite reinforced with ultra-high molecular weight polyethylene. Every layer has a specific thickness that was optimized using MATLAB, to better shield the aircraft.

Moreover, to thermally protect the structure, a thermal protection system was designed making use of a protective coating for the epoxy layers that are exposed to the external environment. The following part of the passive solution focused on the windows: the team chose triple-pane windows, whose layers are in quartz fused, borosilicate and aluminosilicate glass. The gap between the external and the middle panes is a vacuum, while between the middle layer and the inner one there is an inert gas. Again, the thickness of each layer was optimised using MATLAB. The results were validated by OLTARIS. The team researched about active shields, based on the use of an electromagnetic field to deflect charged particles from the spacecraft. This solution has some advantages like a long-lasting effect, adaptability, and low maintenance costs. Three different configurations for this type of shield were defined: toroidal, coupled spires and concentric solenoids. For those layouts, the installation takes place between the passenger's cabin and the skin of the spacecraft. The toroidal layout can offer a wide protection area and a uniform magnetic field, but it can be more complex, heavier, and more expensive than other configurations. The coupled spires, on the other hand, can be simple, with good energy efficiency and flexible but it can create non-uniform magnetic field within the protected area. The solenoid layout was a more reliable and simpler solution, and it was therefore the one chosen by the team. Besides that, the team also studied about which materials would fit properly the shield and the superconductor YBCO showed a promising behavior. Lastly, some requirements for the cooling system of the shield were defined, which are: select a refrigerant, purchase a compressor, choose a heat exchanger, install the solenoids, and add a control system.

Aircraft Design

Chaired by:
Prof. Massimo Viscardi (University of Naples "Federico II")

Business Jet Conceptual Design: A Cost-Driven Approach

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Business aircraft can be classified looking at propulsion (piston engines, turboprop, jet) or the applicable certification category, or the design mission, characterized by its range and payload. Particularly, a classification for business jet (BJ) aircraft that is often used refers to six different classes, ranging from Very Light Jets certified under CS23, with up to eight passengers and up to 1 200 NM long missions, to Long Range Jets certified under CS25, with up to 19 passengers and up to 6 500 NM long missions. A further class is represented by Executive Airliners, i.e. airliners converted to business aircraft.

The present work illustrates a cost-driven approach to the conceptual design and preliminary sizing of a BJ that allows a reduction of operating costs when compared to existing aircraft, while enabling an extended operational usage that goes beyond the traditional classification mentioned above. This is applied to a range of missions of interest from mid-range (4 000 NM) to long-range (6 500 NM). Based on direct contacts with BJ operators and a thorough review of publicly available data, it can be argued that the average amount of passengers carried over long-range flights is equal to 4-5 people, making a 10-to-19-seat aircraft much too large. Therefore, a new BJ concept is developed,

with maximum payload of ten passengers and a design mission consisting in a range of over 5 500 NM with six passengers.

The preliminary aircraft sizing has been carried out using HYPERION, a general, extensively validated preliminary aircraft sizing methodology developed at Politecnico di Milano. Some technical innovations, reflecting the aerodynamic and propulsive improvements that have already been introduced on the latest commercial jets, have been considered. The result is the preliminary sizing of the New Business Jet (NBJ) concept. Figure 1 shows a comparison in economic performance between the NBJ and two reference designs, the Medium Range Business Jet (MRBJ) and Long Range Business Jet (LRBJ), both sized with HYPERION to represent suitable competitors. As apparent, the NRJ can perform long-range missions with sensibly lower costs than the LRBJ, while keeping slightly cheaper than the MRBJ on mid-range missions.

Rapid Aircraft-Level Evaluation of Revolutionary Propulsion Concepts

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Advanced propulsion system technologies remain a key factor in ensuring the aircraft energy and emission reductions needed in order to achieve aviation's long-term climate and sustainability targets. The required step improvements in system efficiency and emission characteristics demands for technological options that go clearly beyond the classic technological evolution. As a result, alternative types of energy have entered the serious discussion of potential systemic solutions for aviation propulsion and power, alongside with revolutionary technological options, such as advanced fuel cells or radical heat engines. Especially, the prospect of green hydrogen as a possible energy source for aircraft propulsion and power has recently been spurring new ideas for revolutionary power plant systems (e.g. [1-3]). A quick incubation and rapid initial technical assessment of such new ideas is necessary in order to identify suitable candidate solutions for subsequent speedy technology maturation targeted to meet the mid-century market demands in commercial air transport.

In order to serve the need for a swift and integrated evaluation of revolutionary propulsion system options, Bauhaus Luftfahrt's existing in-house Aircraft Design Environment (BLADE) [4] has been complemented by a set of simplified methods for the pre-conceptual scaling of advanced aircraft. With a reduced set of design parameters and extremely rapid response times, this "Level 0" model dubbed SAS (Simplified Aircraft Scaling) enables a particularly quick gain of basic knowledge on integrated system efficiency and emissions behaviour. As well, it provides a solution for the immanent starting value problem associated with more sophisticated aircraft conceptual and pre-design tooling.

In this contribution, the methodological foundation of SAS is introduced and its capabilities are demonstrated based on insightful case studies. Therefore, the applied top-down approach to resolving aircraft vehicular efficiency is discussed, including a unified formulation of propulsion system efficiency, aircraft aerodynamic efficiency and aircraft mass breakdown mapping. A library of aircraft and propulsion system design and performance heuristics reflecting key characteristics of state-of-the-art subsonic fixed wing air transport vehicles is introduced. The adopted aircraft and propulsion system design scaling procedure is explained as well as the approach to mapping the integration of advanced technologies. Results for representative aircraft-level validation cases are provided. Beyond the baseline setup, a number of selected methodological extensions are highlighted including capabilities for the evaluation of fuselage Boundary Layer Ingesting (BLI) propulsion integration [5], liquid hydrogen fuel options as well as fuel cell – gas turbine hybrid propulsion systems [1]. To round of, initial assessment results for three hydrogen fueled airliners with revolutionary propulsion system architectures are presented that span the regional, short-range and long-range market segments.

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BLADE: A Modular Environment for Traceable and Automated Aircraft Design

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This paper introduces the Bauhaus Luftfahrt Aircraft Design Environment (BLADE), which facilitates the investigation of novel technologies on aircraft level and has been developed with a special focus on modularity, as well as providing a traceable aircraft design process and its automation. The first aircraft to be designed with BLADE were conventional kerosene-powered short-to-medium-range and regional aircraft utilizing turbofan, respectively turboprop engines and represent the aircraft application focus of this paper. Herein, specifically, Airbus-A320-class and ATR-72-class aircraft are used to illustrate the structure, data exchange philosophy, overall methodology, and underlying methods of BLADE. Furthermore, the software development fundamentals that underpin its architecture are presented. The paper then concludes with a summary of the unique characteristics of BLADE, a description of its current development activities and challenges, and an outlook on future development plans.

Within BLADE, the aircraft design disciplines or aircraft components are covered by dedicated modules programmed in Python, which are communicating via the Common Parametric Aircraft Configuration Schema (CPACS) [1] and executed sequentially. Due to the CPACS-based modular architecture, the design process can be easily customized, and the associated flow of information combined with the used iteration and convergence methodology allows for a full understanding of how an aircraft design is achieved. The architecture of the modules enables a complete automated aircraft design process, e.g., by starting from an A320ceo-class aircraft input file, subsequently the related output file, an A320neo-class aircraft, its year-2035-version, and a concept aircraft, including parametric studies, are automatically derived. This degree of automation significantly reduces manual work and potential errors during the design process. BLADE's modules feature well-known semi-empirical and in-house-developed sizing and calculation methods, as well as detailed table- or neural-net-based engine models and a mission analysis based on the equations of motion.

A method for requirements analysis using probabilistic machine learning

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We present a methodology for rapidly testing "what-if" scenarios in the early conceptual design stages. This comes in the aid of engineers and stakeholders for better understanding the impact setting requirements have on the feasibility and success of the design. Data-driven surrogate methods and probabilistic approaches are employed in a proof-of-concept example for aircraft design.

Enhancing Reliability in Airframe Structures through Digital Twins and Model Updating Techniques

S.M.O. Tavares*, J.A. Ribeiro
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In the realm of airframe structural design and assessment, numerical modeling tools have become essential. These tools allow for the analysis of intricate structural parts, incorporating diverse material properties and loading scenarios while minimizing the need for extensive experimental testing. However, the current models face limitations in accurately capturing the nuanced real-world behavior of aircraft structures. Challenges arise due to factors such as material property scatter, manufacturing-induced geometric deviations and residual stress, and other effects that can only be estimated or fully captured during service.

This work aims to evaluate and discuss the potential impact of digital twins on addressing these limitations and enhancing the reliability of numerical models through model updating techniques. Digital twins, virtual replicas of physical assets or systems, can improve the solutions to overcome the gaps between numerical models and real-world behavior. By integrating and processing data from sensors, operational inputs and historical data, digital twins provide a more comprehensive understanding of the structural behavior throughout an aircraft's life cycle. With the exploitation of machine learning techniques, as graphical neural networks (GNNs), recurrent neural networks (RNNs) and physics-informed neural networks (PINNs), new methods for model calibration and validation combining experimental inputs with simulation models. By leveraging these techniques, digital twins can be continuously updated and refined, allowing for more accurate predictions of structural behavior and performance.

These models can enable real-time monitoring, performance optimization, and decision support. In addition, integrating sensor data and model updating techniques, digital twins have the potential to improve the design, evaluation, and maintenance processes. They can provide valuable insights into the structural health, safety, and reliability of aircraft structures, leading to more efficient and safer operations.

LIGHTWEIGHT AND LOW COST TECHNOLOGY FOR MANUFACTURING OF A GENERAL AVIATION AIRCRAFT CONTROL SURFACES

Massimo Viscardi, *University of Naples "Federico II", Italy*

The present work is connected to a research project that faces the study of low-cost manufacturing technologies and processes of aeronautical structures made of composite material, referring to aircraft belonging to General Aviation (GA). In the specific, the main purpose of this work consists in

the design and manufacturing of the vertical control surface of an aircraft belonging to the VLA class using Light Resin Transfer Moulding (LRTM). Starting from the geometrical characteristics of the control surface and the peculiarities of the related aircraft, the relative load distribution has been calculated according to the requirements expressed in Appendix B of CS-VLA regulations. Using a numerical simulation software for finite element analysis, the load, calculated by the procedure in question, has been used as input to the FEM model for the purpose of structural design, i.e. for the choice of the materials and of an appropriate stacking sequence. Once the model has been completely defined, it has been possible to design and to fabricate the moulds for the following phase, which consists in the production of the prototype.

Following the production process, the last part of the work focuses on the preparation and the implementation of an experimental campaign that aims at verifying the quality of the infusion process (C-Scan) and of the structural properties of the component, paying attention to the comparison with the previously obtained numerical results.

Ultra-Efficient Short and Medium Range (SMR) aircraft

Chaired by:
Mr. Xavier Hue (AIRBUS)

SMR ACAP: The Clean Aviation Short & Medium Aircraft - Aircraft Architecture Project

Xavier Hue, *Airbus Operations, Bremen, Germany*

In the context of the European Green Deal and the need to achieve climate neutrality by 2050, the SMR ACAP (Short and Medium Range - Aircraft Architecture Project) will integrate new, disruptive, aircraft technologies coming from the linked SMR projects to deliver net greenhouse gas (GHG) reductions of no less than 30% compared to 2020 state-of-the-art, support the launch of a new product by 2035 (to replace 75% of the fleet by 2050), and exploit the synergies with other national and European related programmes.

The SMR Aircraft Architecture and Technology Project (SMR ACAP) shall be the central place to assess and integrate all technologies at aircraft level, from across the projects in the SMR pillar. Establishing the link to projects with relevant technologies in the other Clean Aviation ""Pillars"" and transverse projects associated with novel certification methods is part of the work plan of the project. Two main types of SMR concept aircraft will be established to assess the different technologies integrated at aircraft level either for an "Ultra efficient SMR" and a "H2 enabled SMR". The setup of the ACAP project is tailored to steer and manage the definition of the targeted SMR aircraft configurations with all key performance features required for the SMR architecture.

In order to accelerate the maturation of the SMR aircraft technologies, ACAP will provide a digital collaborative framework with tools, means and skills enabling to continuously link all R&T activities within the SMR pillar (strongly linked to other Clean Aviation pillars) to deliver solutions meeting the Clean Aviation high level goals. Coordinated by Airbus, the project consortium is composed of a well balanced mix of innovative actors from the aeronautical industry (including SME) covering almost all technical disciplines of aircraft R&T complemented by a strong foundation of Academia and Research and Technology Organisations, which will be further widened with the planned linking to other CA projects.

Started in January 2023, the ACAP project is aiming to identify "best athlete" SMR aircraft concepts before the end of CA phase 1 by the end of 2025 and, based on sound analysis of the expected impact with respect to the CA objectives, to propose which technologies shall be further developed

and demonstrated in a Clean Aviation phase 2.

The presentation will provide information about the progress of work defining the Clean Aviation SMR concept aircrafts, the establishment of a common backbone of tools and formats to be able to link the activities of the different projects developing technologies associated with the CA SMR aircraft, as well as on the chosen approach for the cooperation between the projects targeting to integrate and assess the "impact" of technologies combined at aircraft level in a common, synchronized roadmap.

Project: UP-WING: Ultra Performance Wing - Challenges and opportunities of an high aspect ratio wing

Jens Konig*, Bruno Stefes

** Airbus Operations, Bremen, Germany*

The Ultra Performance Wing project ("UP wing") will validate, down select, mature and demonstrate key technologies and provide the architectural integration of "ultra-performance wing" concepts for targeted ultra-efficient Short/Medium Range aircraft (SMR).

Independent of future energy carriers, energy efficiency is continuing to be a crucial challenge for future aircraft design. The demand for zero net emissions of greenhouse gases by 2035 is only achievable if the energy consumption is massively reduced. The wing plays the dominating role for a further drastically drag & weight improved aircraft. The more the product concept may change the more the wing design concept has to be adapted.

The two main challenges will be addressed covering most of the potential design space:

Configuration 1: An aircraft equipped with a novel ultra-high performance wing using SAF (sustainable "kerosene-like" fuels)

Configuration 2: An aircraft equipped with a novel ultra-high performance wing exploiting non-drop-in fuels such as hydrogen in cryogenic storage will be investigated, including different types of propulsions

Both configurations will contribute to the targeted product high level ambition of minimum 30% fuel burn reduction at aircraft level compared to a 2020 reference state of the art aircraft with conventional technologies, as defined SMR-ACAP (Short and Medium Range - aircraft architecture Project)

Project: FASTER H2: H2 technology integration - Short and Medium Range aircraft fuselage

Alexander Horn, *Airbus Operations, Hamburg, Germany*

The FASTER-H2 project will validate, down select, mature and demonstrate key technologies and provide the architectural integration of an ultra-efficient and hydrogen enabled integrated airframe for targeted ultra-efficient Short/Medium Range aircraft (SMR), i.e. 150-250 PAX and 1000-2000nm range.

To enable climate-neutral flight, aircraft for short and medium-range distances have to rely on ultra-efficient thermal energy-based propulsion technologies using sustainable drop-in and non-drop-in fuels. Besides propulsion, the integration aspects of the fuel tanks and distribution system as well as sustainable materials for the fuselage, empennage are essential to

meet an overarching climate-neutrality of the aviation sector. Green propulsion and fuel technologies will have a major impact on the full fuselage architecture, including the rear fuselage, the empennage structure as well the integration of systems for the chosen energy source are concerned (H2, direct burn, fuel cell). Not only do the specific properties of hydrogen necessitate a re-consideration of typical aircraft configurations, requiring new design principles formulation and fundamental validation exercises, but they also raise a large number of important follow-on questions relating to hydrogen distribution under realistic operational constraints and safety aspects. The project will explore and exploit advanced production technologies for the integrated fuselage / empennage to reduce production waste and increase material and energy exploitation with Integrated Fuselage concept selected (maturity TRL3/4) until end of first phase in 2025. An anticipated route to TRL6 until end of the Clean Aviation programme in 2030 will ensure entry-into-service in 2035.

Project: HEAVEN: Delivering a step change in efficiency and an optimum propulsion architecture for net zero carbon fuels

Geoff Holt*, Craig Bemment

***** *Rolls-Royce, Derby, United Kingdom*

In 2014 Rolls-Royce announced UltraFan® a new engine architecture to deliver a step change of 25% efficiency compared to the Trent engine, a goal that this now largely in reach. Since UltraFan was defined the imperative for aerospace to transition more quickly to net zero carbon and reduce impact on the environment has increased.

To deliver net zero carbon aviation requires the use of alternative fuels such as Green Hydrogen and Sustainable Aviation Fuel (SAF) combined with the power density of a gas turbine engine for the Small and medium range (SMR) market and above. These fuels require significant energy and investment to produce and in the case of Hydrogen, aircraft fuel storage is more challenging. Therefore, it is more important than ever to minimise the amount of fuel required for aircraft propulsion and systems by optimisation of the gas turbine engine and reducing wasted energy across the propulsion system.

This presentation will explore how the HEAVEN project led by Rolls-Royce will evolve the UltraFan through technology insertion to deliver a further step change in efficiency and how the architecture is scalable to meet different aircraft requirements and needs of different markets and deliver a significant impact on emissions from aviation. It will look at how the architecture can be adapted to take advantage of the properties of net zero carbon fuels such as Hydrogen to improve efficiency, how this can be combined with Hybrid electric technology to reduce wasted energy and how this can achieve the 20% fuel burn reduction targeted by the Clean Aviation Strategic Research and Innovation Agenda (SRIA) for SMR propulsion.

Project: SWITCH: The Sustainable Water-Injecting Turbofan Comprising Hybrid-Electrics

Sascha Kaiser, *MTU Aero Engines, Germany*

The European Green Deal proclaims the goal of climate neutrality by 2050. For the aviation sector, the Clean Aviation programme fosters innovation to enter into the market by 2035 on a new short-medium range aircraft to significantly reduce avia-tion's climate impact. This requires not only a major reduction in fuel burn, and thus CO_2, but also the non-CO_2 effects coming from NOx emissions and contrail formation.

The project SWITCH - Sustainable Water-Injecting Turbofan Comprising Hybrid-Electrics - aims to answer this challenge. SWITCH develops technology for short-medium range air transport by

developing a revolutionary sustainable gas turbine propulsion system – the hybrid Water-Enhanced Turbofan (hybrid WET). It boosts WET technology with hybridization (Electrical Aircraft Propulsion – EAP) to improve energy efficiency by 25% and reduce climate impact by 75% (using net zero-CO_2 sustainable aviation fuel, 50% with conventional Jet-A kerosene) compared to a state-of-the-art engine. It is the only concept to significantly reduce all three major warming effects on our climate: CO_2 through unmatched efficiency, NOx through wa-ter injection in the combustor, and contrails through particle removal and water re-covery. Local air quality and noise levels around airports are improved through elec-tric taxiing.

The SWITCH project will meet this challenge with a global consortium led by MTU with Airbus, Pratt & Whitney, Collins Aerospace, and GKN Aerospace. SWITCH will mature the hybrid WET's two key innovation concepts by 2025: The WET engine to technology readiness level (TRL) 4 through validation of its key enabling technologies and the EAP system to TRL 5 through flight-ready engine ground demonstration of the full propulsion system.

Hybrid-electric flight

Chaired by:
Prof. Andreas Strohmayer (University of Stuttgart)

An overview of the possibilities, current status, and limitations of battery technologies to electrify aviation

María Zamarreño-Suárez*, Francisco Pérez Moreno, Raquel Delgado-Aguilera Jurado, Rosa María Arnaldo Valdés, Víctor Fernando Gómez Comendador

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In terms of Environmentally Friendly Aviation (EFA), the EU's goals are ambitious. The current time horizon for achieving a revolution in sustainability is 2050. To reach the envisaged targets, it will be essential to develop new propulsion technologies (electric and hybrid thermoelectric) and new fuels (e.g., hydrogen or sustainable fuels). The options available are many, but so are the technological challenges that need to be overcome to implement them.

Among the most relevant aircraft application technologies is the use of batteries. Beyond conventional aircraft, the use of this type of technology also has great potential within urban air mobility.

This work aims to discuss the feasibility of including battery technologies to electrify aviation, highlighting their great potential, but also outlining some of the main technological challenges that will be faced in the coming years. The work is framed within the EFACA (Environmentally Friendly Aviation for All Classes of Aircraft) project, a project funded by the European Commission through the Horizon Europe Programme, which focusses on the analysis and development of new technologies to make aviation more sustainable. It also aims to establish a roadmap with the intermediate milestones needed to meet European sustainability targets. Among the technologies covered by the project are batteries.

The first step in determining which applications of battery technology are most suitable for each type of aircraft is to have an overview of these technologies. For this, it is necessary to understand the basic principles of battery operation and the main challenges when including batteries in aviation (battery performance, safety issues, problems in battery manufacturing, and disposal). In addition, it is of the utmost importance to study the performance metrics characteristic of each type and establish a battery classification. From batteries, based on such important characteristics as their

specific energy requirements or operating profiles, it is possible to define aircraft types according to the different applications and extend the study to aircraft classes.

This work presents a summary of all the aforementioned topics, from a first presentation of batteries, their possibilities in the electrification of aviation and the main technological challenges, to a classification of batteries according to their performance metrics. This is followed by a characterisation of which types of aircraft could use these technologies and what technological developments should be achieved to continue progress towards a cleaner aviation.

Energy management of an eVTOL aircraft with optimization based on the Equivalent Consumption Minimization Strategy (ECMS)

Meryem TAGHBALOUT, *Ingenieur, France*

With growing concerns over air pollution, the aviation industry is actively exploring clean energy powered aircraft, particularly electric Vertical Take-Off and Landing (eVTOL) aircraft, as a key future trend. This paper introduces an online optimization-based power management strategy called ECMS (Equivalent Consumption Minimization Strategy) specifically designed for eVTOLs. The hybrid propulsion system (HPS) employed in eVTOLs integrates fuel cells as the primary energy source, supplemented by lithium-ion batteries.

The ECMS strategy aims to achieve an optimal distribution of energy demand among multiple sources, considering their constraints and maximizing operational efficiency. Its primary objective is to reduce environmental impact and enhance energy sustainability by minimizing hydrogen consumption, while ensuring performance and safety requirements are met.

Analytical model-based simulation and optimization methods, specifically utilizing the ECMS approach, are employed to calculate the optimal operational parameters for the eVTOL, taking into account the available energy resources. Initially, these techniques are implemented in MATLAB to conduct performance simulations under various conditions. Moreover, this study explores the implementation of the proposed solution in OpenModelica, which not only yields comparable results to MATLAB but also offers a cost-free alternative by using an open-source software widely used by research community.

The adopted ECMS control strategy demonstrates satisfactory reliability, low computation time, and cost-effectiveness. The study analyzes and presents the power distribution and various results obtained, underscoring the effectiveness of the chosen method. Additionally, a comparison with alternative energy management strategies is provided, emphasizing the advantages of the ECMS approach.

Comparison of Permanent Magnet Synchronous Machines for Hybrid Light Aircraft with traditional and additive winding technologies

Giovanni DiDomenico*, Moreno D'Andrea, Marco Villani, Jakob Jung, Rick Ottolinger
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Electrical motors are key components in electrical transition asked for greenhouse gas reduction programs. Future aircrafts will certain have electrical motors for primary and secondary surfaces control, for landing gears and for other actuations like high-lift system, but they will need also electrical motors for propulsion. The latter is the hardest challenge due to the high power density required, the Hybrid-Electric propulsion represents on of the most important topic in the aerospace industry and a good option to pursue the electrification change especially in light aircraft segments.

The focus of this paper is the comparison among permanent magnet synchronous motors for Hybrid Light Aircraft propulsion with traditional and additive winding technologies.

KINETIC ENERGY RECOVERY FROM A LANDING AIRCRAFT: EVALUATING ONBOARD ENERGY STORAGE SOLUTIONS

Aman Batra*, Robert Camilleri

** University of Malta*

The European Union (EU) is driven by its ambitious strategy Flightpath 2050, which sets aggressive targets to reduce in flight CO_2 emissions by 70% and NOx emissions by 90% and reduction in noise. Despite focus on the airborne phase, EU is legislating that all aircraft movements on the ground should be emission-free by 2050. A typical 10-minute aircraft taxiing consumes approximately 100 kg fuel with a considerable amount of carbon and NOx pollutants released at ground level. To address this, several engineless taxiing solutions have been researched. These can be categorized as external or onboard. External taxiing solutions such as TAXIBOT [1] tows the aircraft from the gate to the end of runway. While this reduces fuel consumption, CO_2 and noise emissions, it requires significant investment and taxiway infrastructure. It also produces an increased ground vehicle traffic and creates new logistical challenges to match tow trucks to aircraft. Conversely, onboard electric taxiing solutions such as Electric Green Taxiing System (EGTS) [1] and WheelTug [1] can use existing infrastructure and allow the aircraft with full autonomy. However, both solutions require additional electrical power which the current aircraft auxiliary power unit could not provide. As a result, retrofitting such systems is not a feasible option. The environmental impact of various taxiing techniques with reference to standard taxiing method was studied in [2]. It was shown that onboard technologies have lower taxiing emissions than fuel powered tow-trucks and offer fewer logistical challenges and allow aircraft to maintain their autonomy in airport operations. However, upgrade of the APU for powering electrical motor is a hurdle to retrofit existing fleet towards zero-emission taxiing.

This paper addresses this issue in onboard solutions and proposes a novel concept of Kinetic Energy Recovery System (KERS) from a landing aircraft. Energy is stored temporarily and reused so that it enables engine-less taxiing. An energy analysis of the concept, including environmental and economic prospects were presented in [3]. It was shown that the use of such technology in low-cost carrier aircraft, would presents a unique opportunity to turn an emission problem into a green solution. This paper evaluates the choice of onboard Energy Storage Solutions (ESSs) (flywheels, supercapacitors or batteries) for storing the energy while braking. The paper uses energy needed for taxiing to size customized flywheel, supercapacitor and battery solutions to store that energy. The resulting ESSs are compared on the basis of weight, charging time, discharging time and complexity in retrofitting to existing systems. The paper also assesses if additional inflight emissions due to added weight of ESSs would offset the economic and environmental benefits of engineless taxiing through a KERS.

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Multifunctional structural batteries – the promise of weight reduction in hybrid electric aircraft

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The introduction of hybrid electric aircraft is one of the envisaged ways to innovate the market of civil aviation while striving for climate neutrality by 2050, as stipulated by the European Green Deal and ACARE's updated European vision for sustainable aviation [1,2], as electrification of propulsion can enable alternative propulsion configurations to increase tank-to-thrust efficiency and to achieve synergies with other aircraft sub-systems.

Hybrid electric propulsion is nowadays considered mainly for aircraft up to regional size with two main options for the onboard electrical power source: mechanical or electrochemical conversion, with a generator or a (H2) fuel cell system, and/or storage in batteries. Either option will show a substantial increase of aircraft empty mass, even when utilizing upcoming ultra-high energy density lithium-ion batteries that are expected to reach the theoretical limits of this battery technology in the coming years [3]. As post-Li-ion batteries (e.g. metal-S or metal-O2) are still far from market, this poses significant challenges for electrifying the propulsion of larger aircraft, ranging from commuter over regional to short-medium range.

Multifunctional electrical energy storage, equivalently referred to as structural batteries, are capable of storing electrical energy while bearing mechanical loads, seamlessly allowing for storage capabilities at zero weight penalty. Over the last decades, many concepts of this technology have been investigated, exploring different degrees of multifunctionality, i.e., from multifunctional constituents and materials to multifunctional structures, and different cell designs have been demonstrated, including reinforced planar cells and coaxial wires. However, multifunctional efficiency adequate for aeronautic applications has not been achieved so far and several gaps in research, technology development and, specifically to the aeronautic field, in airworthiness certification have never been tackled [4,5].

The CleanSky 2 project SOLIFLY (2021-2023, GA 101007577) and the HORIZON project MATISSE (2022-2025, GA 101056674) address the fundamentals of structural batteries, by combining research and technology development in the fields of: (a) structural electrochemistry, developing structural electrolytes for state-of-art high energy active materials (NMC, Si-graphite) that are performant, safe, mechanically capable and thermally stable, (b) integration of structural battery cells into carbon fibre composite laminate and sandwich structures, considering structural materials and manufacturing practices accepted by aeronautic industry, (c) on-cell sensing and monitoring micro-electronics for both energy storage and surrounding structure spanning a sensor network that will make aeronautic parts smart over their entire life, from manufacturing over use to second life and recycling, and (d) manufacturing and certification while exploring the potential of deploying such technology in multiple aircraft categories.

Within SOLIFLY and MATISSE, the feasibility of aeronautic structural batteries will be demonstrated first within a standard interior aircraft part (i.e. a stiffened composite panel of representative size, 2023), and later at full scale in a replaceable wingtip of a fully electric light aircraft (i.e. Pipistrel VELIS Electro, 2025), achieving TRL 4 by 2025.

This paper will present an overview of the current research performed and preliminary results achieved within SOLIFLY and MATISSE with focus on recent tests of functional structural battery coupons and an outlook on the upcoming demonstration of the SB panel. Furthermore, the steps necessary to mature further SB technology and enable industry uptake will be discussed.

Acknowledgment
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Concept Development of the Air Inlet for Fuel Cell-Powered Electric Propulsion Systems for Regional Aircraft

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Electrified propulsion systems powered by hydrogen fuel cells are a promising technology for future, sustainable aircraft. However, operating a fuel cell in an aircraft poses new challenges to other components, like the air inlet system. Not only does the fuel cell have to be supplied with a constant stream of clean air for the cold combustion, but also high amounts of waste heat have to be discarded into the atmosphere.

This paper investigates different air inlet systems using analytical methods. First, concepts are identified by analysing the state of the art in air inlet design. Secondly, promising concepts are selected using a qualitative evaluation. Finally, the most promising concept is sized for the given topology. The results of this investigation highlight the importance of careful air inlet design to achieve operability and acceptable performance with fuel cell powered aero engines. Performance and sizing data gained from the analytical calculations can serve as a baseline for the preliminary design of air supply systems for fuel cell powered aircraft.

Performance data for different air inlet types and engine air protection systems are elaborated and summarized in this work. The potential of the selected concept is analysed and challenges in the design of an air inlet system for new engine topologies are identified, building the foundation of further studies for fuel cell-powered aero engines.

Additionally, the process used in this work can be implemented for inlet systems designed for other engine topologies. Thereby, this work assists the development of sustainable aircraft.

Sensitivity Analysis and Optimization of a Liquid Cooling Thermal Management System for Hybrid Fuel Cell Aircraft

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In the context of climate change leading to a progressive increase in the study of decarbonizing aircraft, hybrid electric powertrains have been generally sought out to be the first step in reaching this objective. This type of powertrain results in its own thermal management challenges with an increased number of electrical systems onboard. Integrating a thermal management system (TMS) in an aircraft can significantly impact performance, as it may result in additional drag, mass and even power consumption. To address the case of a hybrid fuel cell aircraft, a liquid cooling TMS has been modeled and sized for a given case study. Due to the potential significance of the TMS on aircraft design, a sensitivity analysis of the system can provide helpful information and improve design choices. The proposed work includes two parts: performing a sensitivity analysis on the different TMS model input parameters used to design them and, similarly, a study on the design variables, constraints and objective function of the optimization methodology. The final objective is to facilitate aircraft TMS design by having a better understanding of all the parameters impacting the TMS design, which can be difficult due to the numerous couplings in the optimization process.

The first study aims to investigate how the TMS sizing differs with respect to specific input parameters and/or model assumptions. A first analysis focuses on sizing the TMS subject to varying environmental conditions. For example, three different scenarios can be explored: a standard day where the ambient air temperature defined by the International Standard Atmosphere (ISA) at sea level is T_ISA=15°C, a "hot day" where the ambient air temperature is T_hot=T_ISA+20°C, and lastly a "cold day" where the ambient air temperature is T_cold=T_ISA-20°C. The liquid cooling system uses ambient air to cool the coolant traveling through the circuit, therefore the "hot day" is expected to be the most penalizing on the aircraft and the objective is to quantify this impact. In addition, the first fuel cell modeled is a low temperature proton exchange membrane fuel cells (LT-PEMFC) which operates at a fuel cell stack temperature of around T_fc=60-80°C. Opting for a high temperature proton exchange membrane fuel cells (HT-PEMFC) instead, which generally operates at around T_fc=120-180°C, results in the need for a smaller TMS as it is easier to dissipate the fuel cell heat. Thus, the choice of fuel cell and its effect on the TMS sizing can also be considered in aircraft design. Other proposed TMS input parameters to study include the component efficiencies, such as the pump and compressor, and choice of coolant.

The second study focuses on improving the optimization methodology for sizing a TMS. An optimization of the TMS can be performed with respect to different objective functions, such as minimizing the mass or the drag, as well as can include other design variables and/or constraints. Design variables can include the coolant mass flow in the pipes and/or even the ambient air mass flow from cooling air inlets. They can also include a heat exchanger effectiveness or its number of transfer units. Similarly, these variables or other constraints can be defined to bound the optimization. Furthermore, a Pareto front can be produced from a multi-objective optimization portraying the trade-off between the design objectives. An example includes minimizing the drag vs. the mass of the TMS. In the end, analyzing all of the proposed optimization parameters can, once again, facilitate aircraft TMS design choices and lead to better optimization.

PRELIMINARY SIZING WORKFLOW OF HYBRID ELECTRIC REGIONAL ARCHITECTURE WITH FUEL CELL SYSTEM

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The ambition to achieve climate neutrality in the EU by 2050 along with the intermediate target of an at least 55% net reduction in greenhouse gas emissions by 2030 pushes all sectors, including aviation, towards the implementation of technological solutions able to cut pollutant emissions while guaranteeing expected revenues. In this context, the potential of systems electrification to turn the aircraft into a climate-neutral system has been under extensive study in the European framework since the Clean Sky Programmes and it is further explored within the on-going Clean Aviation Programme. Considering a regional aircraft architecture, current research efforts are focused on the establishment of a competitive hybrid electric configuration based on a Fuel Cell System (FCS) able to exploit hydrogen stored as fuel in the tank, to produce electrical power by means of a chemical reaction with the air and to convert it into mechanical power for propulsion. The FCS technology, ensuring a positive impact on the carbon footprint and on NOx emissions by avoiding the combustion of conventional hydrocarbon fuel, is nowadays at low Technology Readiness Level (TRL) for aeronautical applications. Therefore, it is deemed fundamental to pursue a thorough study of such a highly innovative and integrated system since the very beginning of preliminary design activities in order to grasp potential challenges and criticalities in its future implementation.

At this purpose, the sizing of the FCS in terms of mass and power budgets should be carried out by considering it as part of a more complex design workflow involving linked aircraft components in order to guarantee a FCS design optimized at aircraft level. Starting from this introduction, the full-length paper will describe the workflow depicted in Figure 1 and suggested for the sizing of the FCS and related components (i.e. Air Intake and Electric Motor) highlighting the variables used to interconnect models. The rationale behind the introduction of the Converger element shown in Figure 1 will be also elicited. In addition, a brief reference on the literature models used for the sizing of each workflow element will be reported. Then, in order to test the overall workflow in a unique environment and obtain an integrated sizing of the FCS system and related components, the implementation in Remote Component Environment (RCE) software like that depicted in Figure 2 will be discussed, stressing the importance of properly defining interfaces between models to enable the workflow execution. The test of the selected design workflow in RCE will be based on input data for a case study derived from Clean Sky 2 studies. Results from the workflow run will be graphically depicted and discussed, providing an example of integrated design of FCS into a hybrid electric regional platform. Eventually, main conclusions will be drawn and suggestions for future works will be provided.

Preliminary design of a retrofitted ultralight aircraft with a modular fuel cell power system

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Emission-free aerial propulsion can be achieved with a proton-exchange membrane fuel cell (PEM-FC). In the present investigation, this potential is addressed by designing a hybrid electric power system with fuel cells for an ultralight aerial vehicle to be retrofitted from a conventional fossil-fueled piston engine configuration The proposed fuel cell power system is designed in a modular way by connecting low-power stacks in order to preserve the high-power density of air-cooled systems. The power system includes as a secondary storage system a lithium battery that is connected to the fuel cell with an active configuration, i.e., by means of DC/DC converters so to allow the implementation and testing of different energy management strategies. A dynamic model has been developed to analyze the dynamic behavior of the system according not only to the power and altitude profile of

a typical mission but also to the usage of the battery in the different phases of the mission. The model also considers hydrogen losses during the purge process to obtain an accurate evaluation of the overall fuel consumption and to size the hydrogen storage system accordingly. The model, required for the preliminary design, is currently validated with literature data but a suitable test bench is also under development.

Comparative Analysis of Integration Concepts for Hydrogen-based Electric Propulsion in Regional Aircraft

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Besides the advances of electric flight in urban air mobility and general aviation, electrified aero engines are being investigated for commuter and regional as well as short- to medium-range aircraft classes to meet the Flightpath 2050 and ATAG Waypoint 2050 goals. The development of enabling technologies and the modification of existing technologies to the stringent requirements of aviation is the key to enable electrified aero engines for commercial aviation. It is necessary to maximise power density, to increase reliability and to tailor technologies towards the environmental conditions associated with the cruise altitude as well as hottest day and coldest day requirements. Furthermore, an assessment on aircraft and propulsion system level is necessary to understand the full potential and limitations of these technologies.

By introducing electrification to aviation, the design space for an aircraft is being opened up, giving way to novel aircraft and propulsion system integration concepts, such as blended wing body and box-wing aircraft as well as boundary-layer ingestion. The focus of this work is to evaluate the potential and challenges of electric propulsion systems in the medium term and with that employing more conventional aircraft designs. A hydrogen-based electrified regional aircraft concept, H2Electra, is being introduced along with the process, which was developed for sizing both the aircraft and the propulsion system. This iterative design process allows for a holistic approach to the development of an aircraft, its electrified propulsion system as well as the components therein. Two different integration concepts are being considered in the evaluation: one partially fuselage-integrated and one nacelle-integrated propulsion system. For the former, all source-side components are located in the rear of the fuselage and the electric power is distributed across three propulsion units on each wing. In contrast the later concept constitutes of only one propulsion unit on each wing and all components of the propulsion system are integrated into the nacelle. In both cases, a hybrid of lithium-ion battery cells and hydrogen-based fuel cells is used as electric energy source. The battery serves as boost during take-off and climb. A high-temperature polymer electrolyte membrane fuel cell (HT-PEMFC) was chosen as fuel cell technology to be evaluated. Challenges and trade-offs between the two concepts are being analysed and discussed here. Safety and reliability are key design and decision-making metrics, alongside block-fuel efficiency and power density. In particular, the design decision on a suitable bus voltage and its effect on the powertrain sizing and integration are being evaluated in this study.

While the integration into a single nacelle will have advantages with regards to maintainability and lead to a reduced number of components, safety measures associated with the leakage of hydrogen become necessary in various zones of the aircraft. On the other hand, the partially fuselage-integrated concept leads to an increase in challenges associated with electromagnetic interference and fire hazards as well as challenges with trimming and accessibility for maintenance.

Ventilation and Pressurization System for Next Generation Hybrid Electric Regional Aircraft

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The journey to a climate-neutral aviation system through the European Green Deal is ambitious and a formidable opportunity for society and citizens. The answers proposed by Clean Aviation will probably challenge all conventions and classical approaches in bringing forth a real transformation leading to new propulsion solutions and sustainable vehicle configurations and operations. Thermal management is one of the key challenges for the successful realization of the Hybrid Electric Regional Aircraft. Novel propulsion technologies, e.g., Fuel Cells or Electric propulsion, come with challenging thermal management.

The Clean Aviation project TheMa4HERA "Thermal Management for Hybrid Electric Regional Aircraft" aims to develop and mature the key technology bricks to enable efficient thermal management on these new aircraft concepts for the drop-in as well as the non-drop-in solution, where the increasing exploitation of electrical power will come with increasing number and entity of heat sources even more widely distributed in the aircraft compartments. Collins Aerospace provides advanced Thermal Management systems and services for commercial, regional, business aviation, military, and government customers. In TheMa4HERA Collins Aerospace is leading the ventilation work package focused on cabin pressure control and ventilation in unpressurized areas. Collins' participation in the project will further strengthen the position of its business units in cabin air distribution, efficient (less/no bleed) and low-weight air distribution, cabin pressure control and electrically driven fans (e-fan).

Collins will present the work developed in the project related to the design and optimization of a novel e-fan using state-of-the-art Computational Fluid Dynamics (CFD) and Computational Aeroacoustics (CAA) modelling techniques. The end goal is to replace conventional bleed-air-driven subsystems in terms of performance, efficiency, and volumetric flow while reducing their weight. This e-fan is expected to be used for ventilation of unpressurized bay areas during ground operations, take-off, and landing.

Reducing Environmental Impact of Jet Engines by Hydrogen Co-combustion

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Background:
Due to the need to mitigate global warming, there is a growing interest in alternative fuels for various means of transport, including aviation gas-turbine engines.

Goal:
The aim of the work was to check the impact of hydrogen co-combustion on the performance and emissions of aircraft engines.

Methods:
Zero-dimensional models of JetCat P140 RXI and DGEN 380 engines developed in the GSP (Gas turbine Simulation Program) program were used in the research. Combustion calculations in GSP are based on the real gas model and NASA Chemical Equilibrium Applications (CEA) equations.

The performance of the engines fuelled by Jet A-1 and blends containing hydrogen or methane were calculated. The simulations were performed at the design point on the ground, and then in flight for selected altitudes and flight speeds.

Results
With an increase in the gas content in the mixture, the thrust and temperature behind the turbine slightly increase, and the specific fuel consumption decreases, because hydrogen and methane have a higher calorific value.

Conclusions
The performance of JetCat and DGEN 380 engines was calculated for blends of kerosene with methane or hydrogen. This knowledge will be used to convert these engines to gaseous fuels. In terms of fuels and emissions, GSP has limitations related to the set of available chemicals and the zero-dimensional model of the combustion chamber.

Flight Performance Analysis of Distributed Electric Propulsion Aircraft Based on Experimental Data

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Distributed electric propulsion (DEP) aircraft, featuring multiple electrically powered propulsion units distributed along the wing span, have gained significant interest in recent years due to their potential to improve aircraft performance, efficiency, noise and safety. While DEP has great potential, flight characteristics and performance need to be thoroughly evaluated to assess its viability and determine the optimal configuration for future transport aircraft. In the CS2-funded DISPROP project, different configurations of DEP propulsion systems on a wing segment are being investigated in the wind tunnel to provide improved higher-fidelity models for the aerodynamic simulation of distributed propulsion systems.

The presentation will give an overview of the impact of DEP on the overall aircraft level for different configurations. The effects of DEP on aircraft performance will be investigated using a combined approach, where data from DISPROP will be transferred to different DEP aircraft configurations and integrated into the preliminary aircraft design tool SUAVE. In SUAVE, different DEP configurations based on the high-fidelity data gained from DISPROP will be analyzed and their flight performances will be compared with a conventional reference aircraft.

An experimental investigation on the propeller noise in propulsive and energy harvesting configuration

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In this study, the noise emissions of an isolated propeller employed for the propulsion of an hybrid-electric aircraft are investigated. The idea is to utilize the propeller for energy recovery during suitable flight phases since it is important to characterize both the propulsive and the energy harvesting configuration also from an aeroacoustic point-of-view. The tests were perfomed at the Low-Turbulence Tunnel located at Delft University of Technology, using a powered propeller model and a linear array of microphones mounted in the slipstream direction. Several advance ratios were tested to characterize both the propulsive and energy harvesting configurations. For the sake of brevity, only the most interesting results, pertaining to the most efficient cases among the different configurations, are reported in this manuscript.

The results in the Fourier domain reveal a significant modification of the pressure fields. In the propulsive regime, the most relevant noise source is related to tonal noise, whereas in the energy harvesting cases, most of the energy is associated with broadband noise. This effect indicates a energy transfer between the two components. These experimental findings raise questions regarding the feasibility of studying the two configurations in the same manner. Therefore, a new analysis strategy was defined, starting with a noise component decomposition algorithm and then using the principles of wavelet and chaotic analysis. The decomposition algorithm is based on Proper

Orthogonal Decomposition (POD) and allows the separation of the pressure time history into tonal and broadband components without evidence of phase shift or other mathematical artifacts compared to the original signal. The different nature of the noise source in the different regimes is confirmed by the analysis in the wavelet domain and also by the attractors in the pseudo-phase space. In addition, the separation of noise components enables the definition of an appropriate control strategy for each flight condition.

POWERTRAIN DESIGN FOR SMALL SCALE PARALLEL HYBRID-ELECTRIC TEST BENCH

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Parallel hybrid-electric propulsion systems for small scale unmanned aerial systems (UAS) when tested with an internal combustion engine are susceptible to damage due to increased torque compared to all-electric configurations. The University of Victoria Centre for Aerospace Research has conducted testing and identified several locations in the system for potential upgrades. One of the largest issues identified was the electromagnetic clutch's inability to handle the torque of the Corvid-50 engine. Thus, a new clutch was specified which is rated for eight times more torque nominally and weighs 1.5 kilograms (1.18 kilograms increase). The slippage point is identified for both the baseline and upgraded clutch systems to experimentally evaluate the improved performance. The testing includes procedures to quantify the static and dynamic torque limitations of the system. Similar findings are reported based on testing campaign performed at Ł-Institute of Aviation, where on a hybrid-electric powertrain stand, a high amplitude momentum peaks at ICE shaft were measured. The momentum peaks max amplitude were several times higher than the nominal momentum of the ICE, given in the spec sheets. In result, at some working modes, a strong slippage of clutch has been observed. The clutch slippage led to clutch overheating and burning in the most severe cases. In order to confirm current findings, more precise instrumentation is to be used to better understand nature of the momentum peaks, their influence to the powertrain system, and in result to clutch slippage. It is also of highest importance to propose and test potential methods to minimize momentum peak influence to the powertrain. The goal is to increase robustness of such hybrid system, and decrease the overall mass of the system.

In addition, several other upgrades to the system are analyzed for their impact on system performance and include reinforced wider belts, keyed shafts and pulleys, as well as aluminum tensioners. The changes presented are shown to reduce issues such as shaft damage, belt wear, and pulley slippage which will drastically improve the expected lifespan of the parallel HEPS. With these upgrades the system should handle the additional power and torque spikes introduced by the internal combustion engine, resulting in better data and characterization of the hybrid system.

DEVELOPMENT OF A SERIES HYBRID MULTIROTOR

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Hybrid electric power is an appealing technology for multirotor platforms due to their ability to enhance the range of the vehicle while still providing low emissions and the precise thrust control needed for stability. The development of a hybrid-electric propulsion system for a multirotor is an essential step for CfAR as it will be the basis of research on this technology in flight. The designed multirotor, MIMIQ (Modular Inertia Matching Quadcopter), is a 30kg quadcopter with a motor-to-motor diameter of 2.7m and requires a total of 3500W of power to hover. In this case, a large portion

of that power metric is supplemented by the onboard hybrid generator. While this is at hover, peak power consumption at a 2.05 thrust to weight ratio requires 10451W. In these moments of high power demand, the batteries are able to provide quick bursts of power that the generator itself would not be able to handle otherwise.

This multirotor is designed to accommodate a wide range of propulsion configurations to optimize performance. In addition, the mechanical characteristics are also intended to be easily adjustable. Parameters such as center of mass, inertia, and motor distance can be adjusted to mimic characteristics of future flight vehicles that implement a hybrid system. Before hybrid integration, ground tests were performed on various off-the-shelf hybrid generators in order to evaluate their performance and reliability to ensure that it is possible to integrate them into the MIMIQ. To characterize the different modes of operation, an extensive performance map was pursued. A number of parameters were measured over time, the most important being load, power and fuel consumption. As expected, when higher load power is desired, fuel consumption increases. It has been proven that for low power, the generator provides power to the propulsions system while charging the batteries. However, for high power, both the generator and the battery pack need to provide power. The tests demonstrated that the integration of the two propulsion systems into the MIMIQ is possible. It was also verified that when the engines are integrated, both the generator and batteries have to provide power simultaneously in all flight phases.

Battery-Electric Aircraft Flight Operations for Interisland Mobility

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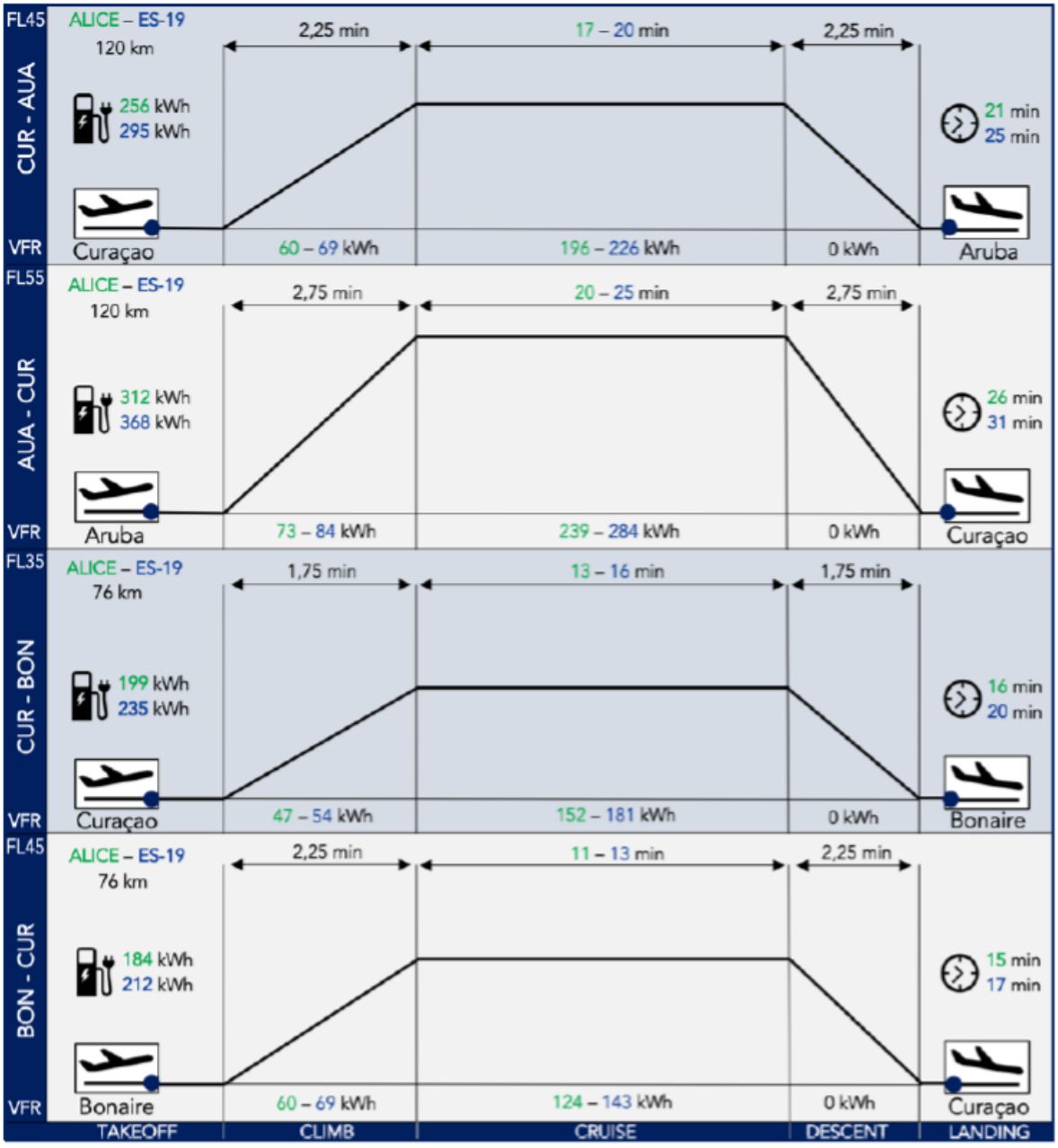
With the development of various new energy and propulsion technologies for aircraft, an industry-wide disruption is currently taking place. Battery-electric aircraft are expected to play a role in this transformation for missions with specific operational and commercial profiles, mostly in the short haul - small aircraft segment. Several studies have shown that such mission profiles can be encountered in flights between the ABC-islands in the Dutch Caribbean, namely the islands of Aruba, Bonaire and Curaçao, where the first generation of electric aircraft will be able to provide the necessary performance requirements. This paper discusses a real-world case study in this geographical area, commissioned by Aruba Airport. The technical and operational characteristics of electric flying in the area are investigated with the involvement of the local aviation authorities, airlines, airports and energy providers.

The study starts with the identification and calculation of the specifications of two passenger electric aircraft under development. Following, the current, conventional flight operations in the area are analysed, with the objective to determine the related energy requirements in the case of a direct replacement of the aircraft flying the current routes with battery-electric ones. Next to this, this study yields results about the comparison between the two technologies in terms of energy costs, emissions and payload. Since the local climate conditions (i.e., temperature, pressure, wind and salinity) affect the aircraft performance and component life of any technology, these aspects are also investigated. Last, operational deviations, safety, and local legislation for performing electric flight operations are examined. Results show that with the current energy mix and prices on the region, CO_2 emissions per seat can be reduced by 98% on average and energy costs per seat by 21% on average. Calculated flight times and payload values per passenger show that it is feasible the proposed electric aircraft to replace the conventional aircraft and fit within current flight schedules. In addition, weather conditions in Aruba show possible technical points of attention. For example, humidity and salinity accelerate corrosion formation in electric motors and connectors. Batteries are also very sensitive to environmental influences such as moisture and heat, so special

recommendations for storage have been suggested when being out of operation, due to lack of active cooling.



A SENSITIVITY ANALYSIS ON THE RANGE EQUATION FOR HYBRID-ELECTRIC AIRCRAFT

Aman Batra, Robert Camilleri and Reiko Raute

As the world faces a climate crisis, there is an urgent need to reduce emissions. While aviation contributes about 3% of the global emissions, only 10% of the global population has access to flight, As the world economy continues to grow and more countries are pulled out of poverty, these too would want to travel. It is therefore important to drive aviation towards net zero if we still want to continue enjoying a lifestyle that we are currently used to. Since a few decades, the European Union

had a very ambitions strategy documented in Flightpath 2050 [1]. This aimed to achieve a sustainable air travel while continuing to serve society's demands. The strategy sets aggressive targets to reduce in flight CO_2 emissions by 70%, NOx emissions by 90% and a reduction of noise when compared to the year 2000 [1]. These goals are now being reinforced through the Green Deal which aims to shift this sector to net zero emissions in the shortest timeframe possible. To achieve this goal, several solutions are being researched such as Electrified aircraft [2] and hydrogen-based aircraft [3].

Electric propulsion systems have its own advantages such as low emissions, less noise and augmented efficiency. It has been found that battery energy density above 800 Wh/kg would be required to sustain an Airbus A320 / Boeing 737 sized aircraft with 1,111 km range. With current state-of-the-art batteries having energy density between 200 to 250 Wh/kg and its value doubling every 23 years [4], it will take around five decades to achieve the electrification targets. Hence, in near future, electric propulsion would not be able to achieve the same range and endurance as present aircrafts. On the other hand, hydrogen powered aircraft still has many unanswered questions. While there is a significant effort to address the challenges related to aircraft design, there are additional challenges to develop the fuel infrastructure and provide the industry with a supply green hydrogen.

In the short-medium term, hybrid-electric propulsion systems may fill the gap. Hybrid-electric propulsion combines conventional fuelled gas turbines with electric drives powered by battery packs. Although hybrid-electric aircraft would still produce emissions during flight, these could be effective in reducing emissions in sensitive areas such as during take-off and landing (i.e. near airports) or when flying through saturated parts of the atmosphere to reduce the formation of contrails. To achieve this, many aircraft design parameters need to be established. In our previous work [5], we propose a new range equation for hybrid-electric equation. That paper revisits the theory of range equation for a hybrid-electric aircraft with constant power split and proposes a new definition to the degree of hybridization (φ). The new definition includes efficiencies of the electric or fuel powered drivetrain which play a significant role on the range estimation of the hybrid-electric aircraft.

This paper carries out a sensitivity analysis on the hybrid-electric range equation, showing the effects of parameters such as lift to drag ratio, payload weight, energy consumption, efficiencies, energy densities, etc. on the aircraft range. The analysis would also depict the implications of the changed of such parameters from an aircraft designer's viewpoint, showing the modifications in the aircraft design required in order to achieve the range of the current aircraft models.

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Exploring the Synergistic Effects of Pressure Gain Combustion and Hybrid Electric Propulsion Integration on an Regional Aircraft Performance

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In this study, the potential of combining pressure gain combustion (PGC) and a hybrid electric propulsion system (HEPS) to improve the performance of a commercial aircraft engine is investigated. Various engine configurations based on a reference turboprop engine benchmarked against the PW127 by Pratt and Whitney are simulated. Fuel consumption, energy demands, and efficiency for different levels of hybridization and pressure gain parameters are analyzed accordingly. Results show that an increase in the degree of hybridization (DoH) leads to a more stable fuel consumption during takeoff, while a rotating detonation combustion (RDC), as a PGC, can contribute to a reduction in fuel and energy consumption throughout the mission. This research demonstrates the potential of these emerging technologies to enhance the efficiency and improve the environmental impact of aviation propulsion systems.

Prediction of environmental benefits introducing hybrid-electric propulsion on regional aircraft

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Despite an average yearly increase of aircraft efficiency of 1.3% between 1960 and 2014, aviation accounts for about 2% of man-made greenhouse emissions and up to 12% of transport-related emissions, as the efficiency gain has been offset by a steady traffic growth. For this reason, it is crucial that all aeronautical stakeholders undertake actions to make aircraft operations more sustainable. For what concerns commuter (19 seats) and regional aircraft (up to 70 seats), traditionally powered by turbopropellers, various solutions are possible:

• Serial hybrid-electric: Electric motors, connected to the propellers, are fed by batteries and/or electric energy coming from a Power Generation System (PGS). The PGS can either be a thermal engine or a hydrogen fuel cell system.

• Parallel hybrid-electric: Both the electric motors and the PGS are mechanically connected to the propellers. In the typical sizing, batteries provide a power boost during high-demand flight phases.

• Full electric: Electric motors, connected to the propellers, are fed by batteries only.

An extended study of the preliminary sizing of aircraft with the proposed propulsive configurations shows that the serial hybrid-electric configuration with fuel cells, fueled by liquid hydrogen, is by far the most convenient in terms of environmental impact. However, an assessment of the TRL of fuel cell and hydrogen tank components, together with the complexity of the new certification framework to be established, suggests that such a technology might be further down the road when compared to hybrid-electric solutions in which the PGS is comprised of thermal engines coupled with electric generators. For this reason, the serial hybrid-electric system with a thermal PGS (thermal hybrid-electric, THE) is assessed. Particularly, two scenarios based on the expected technological development of batteries and motors expected in 2035 and 2050 are considered.

The innovation introduced with the hybridization of the propulsion system reduces the environmental impact of aircraft operations, but comes with a compromise on the design point performance (payload and range of the aircraft). The work presented here aims at pointing to a suitable tradeoff, relying on the networks of existing European airlines. Turboprop regional aircraft are currently heavily

used only in inter-island services in Greece and the Canaries, for which a design range of 600 km and 370 km respectively is enough, excluding the diversion range. Targeting these design ranges, it is possible to obtain a retrofit of the ATR72, that despite the reduction of payload, reduces the fuel per passenger on every flight part of the network. This is clearly more marked for shorter flights, which present a higher energy hybridization factor, and for the 2050 scenario, for which the technology will be more favorable. This allows to reduce the yearly fuel budget by 49% and 68% in 2035 and 2050 respectively, achieving emission-free operations below 1,400 ft.

Smart-UAM in smart-city integrated environment

Chaired by:
Mr. Bartosz Dziugiel (ILOT)

Combined geometrical modifications of propeller blades of urban air mobility vehicles to reduce noise emissions during vertical climb and descend

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Urban air mobility (UAM) including drones and electrical vertical take-off and landing (eVTOL) vehicles for the transport of people and goods is a long-term concept of urban development in the field of transportation. As with most aerial vehicles, the subject of noise generation is of major relevance here as well, since operation takes place in densely populated areas. The propellers are the main source of noise emissions of such vehicles. The aim of this project is to reduce the noise generated during vertical climb and descend as well as hovering flight by geometrical modifications of the propeller blades. Numerous concepts in this regard have been developed in recent years, but no tailored combination of them, which is the focus of the present work. The validation of individual geometric adaptations in terms of aerodynamics and aeroacoustics in the far field as well as the advanced simulations in this regard were carried out using the CFD software OpenFOAM with an externally implemented aeroacoustics library. The optimisations and local adjustments of pitch angle, chord length and blade sweep as well as the addition of trailing edge serration, leading edge tubercles and tip modifications result in reduced tonal and broadband noise in the entire frequency spectrum in comparison to the reference propeller. Special attention has been paid to the combination of features with regard to radial positioning and aerodynamic as well as aeroacoustic effect strength so that they do not adversely counteract against each other. Examples of effective noise reducing combinations of geometrical modifications are presented in contrast to those showing inferior noise performances. The promising numerical results shall be experimentally verified in future research work.

Integrating Urban Air Mobility into smart cities: a proposal for relevant use cases in the next decades

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Urban Air Mobility development and deployment into future cities is gaining increasing and relevant interest in the last years, as a new mobility form suitable to meet the future greener, scalable and efficient mobility targets needed to solve the issues today's big cities are facing in terms of traffic

congestion as well as related environmental consequences. In this framework, the ASSURED UAM (Acceptance, Safety and Sustainability Recommendations for Efficient Deployment of UAM) project has been funded by H2020 and has been concluded in the year 2023, with the main objective, successfully reached, of providing cities with knowledge concerning deployment of UAM services and definition of necessary standards and recommendations assuring common acceptance, safety and sustainability within integrated metropolitan transport system for three time horizons (2025, 2030 and 2035).

In the project, dedicated activities have been carried out to develop suitable operational concepts for Urban Air Mobility (UAM) deployment in the next decades. The main results from these activities were presented in a dedicated paper in EASN 2022 conference, namely including: the identification of the most relevant and promising technologies that can enable the UAM implementation over the next decades, the outline of the regulatory framework in which the UAM will be shaped, the outline of the most relevant aspects and constraints affecting the UAM deployment, the outline of the foreseen UAM concept of operations and of the most relevant use case that are expected to be implemented in the cities over the three time horizons considered in the project, i.e. 2025, 2030 and 2035.

After that, in the project dedicated activities were carried out to further refine and design the most relevant use cases for UAM deployment in the next decades, leading to the public issue of dedicated overall document. The aim of this further paper, therefore, is the one of providing final outline of the ASSURED UAM designed use cases, starting from the analysis of overall identified possible UAM applications and, then, specifically focusing on the description of the six main use cases considered as relevant for the application under the wider societal benefits point of view. In the paper, such main use cases will be described in details and their specificities in terms of expected operational environment, needed technological enablers, envisaged regulatory implications, and so on, will be reported and commented.

Towards smart and sustainable UAM in integrated transport system of future

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The concept of smart city is known and developed since more than 10 years. It determines the way all the most important areas of urban ecosystem work and cooperate making them more efficient, green and tailored to the citizens' needs – more sustainable. This paper addresses UAM being a part of smart-city – smart and sustainable UAM and tries to answer the question how integration of UAM will affect the way it is commonly considered.

The study consists of two steps. The first is devoted to the review of the UAM Concepts of Operations (ConOps) delivered by the most important projects and activities executed in recent years under European Framework Projects. Special focus will be set of H2020 CSA ASSURED-UAM and SESAR ER4 X-TEAM D2D projects. The second steps will aim investigation on IT/ICT technologies and their impact on UAM ecosystem.

Smart-city related technologies should be considered as source of numerous disruptive innovations for the UAM operations. IT/ICT solutions driven by development of BDA and AI will result with revolutionary progress around service integrations resulting with new, unknown before business cases and applications.

Conclusions from the study will change the way the future UAM is considered. It will be source of recommendations for direction of development of key technologies towards new integrated and

sustainable UAM applications and allow for better exploitation of UAV-based solutions within smart-city environment.

IT/ICT solution implemented in urban ecosystem are significant game-changing factor affecting almost all aspects its functioning, UAM as going to be important component of the city environment needs to be considered as smart and sustainable through integration. This study provides the elements of smart-UAM concepts indicating on some possible applications.

ASSURED-UAM project has received funding from the H2020 with GA No 101006696 under European Union's Horizon 2020 research and innovation program.

X-TEAM D2D project has received funding from the SESAR Joint Undertaking with GA No 891061 under European Union's Horizon 2020 research and innovation program.

The role of Special Economic Zones (SEZ) in the development of the Urban Air Mobility (UAM) for urban logistics

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The study aims to investigate what the role of UAMs in SEZs can be for the organisation of urban logistics. Special Economic Zones (SEZs) are considered effective tools to stimulate industrialization and structural transformation. The strategic role of Special Economic Zones (SEZ) at the Italian level has also been underlined by the Italian National Recovery and Resilience Plan, which has provided an important economic endowment to relaunch the national economy, in general, and the Campania region territorial economy, in particular. Based on the international experience with SEZs, the Italian Government, in launching the SEZs through the Legislative Decree No 91 of June 20, 2017, has implicitly assumed that SEZs are areas where fiscal and administrative advantages are provided for all those companies already operating or willing to establishing within them. Their purpose is to boost the local economy by attracting foreign investment and relaunching the economy of the disadvantaged areas where they are located. But the SEZs are primarily located in core nodes of the TEN-T networks and other transport nodes/networks, covering the entire territory of southern Italy. These areas are therefore first and foremost logistics areas and not just production areas. In some of them, (as in the case of Apulia region), they host technological districts that deal with the development of UAM and chemical/pharmaceutical companies two sectors that can be brought together. The UAM cannot but be considered as a complement to the logistics chain of supply and distribution of goods in the smart cities, given its role in recent years.

Investigation of Heterogenous Fleets of Advanced Air Mobility Aircraft in an Agent-Based Simulation

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Advanced Air Mobility (AAM) is envisioned to involve a broad range of use cases posing contrasting requirements on the Aircraft. These use cases involve different ranges, tempos of operations, and expected demand. This translates to a suite of different vehicles being developed by the industry with different architecture and top-level requirements. The aim of this work is to evaluate the need for heterogenous fleets to suit the different operational scenarios envisioned for AAM, and how the requirements of the vehicles differ when composed into a heterogenous fleet. This work investigates the following research questions:

RQ 1. Are heterogenous fleets better in comparison to homogenous fleets considering System of Systems Measures of Effectiveness?

RQ 2. What is the optimal ratio with which to mix the two optimal concepts and does it change when the TLARs of the composing aircraft are varied?

RQ 3. Do the TLARs of aircraft from Optimal Homogenous fleet compose the Optimal Heterogenous fleet?

Two optimal aircraft concepts each of a multirotor and a tiltrotor architecture, derived from a system of systems driven aircraft design approach is first evaluated in a homogenous fleet, and then in a heterogenous fleet with varying degrees of heterogeneity. For this evaluation, a nominal use case is setup to represent a mixed operational scenario of intracity and suburban scenarios. The fleets are evaluated using Measures of Effectiveness composed of the share of passengers choosing AAM, load factor, energy demand, and utilization rates through an Agent-Based Simulation of AAM.

AURORA – UAM in the urban mobility framework: Potential added value for cities and citizens

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** European Passengers' Federation*

The European Passengers' Federation (EPF) will bring the end-users' perspective to the debate and share lessons learned from the H2020 project AURORA (Safe Urban Air Mobility For European Citizens, https://aurora-uam.eu), in which EPF is leading the citizen and stakeholder engagement activities.

EPF has a lot of experience and expertise in understanding transport users' travel behaviour, their needs, requirements, capabilities and constraints in an increasingly digitised transport and mobility ecosystem. In our view, user-centered design is vital for developing customized mobility solutions with enhanced chances for success. Whenever developing new mobility solutions – such as UAM – it is important to avoid a technology push and adopt a user-centred approach, in order to foster adoption and acceptance, and make sure that such new services bring added value to people and to society.

Zooming in on Urban Air Mobility (UAM), this new technology offers a promising opportunity to overcome challenges such as road congestion and a lack of surface transport, while saving infrastructure costs and time, by taking urban mobility to the third dimension – the airspace. However, as UAM is still a fairly new concept for European cities and regions, the implementation of UAM in cities and integration of UAM services into existing mobility plans (in particular SUMPs) comes with various – technological, regulatory, economic, environmental, social and operational – challenges.

The EU-funded project AURORA aims to foster the adoption of UAM by making it more safe, secure, green, quiet and showing its benefits for society. AURORA's demonstrations are focused primarily on emergency-related applications (emergency medical logistics; firefighting operations in hard-to-reach areas; chemical incidents response) as well as smart-city integration. AURORA believes in creating solutions that do not only extend and complement current mobility systems, but also have a beneficial impact on people and

society. By facilitating the integration of UAM in a safe, secure, quiet and green manner, AURORA proposes to pave the way towards smarter cities and pioneering services.

To both investigate and increase public acceptance of UAM, AURORA has involved end-users and relevant stakeholders in all phases of its journey, through dedicated activities such as interviews and workshops. Aim is not only to increase and exchange knowledge about UAM, but also and more importantly, to ensure that AURORA's innovative solutions meet the needs of citizens and stakeholders. Interest in and knowledge of UAM is often concentrated to specific sectors with already strong ties to UAM. Creating awareness, preparing cities and sharing practices can help with UAM's embracement.

EPF would like to focus on the results of the above mentioned stakeholder and citizen involvement process, tackling the challenges and opportunities that citizens, policy-makers and mobility experts see in UAM, which we can group into four main categories: integration needs (with surface mobility counterparts and existing mobility plans, notably SUMPs, but also in terms of regulation); societal challenges (public awareness and acceptance, inclusiveness, accessibility); environment (sustainability, potential environmental impact including noise and visual pollution); safety and security (safety requirements in urban environments, airworthiness, privacy, cyber security).

The results of these engagement efforts are serving as an input not only to AURORA's development activities but also to two key project outputs which we can present: (1) a decision support tool to help stakeholders as cities and regions understand their current readiness level for UAM, the steps they need to take to advance and what issues to be aware of in order to make their UAM activities resilient and (2) a set of recommendations for urban mobility practitioners and policy makers at various levels to point out what processes, regulations and policies need to change in what areas in order to facilitate various UAM services and integrations.

Artifiicial Intelligence in Air Traffic Management

Chaired by:
Prof. Javier Perez Castan (Universidad Politécnica de Madrid)

ANALYSIS OF PATTERNS AND TRENDS IN AIR TRAFFIC BEHAVIOUR IN DIFFERENT EN-ROUTE ATC SECTORS USING A COMPLEXITY INDICATOR

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Air traffic is currently increasing. But the ATC service, which is responsible for providing control of aircraft crossing the airspace, is unable to increase its capacity to cope with this demand. This increase in traffic, coupled with the increase in the number of different routes flown by airlines, and a variety of other factors, makes airspace an increasingly complex environment. This complexity is a topic of great interest to the research community. Being able to measure airspace complexity, and to analyse the causes of this complexity, has great benefits for ATC service management. Correct measurement of complexity and its causes makes it possible to explore ways to reduce this

complexity, and therefore to facilitate the work of ATCOs. This will have a direct impact on the efficiency and safety of aviation, two fundamental factors for its development.

As complexity is such an area of interest, many researchers have tried to investigate this complexity. But no consensus has been reached. Researchers focus on the workload of ATCOs, on the complexity of the flight operation alone, on the combination of both, but there is currently no universal indicator of complexity. Within this topic, ENAIRE, CRIDA and the UPM are developing the FLUJOS project. This project aims to develop a complexity indicator based on the behaviour of the main flows of a sector. To define this complexity, the first step is to define what an air traffic flow is. Subsequently, a methodology is defined within which both air traffic flows and ATC sectors themselves can be characterised according to their complexity. The basis of the whole process is only the flight operation in the sector, in order to avoid the subjectivity that indicators such as the workload that depends on the ATCOs may induce in the methodology. For this, the use of machine learning models will also be a fundamental part of the methodology, as they will be present in the definition of the methodology, and could also help predicting complexity in the future, which is the main objective of its application.

The last part of the development of the methodology is the characterisation of the ATC sectors and the exploitation of the model. The complexity model has been tested in a wide variety of en-route ATC sectors in Spanish airspace. By means of Exploratory Data Analysis, it is possible to obtain a study that allows the complexity of different sectors to be compared with each other, as well as to analyse in detail the complexity of a sector or its causes. This exploratory analysis carried out for the study of complexity is very extensive, and can allow the ATC service to have a general or specific view of the complexity of the sectors, or even of the behaviour of certain air traffic flows. This is of great help, and can be a tool for optimising human and technological resources within the ATC service.

The conclusion reached after the development of the methodology and the characterisation of various sectors is that the methodology can detect trends in air traffic, and is capable of picking up operational patterns well. It can also be concluded that the methodology of characterisation through Exploratory Data Analysis is a great complement to the methodology of characterisation by complexity. It provides great flexibility and allows the focus of the analysis to be placed on different points, helping and facilitating the task of determining the complexity of the sector. Moreover, by using graphs, the exploratory analysis is also intuitive, easy to interpret for the ATC service in the strategic phase and does not require much effort to interpret.

Safety and Resilience Bayesian Belief Network (SR-BBN) for ATM

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1 Introduction: The traditional approach to safety (Safety I), and its relevant models and methods, have contributed greatly to improving the safety of industrial systems, but has limitations in dealing with complex socio-technical systems like ATM. This study explores Resilience Engineering (RE) and Safety II, which focus on learning from a system's ability to adapt in everyday situations. Safety I is reactive, while Safety II and RE are proactive. Combining traditional and new safety approaches is necessary to mitigate negative effects and prevent recurrence. This study aims to quantify safety and resilience in ATM and demonstrate the synergy between traditional safety and RE.

2 Discussion: The Air Traffic Management (ATM) system is a complex multi-agent system that operates through the interplay of technology, organization, and people. The system is built on the TOP approach, which ensures the equilibrium of these three pillars to achieve a safe, efficient, and resilient performance.

Any changes in the technology, organization, or people involved in the ATM system can cause a shift in the balance, resulting in alterations in the allocation of functions and roles within the ATM agents. This research aims to facilitate an understanding of the balance between safety and resilient performance and how the latter is achieved by considering human, system, and organizational factors from a systemic perspective following the TOP paradigm.

Safety in the ATM system is determined by the overall functioning of the system under normal operating conditions. Resilient performance, on the other hand, is about producing a safe outcome, even in conditions beyond the design operating point. The level of safety in a given situation depends on the availability, timeliness, and coordination costs of resources supplied by the organization and humans, and their effective application using available technology. Resilient performance under unforeseen circumstances is achieved by generating strategies for effective resource application that widen the operating conditions of the system while maintaining acceptable safety levels.

To ensure an integrated view of safety and resilient performance, this study proposes the use of the Bayesian Network (BN) model to build a new model, the Safety Resilience-BBN (SR-BBN) model. The SR-BBN model combines the data-driven and knowledge-based approaches to integrate safety variables gained from the safety analysis and resilience strategies identified as the most relevant in describing resilient performance.

The SR-BBN model considers three groups of variables related to separations, external, and nominal conditions, and strategies applied by Air Traffic Controllers (ATCO) in a tactical horizon or by the ATM system in pre-tactical or strategic horizons. The ATCO strategies block is specific per use case and related to resilient performance.

The application of the SR-BBN model has shown its usefulness in predicting safety outcomes after introducing changes to the system. Particularly important is the sensitivity analysis that identifies the most influential variables on the target nodes.

3 Conclusion: In conclusion, the safety and resilience of ANS/ATM operations can be impacted by changes introduced in the ATC/ATM system. The S&R Approach provides a useful framework for organizations exploring the impact of these changes. The approach includes identifying strategies used by the organization and humans, transforming these strategies into quantifiable data, and observing their application over time to cope with unforeseen circumstances and normal operations. The approach also considers the sensitiveness of safety outcomes to operating conditions and the application of strategies by different actors. It is important to identify the operating conditions in terms of supply side and safety levels in current operations, as well as identifying when the system has been operating under resilient or unsafe conditions.

Additionally, the S&R approach is useful when designing a new system as it allows for the evaluation of variations in safety levels under normal or abnormal conditions if the use of a given strategy is altered by a change in the system. The approach also facilitates the elicitation of data requirements at the system level at an initial stage that will facilitate the assessment in terms of resilient performance and safety levels. In summary, the S&R approach provides a comprehensive and valuable methodology for organizations seeking to enhance safety and resilience in ANS/ATM operations, whether in evaluating changes to an existing system or designing a new one.

Preliminary design of an ATC support tool for the implementation of the Ad Hoc Separation Minima concept in an en-route sector.

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The SESAR programme aims to develop the future European Air Traffic Management (ATM) system. One of its four key performance areas (KPAs) is capacity. In view of the expected growth in air traffic demand in the coming years, the current goal is to increase airspace capacity, which is already close to saturation in many cases. One of the determining factors that limit airspace capacity is separation minima. Separation minima are the minimum distance required between aircraft in vertical or horizontal dimensions in order to ensure the safe navigation of aircraft in controlled airspace. Separation minima values are unique in a specific volume of airspace and current values are in use since more than ten, twenty or thirty years ago, depending on the state. It seems that with the current applied separation minima it has not taken full advantage of the developments that have taken place in recent years in the aeronautical industry (new aircraft functionalities and performance, new ATCo support tools, performance-based navigation, among others). Therefore, separation management is an area where improvement is sought, namely through the implementation of new operational concepts (ConOps), which include both the redefinition of the separation minima and the way they are applied. Ad Hoc or Variable separation minima is one of these new concepts, proposed by the authors, which refers to the application of different separation minima values in the same volume of airspace depending on a set of factors: aircraft model, encounter geometry, aircraft weight, wind conditions, among others. These separation values are strategically determined for each particular aircraft pair in each particular situation (Ad Hoc separation). The application of different separation minima in the same volume of airspace implies a substantial change in some of the ATC activities. Also, new functionalities or new ATC support tools are needed, since the Air Traffic Control officer (ATCo) cannot mentally calculate which value of separation minima corresponds in each situation. For this purpose, a new ATC support tool is proposed in order to implement this concept in an en-route sector without any change regarding the ATCo responsibilities. This tool is called Ad Hoc Separation Minima Tool (ASMT) and consists of three modules: trajectory predictor, Ad Hoc separation determination and Ad Hoc loss of separation (LOS) detection and resolution module. In this study, the Ad Hoc separation minima ConOps and a high-level architecture of the ASMT is presented. The functional system of this tool has been assessed in an en-route sector through simulations in MATLAB®.

Air Travel Itinerary Market Share Prediction using Artificial Intelligence

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Understanding how passengers choose among different flight itineraries between two cities is crucial for the future of the air travel industry. Recognizing the factors that influence customer decision-making is essential in optimizing offerings and adapting to market conditions. Itinerary-level forecasts play a critical role in ensuring precise planning and development of flight schedules.

The most representative method for estimating the air traffic of a certain itinerary is the Quality Service Index (QSI) model. For each itinerary, a set of attributes such as capacity, connectivity, and travel time may influence its market share with respect to the origin-destination pair (OD) market. A conventional QSI model combines these features weighting them based on its significance to determine the attractiveness of the itinerary to the passenger, generating a score for each itinerary. This way, provided the demand of the OD and the scores of each of the itineraries comprising it, the market share of every itinerary can be calculated. The key is therefore to select the optimal set of attributes such that, combined and weighted using the most adequate parameters, they are able to forecast the market share of each itinerary with the desired accuracy. However, in a traditional QSI model, these features and parameters values are obtained based on expertise and experience in previous states of the market, making it difficult to extrapolate models and identify new features.

In this study, the most suitable attributes are found using a machine learning approach over a set of historical data. Additionally, an artificial intelligence model capable of capturing more complex feature relationships is presented as an alternative to the traditional QSI models. Hence, this work

presents the development of a generalized rationale based on artificial intelligence that enables both, the understanding of features related to aviation traffic and the fitting of a forecasting model.

HUMAN-AI teaming for Air Traffic Controllers (The CODA project)

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This paper presents the development of a controller adaptive digital assistant (CODA) system aimed to be adopted in hybrid human-machine teams for better workload prediction and more sophisticated task allocation. As artificial intelligence (AI) establishes its position in the automation of complex systems and taking important decisions, it raises more and more concerns about how to keep the human in the loop and divide tasks between operators and AI. In the more sensitive domains such as air traffic control (ATC) where more critical decisions need to be made, these concerns get even more gravity. Hence, this paper presents how the SESAR 3 Project CODA (COntroller adaptive Digital Assistant) will demonstrate how a system could use advanced adaptive automation principles in order to dynamically guide the allocation of tasks between operators and AI according to the varying stream of workload and cognitive status of the operators. To do so, the system will assess the operator's cognitive status, use current traffic data to foresee the future tasks that the operator will need to perform in the future, and calculate the impact of those tasks in terms of cognitive complexity. With this information, the system will predict the future mental state of the operator and will act accordingly by developing an adaptive automation strategy. In order to implement such a system, the state-of-the-art from several different fields needs to be put together:

i) Prediction models, to foreseen future situations, to have the system knowing which activities will be carried out in the future by the operators and their impact on the same human factors; ii) Neurophysiological assessment of mental states, to enable the system to recognize operators' real current level of workload, attention, stress, fatigue and situation awareness;
ii) AI-based adaptable and explainable systems, to have the system manage the task allocation and provide proper information in order to prevent future performance or safety issues.

The CODA project will focus on a specific use case: an en-route sector with a congested traffic situation. Different scenarios will be defined to test the system on relevant traffic situations and sector configurations. To efficiently capture the end user needs, a user-centered design process will be conducted where air traffic controllers (ATCo) and ATC practitioners will be involved in the design process at every stage of the conception pipeline. The work starts with the definition of the current and future role of ATCo and will continue with a couple of major steps which include the development of task prediction model, cognitive impact prediction model, HMPE indexes, adaptive automation system, human-AI teaming guidelines, and finally, the validation plan. The CODA project will improve the current state-of-the-art in several domains, namely prediction models, adaptive automation, and AI transparency and explainability. The outcome of the project will impact scientific advances across and within different disciplines by creating new knowledge and reinforcing scientific equipment, instruments, and computing systems. It will also contribute to technological and economic development by bringing a new product into the market that helps increase air traffic management (ATM) efficiency and profits.

Hydrogen Powered Aircraft

Chaired by:
Dr. Jean-François Brouckaert (Clean Aviation JU)

Estimating the scheduled maintenance implications for a hydrogen-powered aircraft

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The aviation industry is faced with an existential challenge of reducing their ecological footprint within the coming decades to meet regulatory requirements such as the European Green Deal. While the industry has followed the approach of incremental fuel efficiency gains in the past, much of the associated greenhouse gas reduction has been negated by an increased air traffic volume. Therefore, more disruptive technologies such as the use of hydrogen as energy carrier are required to comply with international regulations in the future.

However, despite initial euphoria and first conceptual studies for hydrogen-powered aircraft several decades ago, there has been no mass adoption to this day. Besides the challenges of a suitable ground infrastructure, this can be attributed to uncertainties with the associated maintenance requirements and the expected operating costs to ensure economic viability for operators.

With this study, we address this knowledge gap by estimating changes towards scheduled maintenance activities when substituting a kerosene-based with a hydrogen-powered, fuel cell-based auxiliary power generation. In particular, we develop a detailed system design with strong focus on regulatory compliance and perform a comparative analysis with an Airbus A320 legacy system. That analysis allows us to (a) identify changes for the expected maintenance effort to estimate implications on the economic viability for operators, (b) identify how specific design assumptions correspond with subsequent maintenance activities and (c) describe the impact on the resulting task execution. Consequently, this study can support practitioners in the development of prospective hydrogen-powered aircraft, especially by including maintenance requirements in early design stages of possible system architectures. Furthermore, since the presented methodology is transferable to different design solutions, it provides a blueprint for alternative operating concepts, e.g., the complete substitution of kerosene by hydrogen for the aircraft's propulsion.

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Design and optimization of a Hydrogen power train for ultra-light aircrafts propulsion

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Growing concern about global emissions has led many and international agencies to set aggressive emissions and noise reduction targets for the future. Flightpath 2050 and the Green Deal set highly ambitious goals for emissions of CO_2, NOx and noise. Specifically, a reduction of 75% in CO_2 emissions per passenger kilometer, a 90% in NOx emissions, and a 65% in perceived noise relative to aircraft of the year 2000.

In this scenario, the development of new, innovative propulsion systems based on the reduction or elimination of pollutant emissions for all types of aircraft becomes inevitable. It is in this international context that the SERENA project takes place, proposed by the University of Salento in collaboration with Novotech s.r.l., an important partner company in the aerospace sector. The SERENA project aims to develop an innovative hydrogen powertrain for ultralight aviation, which could be either a demonstrator, a flying laboratory or a new working aircraft itself.

However, the aim of this thesis is to study the feasibility of a version of the Seagull, ultra- light aircraft designed by Novotech s.r.l., powered by a fuel cell-based propulsion system, and therefore to begin sizing the main components that will form the core of the complete power plant, selecting them from those that are commercially available at the time of this writing.

Figure 1 shows the proposed architecture for the fuel cell based propulsion system.

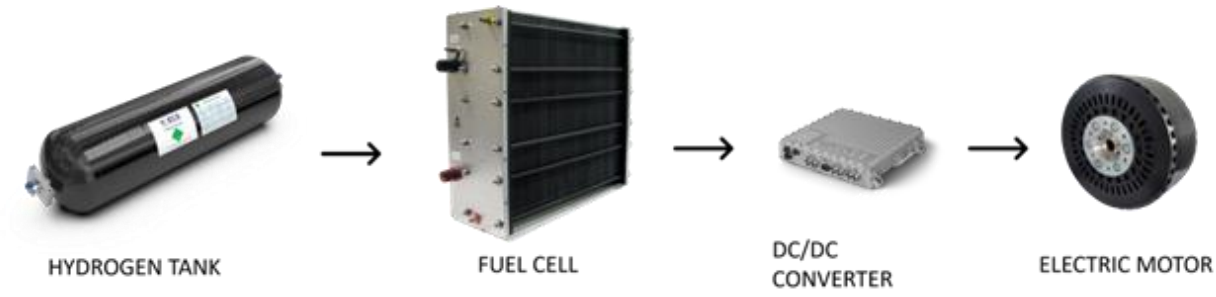

Figure 1: Propulsion architecture proposed

After an initial evaluation of the technologies currently available for various components, the following components were identified as best suited for this type of application. Hydrogen is stored in several tanks, both cryogenic storage and gaseous storage have been under investigation. The proton exchange membrane (PEM) fuel cell powers the brushless direct current electric motor (BLDC) that drives the propeller shaft. The use of a DC-DC converter is necessary to properly match the different voltages between the fuel cell and the electric motor.

Before selecting components from the market, an initial estimate of the maximum take- off mass (MTOM) must be made. Therefore, a dedicated Matlab script is developed that takes into account the operational empty mass (OEM) and the power loading (P/W) of the actual Seagull, the estimated mass of the new propulsion system, and the relative hydrogen consumption. To estimate the total propulsion unit mass before selecting the components, an equation from the literature that takes into account the gravimetric efficiency of the tank and the specific energy of each component is used. For the estimation of the hydrogen burned, a reference 1 h 16 min mission is considered, composed by a takeoff, two climbs, a low and a high cruise, and a final descent. It is shown in figure 2.

The hydrogen consumption during the cruise is evaluated using the Breguet equation, in which the specific consumption is adjusted for the case of a fuel cell propulsion system. For all other mission phases, the consumption is evaluated taking into account the current required by the fuel cell during these phases. The selection of components required many trials because knowing the MTOM and selecting the components for that given mass changes the fuel consumption and therefore the tank size. Therefore, in the MTOM calcula tion, changing the tank size also changes the estimated total

mass of the entire propulsion system, which in turn changes the consumption. This brings us back to the point of selecting new components that are optimized for the new mass.

Finally, after some trial and error, two versions of the alternatively powered version of the Seagull results, showed in table 1. The first version shown is the one with a cryogenic tank, while the second one is equipped with a gaseous tank in which hydrogen is stored at 350 MPa. For the lighter cryogenic version, two solutions are proposed, one with an electric motor with a small gearbox to match the right speed to the propeller to avoid transonic tip speed phenomena, and the other with two EMRAX motors stacked without gearbox. For the heavier version equipped with three Quantum Fuel System type IV vessels, a more powerful engine suite better with a corresponding increase in fuel cell power.

The increase in MTOM compared to the original version of the Seagull is negligible for the lighter version, but in the heavier version the increase in mass is limiting to maintain the same performance of the Seagull powered by internal combustion engine. Consequently, one solution might be to change performance requirements such as minimum take-off distance, or to design an ad-hoc version of the Seagull to accommodate the innovative powertrain. Another strategy to reduce mass and increase performance could be the use of components designed specifically for aeronautics, as they are not yet commercially available. Indeed, this is the path taken by some of the companies that have proposed their fuel cell aircraft demonstrators. Finally, it should be noted that no systems other than cooling and air com- pression were included in the mass of the fuel cell, so the estimation of the mass of the propulsion system could not be so accurate.

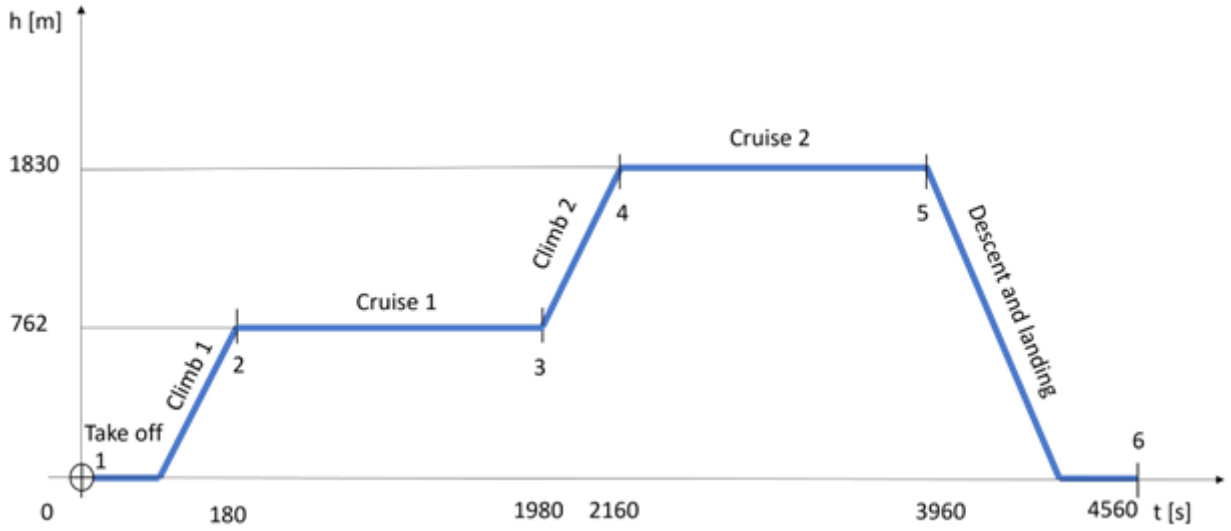

Figure 2: Reference mission for Seagull aircraft

Table 1: Components selection of the propulsion system.

Table 1: Components selection of the propulsion system

MTOM [kg]	E.M.	DC/DC conv.	F.C.
727	EMRAX 228 (wr)	ARADEX VP5000-DCDC200	Powercell S3 (125 *kW*)
860	EMRAX 228 x 2 (w/o r) EMRAX 268 (w/o r)	ARADEX VP5000-DCDC200	NM-12 Double (203 *kW*)

Conceptual design of a hydrogen-hybrid dual-fuel regional aircraft

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A wide range of aircraft propulsion technologies is being investigated to reduce the environmental impact of commercial aviation. As the implementation of purely hydrogen-powered aircraft may encounter various challenges on airport and vehicle side, combined hydrogen and kerosene energy sources may act as an enabler for first operations with reduced emissions. The presented studies feature the conceptual design of such a dual-fuel regional aircraft with a payload of 40 passengers and an evolutionary technology projection into the year 2035 for the non-propulsive systems. By electrically assisting the power shaft of the conventional turboprop engine with the power of hydrogen fuel cells, the powertrain architecture enables the reduction of emissions in part-power phases as cruise. As the sole integration of a hydrogen-hybrid powertrain induces a relatively large mass increase, various hybridization strategies are analyzed on aircraft level and the results compared against a conventional baseline configuration in terms of energy and fuel consumption as well as general design parameters. Both aircraft with their relevant components and disciplines were modelled and investigated using the Bauhaus Luftfahrt Aircraft Design Environment (BLADE). A description of this design platform and the incorporated methods to model the hydrogen-hybrid powertrain is given. Special emphasis is laid on the implications of liquid hydrogen and kerosene dual-fuel system design to be able to assess the potential benefits and drawbacks of the best-performing configuration with the required level of detail.

Thermo-fluid Analysis of Tank Performance in Liquid Hydrogen Fuel System

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The design of fuel systems significantly influences aircraft and propulsion system performance. While fuel system components and design considerations for Jet A-1 fuelled aircraft are well-established, fuel system architectures for LH2-fuelled aircraft are still at very low Technology Readiness Level (TRL). There are significant improvements and modifications required on the Jet A-1 fuel system architectures to tailor them to be used in LH2-powered propulsion technologies.

Since the fuel tank is the first and one of the most important components in the liquid hydrogen fuel system due to the low-temperature demand for hydrogen storage (-253 C) and the sensitivity of hydrogen to small changes in temperature and pressure, this paper will analyse the thermo-fluid behaviour and effects of different parameters on liquid hydrogen (LH2) tanks. In order to design and evaluate the performance of the entire fuel system, understanding the physics associated with the tank is one of the first essential steps. Accordingly, in different scenarios (e.g., venting, feeding, filling), the effect of heat transfer, hydrogen (in gaseous or liquid phase) temperature and pressure, and tank shape in the liquid hydrogen tank performance will be investigated, and then the practical research challenges for developing LH2 fuel systems will be addressed through a sensitivity analysis.

Structural Model of Liquid Hydrogen Tank for Preliminary Design of Commercial Aircraft

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To respond to the current climate crisis, countries around the globe signed in 2015 the Paris agreement promising to cut their greenhouse gas emissions to stay below a 2◦C increase on earth by 2100. The aviation sector made a similar declaration in 2022 when ICAO said the industry will

become climate neutral by 2050. Hydrogen powered aircraft are therefore seen as a promising solution as they would indeed emit no CO_2 if hydrogen is produced in a green way and could also reduce aviation non CO_2 impact. Using hydrogen as energy source on an aircraft presents however huge challenges, especially due to its complex storage. To achieve reasonable fuel energy density, hydrogen must indeed be stored in liquid form in pressurized tanks that would still be roughly four time the volume of current kerosene tanks. This turns into additional dry weight for the aircraft which has a huge impact on future H^2 aircraft concept sizing. The resulting weight penalty must therefore be evaluated at preliminary design level with methods offering a more accurate estimate than the ones based on gravimetric index.

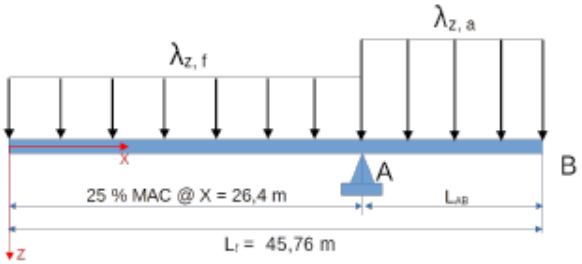
This study proposes a structural sizing methodology of a liquid hydrogen tank for a commercial aircraft. A parametric model of a cylindrical cryogenic tank with hemispherical or ellipsoidal heads is created, with its parameters constraint by the aircraft geometric design. The model consists first in determining the sizing load cases for the hydrogen tank. This is done by representing the tank with a beam model subject to shear and torsion stresses and bending moment created by the pressure differential and the forces acting on the aircraft. The tank is sized for the situation resulting in the highest stresses and/or moment between gust load, take-off and (hard) landing according to current CS 25 regulations. Once the sizing load case is known, the model determines the tank geometry that will withstand these loads with a security margin. This includes the determination of the skin thickness or the dimensions and number of stringers and frames. Supporting truss, linking the tank to the rest of fuselage, is also evaluated for a given geometry, thus allowing a refinement of the weight evaluation scheme.

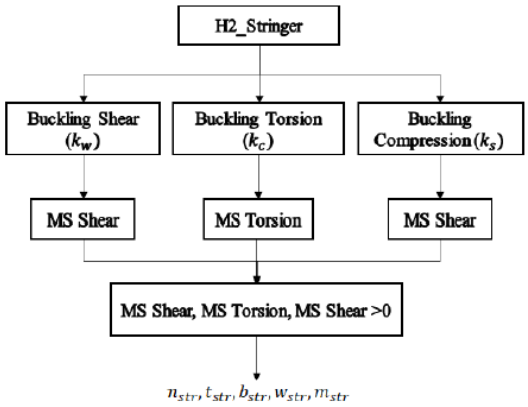
The sizing load depends on the aircraft and tank configuration. In the case of a conventional tube and wing configuration, the tank can be a section of the fuselage and is then called integrated. If it is an independent tank placed inside the fuselage is it said to be non-integrated. The model remains still general enough to consider and compare both concepts or even more exotic configurations which could involve other types of sizing loads.

Stand-alone weight evaluation - to be integrated the overall aircraft design procedure - predicts, for example, that an empty integrated tank for a SMR aircraft of the Airbus A318 class could represent more than 6.5% of the MTOW.

The proposed methodology will allow to design the structure of a cryogenic hydrogen tank and have a first idea of the weight penalties brought by the storage of hydrogen for an aircraft. The integrated and non-integrated tank configurations will also be compared to see if one presents a clear advantage in term of weight.

Furthermore, such a parametric structural model is to be coupled in the future with a thermal behavior model, and integrated into the conceptual design process code FAST-OAD to evaluate trades at overall aircraft level.





Multiparametric Thermal and Structural Finite Element Simulation of a General Aviation Cryogenic Hydrogen Tank

George Tzoumakis*, Konstantinos Fotopoulos
** University of Patras, Greece,*

As the effects of climate change are becoming evident, with temperatures rising and extreme weather phenomena occurring more often, guidelines regarding significant emission reduction emerge from entities all around the world. As transportation accounts for a significant part of the overall emissions, several propulsion systems are investigated. Hydrogen is currently considered as one of the most promising alternative fuels for the future, as it allows the complete elimination of CO_2 and CO emissions when produced carbon-free.

Hydrogen is exceptionally attractive as an aviation fuel due to its heating value, yet its extremely low energy density is causing serious storage issues. Compression can significantly increase the energy density, while the highest practical density can be achieved by liquefaction at a temperature of -253 oC. The limited space on board aircraft means that Liquid Hydrogen (LH_2) is the only viable solution. Therefore, a huge challenge lies in the design and manufacturing of a cryogenic tank capable of meeting the low mass requirements, while sufficiently insulating the cryogenic fuel. Although the feasibility of liquid hydrogen as aviation fuel is already investigated and proven in projects like the Tupolev Tu-155 and the Cryoplane, only a handful of prototypes and demonstrators have been successfully tested.

The majority of the components required for commercial aircraft powered by liquid hydrogen, including the large cryogenic tank, are at a low Technology Readiness Level meaning advanced parametric modelling is required to support their design and optimization. The liquid hydrogen tank should meet conflicting requirements, as it has to demonstrate low heat losses in order to meet the boil off requirements, high strength in order to meet safety requirements and a low weight fulfilling the mass requirements, while having a low cost. In this direction, the present work refers to the development of a parametric multi-physics finite element model of a liquid hydrogen fuel tank for aviation applications. The developed finite element model comprises of a thermal part for calculation of temperature distributions and heat transfer and a structural part that uses the results of the thermal as inputs and combines them with other mechanical loads in order to perform stress/strain analysis. The modelling approach combines 3-D solid elements with 2-D thin-shell elements and 1-D beam elements and defines the geometry in a parametric manner allowing different tank variations, variable wall thickness, variable insulation thickness and variable supporting structure layout. The developed model is able to assess the structural and thermal performance as well as the mass efficiency of a large number of concepts aiding the design process.

In the present work, the functions of the model are demonstrated by the design process of a small scale tank. The investigated tank is designed to store liquid hydrogen with an energy content equivalent to the average amount of avgas carried by 4-6 seat general aviation aircraft. A variety of materials, insulation and structural concepts are investigated, leading to the preliminary design of a cryogenic tank capable of being fitted inside the fuselage of such aircraft.

This work was partly funded by FLHYing tank (flight demonstration of a Liquid HYdrogen load-bearing tank in an unmanned cargo platform), and H2elios (Large Scale Lightweight Liquid Hydrogen Integral Storage Solutions) projects, which are Clean Aviation projects funded by HORIZON-JU-CLEAN-AVIATION.

Multi-material design and integration of new functionalities

Chaired by:
Dr. Angelos Filippatos (University of Patras)

Advanced and innovative design of the traversing system for High speed - Low pressure turbine testing

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** Łukasiewicz Research Network – Institute of Aviation, Poland*

The paper presents the approach and outcomes of the traversing system design of the HS-LPT - High speed - Low pressure turbine. The design requirements included full integration with existing infrastructure and the testing rig. The traversing system performance was required to assure radial, yaw and circumferential movements of the probe inserted into the turbine's cross-section to obtain data about the mass flow and the pressures in specified areas. The most challenging issue that the design had to overcome was high temperature of the working environment, reaching 400 degrees Celsius. Due to the high temperature and pressure inside the turbine, the traversing system had to exhibit limited air leakages that may lead to deteriorated performance of the turbine. To satisfy those requirements, trade study was performed to select optimal sealing system aiming to reduce the complexity of the design. After multiple iterations of mechanisms design, thermal evaluation was performed in terms of heat transfer within flow through micro channels (non-ideal sealing) and cooling passages. Furthermore, mechanical assessment involving stress and modal analyses of the mechanisms was conducted as well as wear calculations to evaluate the lifetime of crucial components. All the analyses and their results allowed to obtain the innovative design of the traversing system suitable for turbine testing in adverse conditions.

Improving thermal Management of Structural Batteries by Nanomaterials

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Due to the growing demand for lithium-ion battery packs' high specific energy density, thermal stability in abused conditions is becoming increasingly important. Thermal runaway is a relevant issue for keeping safety and proficient employment of accumulators, therefore, new solutions for thermal management are mandatory. The use of high thermal conductive materials for spreading heat is gaining attention as a suitable treatment for improving battery performance. For this purpose, a hierarchical nanomaterial made by graphite nanoplatelet has been considered as interstitial material. High content graphite nanoplatelet films have a very high thermal conductivity and would enable the heat-spreading effect.

This study investigates the use of a thermally conductive material as a method for safety enhancement for a battery module included in a composite structure. A three-dimensional model based on finite element method has been developed to predict the heat generation during a battery pack's charge and discharge cycle using the Multiphysics software Comsol. The initiation and propagation of thermal instability involve multiple nonlinear thermal processes. Therefore, it is necessary to use a numerical model that accounts for these processes and their interaction to predict whether TR propagation will occur. In the present work, a coupled electrochemical-heat transfer model was set up to investigate the effectiveness of using a thermally conductive layer for

mitigating the temperature field. To account for the thermal response of a battery pack, the model includes the (i) the effect of charge-discharge on the temperature distribution and (ii) the thermal runaway modelling by including the heating kinetic. The results indicate that for the safety design of the battery pack, the thermal path should be effectively controlled, and particularly the heating related to the exothermic reaction must be directed away from adjacent cells. Using graphite nanoplatelet-rich films as an interleaved layer resulted in an effective temperature mitigation strategy since it acts as a temperature mitigation layer when connected to the ambient.

Investigating Structure-Property-Function relations of CNT-doped strips and CNT-doped veils using numerical methods and experimental data

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The aerospace industry requires materials with exceptional mechanical, thermal, and electrical properties that can withstand extreme conditions, including high speeds, temperatures, and pressures [1]. Additionally, since the demand for advanced material properties in aircraft structures is constantly evolving, there is a need for innovative functional materials [2].

In this concept, thermoplastic strips and low gsm melt-blown nonwovens, namely veils, doped with multiwall carbon nanotubes (MCNTs) have recently emerged. These materials are as promising candidates for aerospace applications, owing to their lightweight, high strength and exceptional electrical properties [3]. To fully harness their potential and meet performance requirements, it is crucial to understand their Structure-Property-Function (SPF) relations. These relations describe how a material's topology and microstructure affect its properties and ultimately its function in a specific application. Therefore, it is essential to understand how the microstructure of CNT-doped strips and CNT-doped veils will affect their mechanical and electrical properties and how these properties will translate into specific targeted functions. By studying the SPF relationships, scientists and engineers will be able to design and optimize materials that satisfy the demands of the aerospace industry, as well as other applications that require high-performance materials.

To address this idea, we conduct a computational investigation of the mechanical and electrical properties of copolyamide (coPA) strips and veils containing MWCNTs (both manufactured by TMNK Partners) using Finite Element Analysis (FEA) in the software package ABAQUS. We take into account the concept of SPF relationships to establish the link between material topology and specific properties, namely Young's Modulus and electrical conductivity, using either numerical methods or experimental data. We target specific functions, such as the structural function, strain sensing, lightning strike protection and electrical insulation. At the end, we aim to map the properties of the studied structures to the specified functions. Through this scope, we explore the capabilities of CNT-doped strips and CNT-doped veils, providing a better understanding of their potential and applications on a larger scale in aircraft structures. After analyzing the data, we conclude that it is possible to fulfill up to three functions concurrently. Additionally, we deduct that different functions can be targeted in various length scales of materials."

Keywords: carbon nanotubes, non-woven material, veil, strip, finite element simulation, experimental validation

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Integrating Sustainability in Conceptual Design: A Multi-Criteria Approach for Aircraft Composite Component Development

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The present work focuses on developing a novel design process that incorporates sustainability considerations in the early stages of product development, recognizing their critical importance in today's context [1, 2]. In the present work, sustainability is viewed as a quantifiable metric that encompasses technological, economic, and ecological aspects, including circularity throughout the component's lifecycle [3]. The aim is to integrate sustainability as a function within the conceptual design phase using a spiral design approach, introducing multi-criteria optimization requirements and trade-offs between potentially contradicting decision criteria.

In this frame, the impact of material selection on the sustainability of an aircraft composite component is examined. Use of both virgin and recycled carbon fibre reinforced plastics (CFRP) as potential materials is explored. To efficiently explore various design alternatives, a finite-element parametric numerical study using ABAQUS is employed, following a design of experiments (DOE) approach, which allows to systematically evaluate different stacking layups and combinations of virgin and recycled CFRP layers. This helps in identifying the most effective configurations that meet the specific functional requirements of the component. To comprehensively assess the sustainability implications associated with different design alternatives, a multi-criteria decision-making (MCDM) methodology is incorporated in the analysis. This approach enables trade-offs between different aspects of sustainability, considering factors such as environmental impact, cost, and circular economy aspects. Once the design configurations meet the functional requirements, an integrated sustainability metric, incorporating the above dimensions, is calculated. This metric quantifies the overall sustainability performance of each design alternative. Optimization algorithms implemented in R, are then employed to determine the optimized set of values of the design variables that result in the most suitable, sustainable design solution for the specific aircraft component. After obtaining the optimized set of values of the design variables, the next step is to validate the design against the specific functional and technical requirements of the aircraft component.

By adopting this approach, the intention is to address the current lack of attention given to sustainability in the conceptual design phase. Instead of focusing solely on ecological impacts or conducting post-design assessments, the proposed approach seeks to embed sustainability requirements into the conceptual design process itself. This way, designers can decide and balance various criteria, while creating solutions that align with sustainability goals during the conceptual design process.

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3D printed soft actuator with integrated Flex sensor and SMA wire for closed-loop control

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Smart materials have become increasingly popular due to their unique ability to sense and respond to stimuli, making them valuable for a wide range of applications. The integration of these materials into soft matrices has made it possible to create soft actuators and sensors that are lightweight and flexible, making them ideal for use in advancing fields of human-machine interaction and dexterous robots. In order to respond to stimuli in real time, it is essential to integrate sensors and actuators into the soft matrix and build closed-loop control. One of the most commonly used smart actuator materials is shape memory alloy (SMA), which can provide a high level of active force that other materials cannot achieve. The flex sensor, which detects the bending of an object based on changes in conductive material resistance, is another crucial component in this process. This article presents a novel soft SMA-driven actuator capable of achieving a desired bending angle. To create the actuator, Flex sensors and SMA wires were embedded into the TPU matrix of the sample during 3D printing. By deactivating and activating the two SMA wires according to sensing signals, the sample could track the input deformation angle. This approach enabled closed-loop control and improved the overall efficiency of the system. Additionally, the presented manufacturing method provides a simple and cost-effective solution for the rapid prototyping and custom design of smart materials with complex structures and high resolutions. This process has the potential to open up new possibilities for the use of smart materials in various fields.

From Sensors to Systems

Chaired by:
Prof. Cezary Szczepański (ILOT)

Selected aspects of electronic hardware development and testing for the Flight Reconfiguration System in accordance with the RTCA DO-160G standard

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Every airborne equipment must be design to be able to work in harsh environmental conditions which could potentially be encountered during aircraft operations. Hence, during development phase avionics systems must be tested according to standard procedures and environmental testing criteria which are included in certain standards, such as RTCA DO-160G document. In order to successfully pass the tests, the electronic device must be correctly designed. Therefore, all necessary aspects of environmental conditions have to be presented in system requirements. DO-160G procedures consists of 26 sections and three appendices. Covered tests include vibration, power input, lightning, and electrostatic discharge, pressure, salt, water, magnetism and many more environmental conditions. The purpose of these tests is to provide a controlled means of assuring the performance characteristics of airborne equipment under similar environmental conditions when operating equipment in air.

This paper will present applied solutions for input power protection in the electronic design of the Flight Reconfiguration System (FRS) developed within the scope of the Clean Sky 2 / Clean Aviation COAST project. In this article methods of circuits protection from input power disturbance according to Section 16 in DO-160G will be discussed. Computer simulations and laboratory test results will be presented and analysed. Achieved results allow for claiming, that the applied methods of circuits protection assured their proper work. It was observed that the developed electronic equipment worked correctly after completing environmental and input power testing.

Comparison of Two Aerodynamic Models for Missile Trajectory Simulation

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To achieve their intended targets, artillery-launched missiles require precise trajectory tracking. The accuracy of which is largely determined by the aerodynamic model employed in flight simulations, which impacts how the missile interacts with the surrounding air. In this work, the performance of missile path following with two distinct aerodynamic models was examined for their possible influence on trajectory following accuracy. The study incorporates the path following guidance algorithm, which enable the missile navigate along a predefined path. The simulation mathematical model was developed in the MATLAB/Simulink environment. In addition, by integrating the path-following algorithm with the two aerodynamic models, the dynamic behaviour of the artillery missile can be compared. This allows for a more comprehensive analysis of the trajectory and the effects of each model on the desired flight path.

Further research could explore the differences between the two models in greater detail and quantify their impact on missile trajectory predictions, in addition to further exploring the specific characteristics and limitations of each model. This would involve analysing their assumptions, computational methods, and inputs to identify potential sources of error or uncertainty in the simulations. Moreover, these results have important implications for the design and operation of aerodynamically controlled artillery-launched missiles, as well as for military planning, decision-making and contribute to the overall effectiveness and efficiency of artillery operation.

Integrated visual-inertial navigation for flying vehicles in GNSS-denied areas

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Flying objects require continuous and accurate information about their position and orientation. For this purpose, integrated INS/GNSS navigation systems are commonly used. INS provides reliable continuous measurements of motion parameters to determine an object's position and orientation, but with accuracy that deteriorates with time. On the other hand, GNSS provides consistent accuracy, but the signal is not reliable, as it may be lost, jammed or spoofed, which is unacceptable for critical systems. To counteract the adverse consequences, it is necessary to use alternative measurement sources to ensure reliable navigation.

This issue is addressed by a research project started in the Avionics Department of the Łukasiewicz Research Network – Institute of Aviation, which aims to develop a navigation system relying on inertial measurements supported by correction data other than GNSS. From the previous analyses, it has emerged that the use of data from vision and lidar/radar systems for correction is the most promising. These systems can provide an alternative to GNSS as a source of the data required for reliable navigation, while meeting expectations for autonomous and passive operation.

Current efforts are continuing towards a more thorough investigation of integrated navigation for a flying object in a GNSS-denied area using INS as the core. It was assumed that small and relatively inexpensive MEMS-type inertial sensors would be used for INS and corrected with information from geo-referenced images from the vision system. Navigation algorithms have been developed and implemented on target devices. This paper presents the results of a theoretical analysis of the achievable accuracy, as well as the results of software simulation and hardware-in-the-loop laboratory tests.

Comparison of flight parameters in SIL simulation using commercial autopilots and X-Plane simulator for multi-rotor models

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Modern aviation technology development heavily relies on computer simulations. SIL (Software-in-the-Loop) simulations are essential for evaluating autopilots and control algorithms for multi-rotors, including drones and other UAVs. In such simulations, it is possible to compare the flight parameters achieved by flying platforms using various commercial autopilots which widely used in the UAV sector.

The article examines the simulated flight test results of a drone performing the same mission using different autopilot systems. The X-Plane software was used as an environment to simulate the dynamics of the drone and its surroundings. Matlab/Simulink provided the interface between Autopilot software and X-Plane models. This research focused on analyzing UAV flight characteristics such as stability, trajectory tracking, response time to control changes, and overall effectiveness of autopilots. Various flight scenarios including take-off, landing, flight at constant altitude, dynamic maneuvers and flight along a planned trajectory were also examined. In order to obtain the most accurate and realistic results, the tests were carried out in various weather conditions. The aim of this research is to provide objective data and analysis to compare the performance of commercial autopilots.

The findings of this study may have a considerable impact on how autopilot designers and developers choose the best platforms and technologies for their projects. Future research on this topic will compare the obtained data with flight test data.

Detect and Avoid for Small Unmanned Aerial Vehicles using Mode-S Transponder

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A new Detect and Avoid (DAA) method for safe navigation of small-sized UAVs within an airspace is proposed in this paper. The proposed DAA method relies upon cooperation between the UAV and the surrounding transponder-equipped intruders. To do so, the intruders share their altitude and their identification code with the UAV by using a miniaturized Mode S operation Secondary surveillance radar (SSR) after UF11 and UF4 interrogations. The proposed DAA method removes the need for primary radar and a clock synchronization for ranging because it uses the estimate of the elevation angles of the intruder from its DF4 reply and the decoded altitude information for ranging. The proposed ranging method outperforms the round-trip time (RTT) ranging because Mode S transponder replies allows small variances in timing which, although small affect the system performance of the RTT-based ranging. However, our ranging method is an Angle of Arrival (AoA)-based ranging.

In addition, the proposed DAA system takes the advantage of a new radial velocity estimator that can estimate the radial velocity of the intruder from a single DF4 reply. Moreover, the DAA system is equipped with an intruder identification mechanism that classifies the intruders into high-, medium-, and low-risk intruders based on the estimated parameters from DF4 reply. The output of the classifier enables the UAV to adjust its navigation parameters for safe navigation accordingly.

The block diagram of the proposed DAA method sensing the kth, k = 1, 2, . . ., N, aviation obstacle is illustrated in Figure 1. As seen, there are Na + 1 down-conversion receivers. including bandpass filter (BPF), power amplifier (A), local oscillator (LO), lowpass filter $H(f)$, and analogue-to-digital converter (ADC). The blocks S2V and V2M are the stream to vector and the vector to matrix buffers, and ↓M is the M-fold decimation block. As seen in Figure 1, the output of the S2V, i.e., the vector y, is the input of the TO-E, NC-SD, and RV-E blocks, and the output of the V2M, i.e., the matrix Ya, is the input of the AOA-E block.

The TO-E block is the timing offset estimator and is used to estimate the beginning of the received DF4 mode S reply of the kth aviation obstacle, i.e., $\hat{nk}$. The NC-SD block is the noncoherent symbol detector and is employed to demodulate the DF4 reply packet of the kth aviation obstacle, i.e., $\hat{bk}$. The RVE block is the radial velocity estimator and is used to estimate the relative radial velocity of the kth aviation obstacle, i.e., $\hat{vk}$. The AoA-E block is the 2D AOA estimator and is employed to estimate the elevation and azimuth angles of the k aviation obstacle, i.e., $\hat{\Theta k}$ and $\hat{\Phi}\ k$ respectively. The Decoding block is employed to decode the altitude information of the kth aviation obstacle, i.e., hk from $\hat{bk}$, and the cyclic redundancy check (CRC) block is used to validate the integrity of the data in $\hat{bk}$. As seen, the outputs of the parameter estimators, i.e., $\hat{vk}$, $\hat{Rk}$, $\hat{\Theta k}$, and $\hat{\Phi}\ k$ are used as the inputs of the intruder identification block.

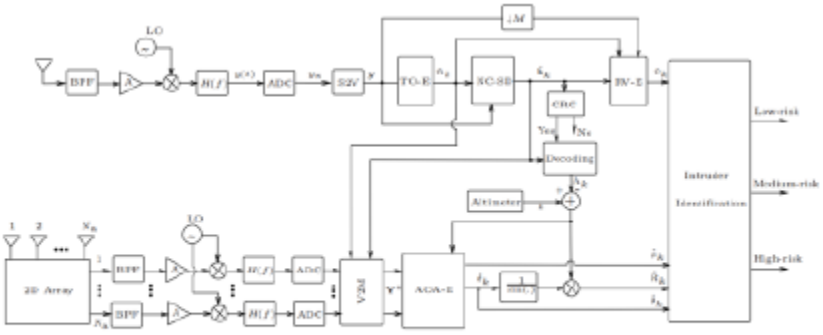

Figure 1: Block Diagram of the proposed DAA system.

Flight test evaluation of trim tab stabilisation system lateral channel on a PZL-130 Orlik aircraft

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** Łukasiewicz Research Network - Institute of Aviation, Poland*

Previous research on the flight stabilization system that uses trim tabs for the PZL-130 Orlik aircraft resulted in the development and simulation testing of the system. Positive simulation results allowed for the next stage of system verification – flight tests. The paper presents the evaluation of the flight test results during which the lateral channel of the stabilization system was inspected.

The system itself was designed using modern methods of model-based design, automatic code generation from model, software and hardware in the loop testing. This approach allowed us to discover and correct errors before installation in the aircraft and flight tests. The onboard computer and trim tab actuators were also developed and tested in hardware in the loop simulations using the same interfaces (Arinc 429 and analogue) as in the real aircraft.

The lateral channel of the flight stabilization system was tested as the first one in flight. The internal loop of this channel has PID controller with roll angle feedback, while the external loop has PI controller with heading angle feedback. The channel computes required aileron trim tab angle to stabilize aircraft heading. During the flight tests, a specially developed application was used by the flight test engineer to send commanded heading and roll angles to the stabilization system and tune the controller gains. Evaluation of recorded data presented in the paper gave insights of how the automatic trim tab stabilisation system responds to given setpoints and allowed for assessment of its control quality.

The capability of retrofitting the aircraft's fuel level measurement and indication system based on the Mi-8 medium-lift helicopter

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The retrofit of the fuel level measurement system can present various engineering and regulatory challenges. The operation focuses on replacing outdated, inaccurate, technically complex or hard-to-procure components while simultaneously adding new features to the system.

Upgrading any avionic system requires ensuring compatibility with the existing aircraft infrastructure. It may be necessary to integrate new components into existing aircraft structures, which can present physical constraints. Limited space, restricted access, and weight considerations can complicate installation and may require innovative engineering solutions. The fuel level or mass measurement and indication system as a distributed system, consisting of many dependent devices, sensors, or indicators can reveal complexity in terms of integration.

One of the greatest advantages of replacing the fuel indication system is the increase in indication accuracy. The system equipped with old-type liquid level sensors and a single-scale analogue indicator can be highly inaccurate, as is the case with the Mi-8 helicopter. Accurately precise fuel level measurements are crucial for safe and efficient aircraft operations. Accuracy improvements can be achieved by incorporating modern liquid-level probes, digital indicators, and digital data transmission between system components.

System replacement can pose challenges from a regulatory standpoint, especially when fuel measurement is critical for flight safety. Safety assessment analysis should encompass the overall impact of the system on potential threats to the crew and passengers. Retrofitting must adhere to relevant regulations and guidelines, necessitating comprehensive documentation, testing, and certification processes.

In summary, this paper aims to explore the challenges and benefits of retrofitting the fuel level measurement system on the Mi-8 helicopter, offering insights into the necessary improvements for enhancing its performance and safety. As an ageing aircraft, the Mi-8 helicopter, necessitates these upgrades for optimal functionality, especially due to its enduring popularity as a widely utilized aircraft with a large number of units in service.

Clean Sky 2 T-WING Project: towards the first flight

Chaired by:
Ms. Marika Belardo (CIRA)

TWING PROJECT: FROM DESIGN TO MANUFACTURING

Marika Belardo*, S. Orlando, P. Ariola, J. Beretta, C. Pezzella, A. Menichino, A. Chiariello, D. Alberotanza, F. Dell'Anno, P. Villano, L. Di Palma

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The purpose of this work is to assess the results obtained so far by the project T-WING, funded by Clean Sky 2 Program. The project is aimed at developing, up to experimental flight, the innovative composite wing of the Next Generation Civil Tiltrotor (NGCTR-TD) under the guidance of Leonardo Helicopters Division acting as team leader. NGCTR-TD is one of the two Integrated Aircraft Demonstrator Platforms which will be delivered under Clean Sky 2 Fast Rotorcraft. The main challenges encountered within more than 5 years of hard work will be illustrated. Starting from the overall design integration: fuel storage, aeroelasticity and crashworthiness played an important role from the very beginning. Suitable numerical methodologies and models were developed to accomplish often contrasting requirements. Sub Systems integration was another aspect which needed proper management of concurrence with the other owners namely the aircraft integrator and the other Consortia committed to deliver those systems. Manufacturing of the innovative highly integrated composite skin was accomplished thanks to a modular tool chain aimed at minimizing spring back and non-conformities in the specimen. Assembly of the flight article foresaw also some systems integration, such as fuel lines and flight instrumentation. Last, but not the least, the main aspects regarding the static test qualification will also be described.

HIGH FIDELITY CRASH ANALYSIS OF NGCTR-TD COMPOSITE WING

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A highly impulsive phenomenon like a crash event of an aircraft needs a nonlinear dynamic analysis to be set-up to properly catch the structural behaviour of the specimen. The present work regards crash analyses that were performed on the NGCTR-TD composite wing by T-WING team, to study wing crash behaviour in order to identify the frangible section location as a function of the load factor applied. The analysed wing model was derived by the Nastran model used for the static analyses, properly converted in Ls-Dyna solver. Virtual accelerometers were placed along the wing span to record local accelerations. To simulate the crash event and consequently the loads applied to the wing, a prescribed acceleration of 5 g's was applied to the lift beams which simulate the fuselage attachments. The results obtained showed wing failure in an area located just outboard of the central wing sub-assy with the fracture propagating from the bottom stringer to both front and middle spars and ultimately to the rest of the wing section. The analysis confirmed that under 5 g's the wing breaks in such a manner to alleviate the loads on the fuselage structure and thus in principle could preserve survivable volume for the occupants.

A methodology to tune the stick-beam dynamic models of a tiltrotor

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The T-WING project is a CS2-CPW research project aimed at designing, manufacturing, qualifying and testing the new wing of the Next Generation Civil Tilt-Rotor (NGCTR), as part of FRC IADP activities.

This paper presents a methodology that has been developed to tune the stick-beam model of the wing of the NGCTR in order to match the GFEM wing's dynamic behaviour in terms of eigenfrequencies and mode shapes. The initial guess of the stick-beam model has been generated by the use of a static condensation of the GFEM wing.

The tuning process has been set-up as an optimization problem where the variables are the beam properties, and the objective function (to be minimized) is the sum of the weighted quadratic errors of both eigenfrequencies and MAC (Modal Assurance Criterion) values. Since the optimization process acts modifying the beam properties, a MAC analysis tracks the target modes at each iteration. At the end of each iteration, until the convergence criteria are reached, a new guess of the variables is estimated as function of the gradient vector and hessian matrix of the objective function.

The result of the application of this methodology is the fine tuning of the stick beam model in several mass cases such as maximum take-off weight (MTOW) and maximum zero-fuel weight (MZFW).

A ROBUST METHOD TO DESIGN AND OPTIMIZE TEST RIG SET-UP FOR THE QUALIFICATION OF THE COMPOSITE WING OF A TILT-ROTOR

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The full-scale static test is a very demanding phase for the qualification of an aeronautical structure. Within the Clean Sky 2 T-WING project, a CFRP wing for the Next Generation Civil Tiltrotor Demonstrator was designed and manufactured by a consortium of research entities, SME and industries. During the design phase, the most critical load cases have been identified with the aid of Shear Forces/ Bending Moments (SFBM) and failure modes. In order to qualify the wing item, the engineering team has to prove the wing capability to withstand forces and moments and performance up to ultimate loads. So, a specific test rig was designed in order to replicate as faithfully as possible the SFBM diagrams on the wing through a series of hydraulic jacks and test rig setup. The hydraulic jacks cannot be placed in any position and with any orientation, but they shall respect their specifications (in terms of maximum applied force), have to meet the geometrical constraints of the setup (the jacks can be placed only in certain positions and directions) and they shall replicate the SFBM diagrams with sustainable efforts and limited errors (5%).

In order to meet these goals, an efficient robust algorithm has been used to identify the best configuration. This algorithm consists of five phases: in the first one, the number of significant components is determined through an analysis of the independent components of the influence matrix (the matrix that link a component of the jacks forces to the SFBMs generated); in the second phase, least square linear optimizations without constraints are launched in order to identify the most suitable points where to apply the jacks forces (efficient components); from previous optimizations, the solutions that satisfy directional constraints are selected and ordered in terms of the global error on SFBMs and the entity of the jacks forces (third phase); in the fourth phase, the best solutions on the Pareto front are analysed and least square optimized in order to match all the constraints and to choose one final solution; in the last phase (the fifth), the external jacks forces are evaluated to replicate the reaction forces on points of the wing attached to the supporting struts. The result of this procedure is a test rig setup configuration with a feasible set of hydraulic jacks forces able to reproduce the SFBMs on the wing with a minimum number of employed hydraulic jacks and a minimum effort in terms of overall applied forces.

TWING: FLIGHT TEST INSTRUMENTATION DESIGN AND INSTALLATION

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In order to validate loads and aeroelastic models, a number of sensors were foreseen on the wing of the Next Gen Civil Tiltrotor. Moreover, a number of additional sensors were put on critical areas of the structure, for safety of flight reasons. Numerical activities were developed in order to optimize the number and type of strain measurements for the loads validation purpose. A complete list of sensors with their positions on the structure was agreed with all the stakeholders, that was the input of the Design Activity of the flight instrumentation system. Preliminary Design Review and Critical Design Review were accomplished in order to deliver a complete DMU of the instrumentation system, with all the components, including the cables. One of the challenges was to minimize the cable routing, optimize soldering pads position with minimal impact on the other systems to be installed on the wing. Concurrence with the Leader was crucial to achieve the expected results in terms of Design. Experimental activities dealing with strain gauge thermal compensation strategies were conducted and the dummy gage technique was chosen for the implementation of the NGCTR-TD wing. Installation activities were performed by following strict procedures agreed with the leader. Some sensors were installed on the parts out of the jig (e.g. the upper skin), other were installed with a partially assembled specimen on the jig. The position of the sensors was traced by means of laser tracking techniques, to reduce time and risk of positioning errors, by following the DMU data. Despite the availability of a complete DMU it was, for critical areas, necessary to have 3D mockups of systems, in order to minimize the risk of improper installation.

TWING: Preliminary Vibration Test Activities

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A vibration test is the most used method for performing the modal analysis of a structure. The purpose of the vibration test is to determine dynamic characteristics such as the natural frequency, mode shapes and structural damping coefficient of the most important vibration modes inherent to the dynamic response of a test or flight article referring to its stiffness and mass distribution.

A Ground Vibration Test (GVT) has a unique combination of the importance of structural dynamics in aircraft and safety requirements. A vibration test on a large structure always involves multiple inputs and multiple outputs (MIMO) frequency response testing. Random excitation is sometimes used, but most often techniques, such as step sine excitation, are used to supply the required energy for the system. Phase resonance testing allows the user to obtain test results by exciting a single frequency at a time and sweeping through frequencies. These techniques may result especially useful when nonlinear behavior is expected from a particular structure.

The main objectives of the T-WING vibration tests are:

- to characterize the dynamic behavior of the primary structure and its movable surfaces,
- to validate and update the Finite Element (FE) models,
- to perform aeroelastic calculations based on experimental results,
- to gather auxiliary data for flight flutter testing,
- to contribute to the wing qualification.

The first part of this paper contains a preliminary numerical activity consisting in the employment of simplified FE models that reproduces the dynamic behavior of the T-WING to perform sensitivity analysis with respect to masses and constraint conditions. Subsequently, an experimental test campaign has been performed to manage the MIMO procedures and define the planning of the real full-scale tests, and the test setup, mainly with reference to the boundary conditions, Figure 1.

The second part of this paper refers to preliminary test results on a mockup of the full-scale equipped wing which has been performed during the manufacturing of the wing to be installed on the real aircraft, Figure 2, and the preliminary experimental activities concerning both the primary structure of the T-WING and movable surfaces, Figure 3.

GAPPY POD METHODOLOGY APPLIED FOR THE STRUCTURAL COMPLIANCE OF THE WING OF A CIVIL TILT-ROTOR

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Most design and modelling goals require accurate predictions of numerical results in order to gain good design information for a proper insight into complex systems. The need to analyse systems with greater refinement and sophistication requires the support of methodologies, for instance, Finite Element Methods (FEM), able to cover complex phenomenologies with major precision but resulting in more computational effort. Typically, stress analysis is crucial during the aircraft sizing phase to validate the preliminary design and perform design modification loops to recover from the lowest or negative margin of safety. Aircraft structures are sized to resist a huge amount of load conditions (o

f the order of tens of thousands) expected during their operative life. The Load Department defines these loads and stores them in the Design Limit Load Book (DLL). In a certification context, it is expected that all these loads will be analysed to provide structural safety justification in front of the Authority. In an experimental prototype context, such as the context of Collaborative Research projects funded by the European Commission, to substantiate the structural safety for a first Permit to Flight, the investigation on the DLL have to be kept to a minimum, due to time constraints of the project. This could mean to analyse, among the thousands of Loads, only the most critical subset. This task is not straightforward because a significant amount of engineering judgment is needed to select critical loads. One of the methodologies to sort out the most critical loads is based on maximum shear,

bending, and torsion (SFBM) cross-plot diagrams along the wingspan. An alternative methodology, fed only in part by FEA, can contribute to optimise the job of the structural department to sort out the critical loads subset to be then stress analysed in detail. This could be the case with surrogate modelling methods. The principle of surrogate modelling is to replace a high-fidelity system model (e.g. a detailed FEM) with a model (surrogate) that is less demanding from a computational standpoint while showing at the same time an acceptable representation of the original governing equations. In the framework of H2020 Clean Sky 2 T-WING project, a methodology to build, train, assess and use a surrogate model of the wing structure has been set up. The aim is to aid the structural department in the downselection of the most demanding loads among the thousands of DLL. It is based on a well-established methodology within the computational fluid dynamics domain, namely Gappy - Proper Orthogonal Decomposition (G-POD). It consists of building a number of POD based "surrogate models" of the wing structure that need limited knowledge from FE calculations. A restricted set of design limit SFMB conditions has been selected thanks to a preparatory clustering process, based on the maximum value of shear, bending, and torsion quantities in order to start the surrogate model building process, i.e. to choose the number and type of loading conditions to be run in the first iteration.

At the beginning of the whole activity, a number of FEM control points are chosen based on the most critical locations to monitor. These critical locations are decided in concurrence with stress analysts since they represent the critical locations of the structure (e.g. wing root rib, front and rear spars, upper and lower skin and wing-fuselage interface links). FE simulations in correspondence with the first set of loads are then run to estimate the structural stress state in the control locations. These simulations will act as a model set-up at the first iteration. After the first iteration, an assessment based on the definition of an empirical norm gives the degree of reliability of the model in predicting the outputs. Based on this assessment, in an iterative manner, additional FE runs can be performed to enhance the surrogate model reliability. Once built and properly trained, the surrogate POD-based model can be used to predict, in a predefined subset of FE elements, the strains, the stresses, and the internal forces with a controlled degree of reliability. Knowing the structural safety limits (allowable stress, for instance), the prediction of the surrogate model will identify the DLLs that give rise to negative margins of safety. These load conditions will be considered as critical in order to perform a detailed stress verification. In this preliminary work, the main pillars on which the methodology is based are reported, focusing on the error's management and on the potentiality of the surrogate models of being adaptive, with an advantage in terms of reliability of the prediction. The obtained results will be validated with a cross-check process based on FEA available results.

Post buckling and non-linear strength analysis of a civil tiltrotor composite wing on full scale static test rig configuration

ANTONIO CHIARIELLO*, G. PERILLO, P. VITALE, S. ORLANDO, M. LINARI, R. RUSSO, M. BELARDO
** CIRA, Italy*

The paper presents analysis of the buckling and post buckling and method adopted to predict the behaviour of Test article of the tiltrotor wing on test rig. The reference vehicle is the Next-Generation Civil Tiltrotor Technology Demonstrator (NGCTR-TD) developed by Clean Sky research consortium framework. The nonlinear analysis of a wing is one of the most important and challenging activities to understand the behaviour of the structure during the subsequent phases of flight. It is demanding to properly size the wing which must withstand high loads for prolonged periods of time. The authors propose a detailed nonlinear finite element model, with contacts, large displacement and response including material plasticization for all metallic parts, based on the MSC Nastran (MSC Software) SOL-400 solver of the test article of the wing plus test rig and post-processing. During the simulation the wing structure is loaded by discrete forces (by means of whiffle tree and jack load actuator) , which envelop the shear and bending moment diagrams (SFBM). The two test conditions have been applied progressively until 100% of the load has been reached (limit load). This is only the first part, the goal is to predict the behaviour of the wing at 150% of the limit load to reach up to 181.5% or 189.5% of the limit load depending on the load conditions. In this phase the survival of the laminate is essential to anticipate the results of the real test of the wing.

Project Session: OAPES

Chaired by:
Prof. Gustavo Alonso (Universidad Politécnica de Madrid)

Hybrid energy storage systems for high power spacecraft missions

Sergio Marín-Coca*, Elena Roibás-Millán, Santiago Pindado, Miguel A. de Miguel, Hugo Valente
** Universidad Politécnica de Madrid, Spain*

This work aims to analyze the feasibility of utilizing hybrid storage systems to enable the operation of high-power payloads during eclipse periods. The main objective of the study is to achieve configurations with the same performance as traditional designs, but with reduced mass and/or volume, or to maintain the mass and volume while increasing the peak power capabilities. The proposed solution involves the use of supercapacitors and high-energy lithium-ion cells, with the former serving to meet peak loads and the latter supplying the mean power needs. We propose a simple architecture for the electrical power system and derive the sizing equations for the supercapacitors and lithium-ion cells from the governing power and energy balance equations. Our results allow for informed decision-making on the suitability of the hybrid configuration based on the peak power demand and its duration, as well as the mean power demand during eclipse operations.

Development of Sun-tracking law for payloads with pointing restrictions in the UPMSat-3 mission

Angel Porras-Hermoso*, Sergio Marín-Coca, Javier González-Monge, Juan Bermejo-Ballesteros, Elena Roibás-Millán, Juan Zamorano, Ángel Pérez
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Satellites dedicated to remote sensing whether of the Earth or space, require their instruments to be pointed towards the place where their object of study is located. These satellites can face significant challenges as different components also have its own pointing requirements to be operative or work optimally. That is the case of solar panels for electrical power generation, where perfect pointing of the panels towards the Sun can affect negatively to payload operation. Common solutions for maximizing power generation include using orientable solar panels. However, this approach

increases the complexity of the satellite, and increase the cost of the solar panels. In this study, a new approach is proposed that enables high-consuming remote sensing payloads to operate for extended periods without the need for orientable solar panels. To ensure maximum power generation without compromising the satellite's pointing constraints, an optimal tracking law is derived. This law maximizes the projected solar array area at each instant, resulting in maximum electrical power generation. The proposed approach and its implementation is validated against an actual mission scenario. This work offers significant benefits for satellite operators, reducing the need for costly orientable solar panels and enhancing the overall efficiency of satellite missions.

Use of thermal data to estimate satellite rotation rate in the UPMSat-2

Angel Porras-Hermoso*, Javier Piqueras, Javier Cubas, Elena Roibás-Millán, Alejandro Alonso, Hugo Valante

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Attitude determination is a fundamental task of the Attitude Determination and Control Subsystem (ADCS). It involves determining the spacecraft's orientation with respect to a reference system and calculating its angular velocity, which is essential for understanding where the payload is pointing and the spacecraft's stability. The determination of the attitude is obtained using sensors such as Sun sensor, Nadir sensor, or Star tracker. Regarding the spacecraft angular velocity, gyroscopes or MEMs can be used to measure the angular velocity of the satellite, but in their absence, the velocity can be derived from the attitude data of the other sensors. However, this method requires a sampling rate to be two times the frequency of the movement, otherwise the angular velocity cannot be calculated with traditional methods. To address this issue, this study proposes a thermal analysis of the external temperatures of a rotating satellite to obtain its rotation rate. This method is especially useful for satellites with poor or limited data sample rates. The proposed methodology is demonstrated using the UPMSat-2 case to prove the functionality of its experimental ADCS.

Including experiments of AI techniques onboard UPMSat-3 satellite mission

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AI techniques are currently being used in general purpose industrial computing systems. There is a great interest in expanding its use across other types of systems. However, they are not immediately applicable to embedded safety critical systems. In particular, in space systems there are subsystems with high integrity requirements, which means that their failure could affect the overall behavior of the vehicle. It could even mean the loss of the mission.

This paper deals with the use of some relevant AI techniques onboard space systems. In particular, the aim is to carry out specific experiments to evaluate their behavior and their possible effect on appropriate subsystems. Machine Learning and Neural Networks are potential techniques for these experiments. The objective would be to evaluate its applicability, select the most appropriate tools and determine its feasibility to place onboard.

The authors of this paper have participated in the development of UPMSat-2, which is a micro-satellite that was launched in September 2022. Its software implementation is conformed to safety critical space standards. The received telemetry, along with models of its behavior, will serve as a starting point to characterize the potential IA components and their integration.

Currently, the new UPMSat-3 satellite is being developed. Work is underway to include experiments using AI techniques in two subsystems: Attitude Determination and Control Subsystem, and Thermal Control Subsystem. Software developers are collaborating with their leaders to identify the most appropriate and useful features, and integrate their behavior into the subsystems.

An additional challenge in this approach is to guarantee that the behavior of these experiments does not affect the global system of the satellite. Specifically, there are two important aspects: to ensure that the temporal behavior of the AI components supports the proper behavior of the most essential subsystems, and dynamically analyzing and validating that their outputs are within reliable ranges.

CFRP Bonded Repair/Certification of Bonding

Chaired by:
Ms. Noelia González Castro (AIMEN)

Investigation on Advanced Joining for Reactive Acrylic Thermoplastic Composites

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Fibre-reinforced thermoplastic composites (FRTPCs) are widely used in several industries due to their recyclability, re-processibility and weldability properties, besides their high strength-to-weight ratio[1]. Thanks to molecular mobility, thermoplastics (TPs) resins flow like viscoelastic liquids if heated above the glass transition temperature, Tg or at the melting temperature, Tm (in the case of semi-crystalline polymers). Thanks to this property, they can be assembled by the fusion bonding process.

Joining of reactive thermoplastics by welding technologies is suitable as an alternative to adhesives, and mechanical fastening due to the easy automation and fast joining processes and as repairing technology. Joining thermoplastic composites by welding techniques overcomes some of the issues of the traditional joining technologies such as extensive surface preparation and long curing cycles (adhesive bonding) or stress concentration typical of mechanical fastening. For these reasons, welding is considered one of the most attractive features of thermoplastic composites [2]. Among the different welding techniques, the most suitable for the carbon fibre reinforced thermoplastic composites (CFRTPCs) are ultrasonic and induction welding. Ultrasonic welding relies on the conversion of high-frequency and low amplitude mechanical vibration into heat by the contact surface and intermolecular friction. Induction welding is based on the heat generated by joule and dielectric heating when an alternating magnetic field is applied to an electrically conductive material.

While TPs are suitable for joining by fusion bonding techniques, the main disadvantage of these materials is the need for high processing temperatures and pressures caused by the high viscosity of melted matrix. Therefore, novel thermoplastic monomers, viscous at room temperature thanks to their short chains, are being developed. An example is the Elium© resin, recently developed by Arkema, which is based on an acrylic thermoplastic and can also be cured at room temperature [3]. The liquid state at room temperature and the relatively low viscosity of 0.2 Pa·s make it suitable for VARI and RTM processes.

The study presented in this article investigates the effectiveness of fusion bonding of carbon fibre reinforced composites (CFRC) manufactured by Elium 188-O resin, by ultrasonic and induction welding. The welding characteristics of Elium composites were investigated by optimizing the welding

parameters with preliminary Interlaminar shear tests ILSS (Inter-Laminar Shear Strength). The fracture behaviour of CF/Elium composites has been investigated through end-notched flexure (ENF) to investigate the delamination critical energy in Mode II. A comparative study of some process variables such as welding and consolidation time required power and energy were also performed. This work showed that induction and ultrasonic welding of reactive thermoplastics are promising technologies for reactive thermoplastic composite.

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[2] J.P. Reis, M. de Moura, S. Samborski, Thermoplastic composites and their promising applications in joining and repair composites structures: A review, Materials (Basel). 13 (2020) 1–33. https://doi.org/10.3390/ma13245832.

[3] B. Palmieri, A. Petriccione, G. De Tommaso, M. Giordano, A. Martone, An efficient thermal cure profile for thick parts made by reactive processing of acrylic thermoplastic composites, J. Compos. Sci. 5 (2021). https://doi.org/10.3390/jcs5090229.

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Smart cure of thick composite filament wound structures to minimize the development of residual stresses

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The manufacturing process has a significant influence on the product quality of filament wound composite parts. During the filament winding process, a large tensile load to the fibre was applied and maintained during resin curing, resulting in residual stress. This residual stress gradually relaxes due to the fibres' slippage, the matrix's crosslinking, and different coefficient of thermal expansion between composite parts and mandrels. As a result, increasing the number of layers becomes more problematic. In the winding process, the relaxation phenomena can be divided into mechanical ones caused by fibres' radial movements and chemical and thermal ones due to the resin curing. This work aims to provide an analytical and optimisation tool to find the optimal winding parameters to obtain better mechanical performance of the filament wound composite accounting for the process-induced residual stresses.

In this work, a finite element analysis (FEA) has been carried out to study the effect of the viscoelastic behaviour of the material on the rise of residual stress on thick cylinders. The FE model was developed to predict the temperature distribution and the degree of polymerisation during the consolidation process. In addition, the polymerisation kinetics of the epoxy resin system has been investigated by thermo-mechanical test.

The reaction kinetics was developed by analysing the DSC thermograms and modelled according to the Kamal-Sourour semi-empirical model. The viscoelastic properties of the resin and the composite have been evaluated by dynamic mechanical tests. The coupled Heat Transfer/Mechanical analysis, where the heat generation due to the curing process was coupled with the heat generated due to the resin polymerisation, has been implemented for calculating the residual stress. The effect of the mandrel thickness and material has been discussed, and the optimal

cure profile was identified as a function of process parameters to minimise the thermal gradient within the composite element.

Acknowledgement: This research was carried out in the framework of the project SMART TOW WINDING CUP, founded by the Ministry of University and Research, grant number ARS01_00871, PON "Ricerca e Innovazione" 2014 – 2020 Azione II – Obiettivo Specifico 1b.

Hard-patch induction welding of fiber reinforced thermoplastics using flexible induction heating blankets as part of the EU-funded RetPair project.

Markus Kaden, *Msquare GmbH, Germany*

In order to make components of FRP competitive and economically viable, in comparison to previously used metallic materials, it is of fundamental interest of the OEMs or suppliers to develop a repair concept suitable for the material. Especially in terms of sustainability of the products, the extension of the useful life and the avoidance of premature disposal are required.

Compared to other types of heat generation/ heat transfer techniques, such as conduction or convection, induction heating offers a heat transfer with higher efficiency and preciseness without any physical contact to the material itself, the heat is induced within the part itself by alternating electrical current.

The company msquare GmbH located in Stuttgart carries out researches in the field of inductive heating for different applications regarding composite repair and processing. In this presentation, the results of the research project RetPair are to be presented.

The results of the hard-patch induction welding concept will be presented as well as the test setup and the equipment used for the validation. In addition, an outlook is given on how the application can later be used in the service.

The concept of hard-patch welding is to heat an interface material between the patch and the surrounding structure, which later remains in the interface zone. Different types of induction coils and different materials to be inductively heated were investigated.

REsearch on ThermoPlastic repAIRs: 3D scanning technologies for CAD generation of the repair patch, correlation of repair coupons with non-linear FEMs and analysis of applicability in full scale demonstrator with 3D experience

Javier García-García*, Rodríguez Valenzuela Jose María, Cordomí García-Milla Francisco
** CT Ingenieros, Spain*

RETPAIR project is focused on the development of new technologies to repair thermoplastic aeronautic structures. To do so, the development of high performance, flexible, green and cost-effective technologies to be integrated in manufacturing line and in-service have been investigated.

Within the frame of RETPAIR project, CT Ingenieros, has worked in three different investigation lines:

• The digital path repair design methodology proposes the use of 3D scanning technologies to transform physical world damages into their virtualized digital representation. Once the virtual representation is created the developed software will automatically assess the damage to create the optimum patch to comply with repair validation criteria.

• With the objective of characterize the capabilities of RETPAIR technologies for thermoplastic materials a wide variety of mechanical testing has been performed. The mechanical testings, Interlaminar Shear Strength, Mode 1 Fracture Toughness and Single Lap Shear, are done for coupons manufactured using ATL and FFF technologies. These tests have been modelled using non-linear FEM methodologies (ABAQUS) and cohesive contacts at the interfaces of the repaired coupons to predict initiation and propagation of damage. This FEM model together with the test results will allow the correlation of these cohesive contact properties and the simulation of large complexity repairs without running the specific testing plan.

• Finally, using 3D Experience, the new repair solutions have been tested in the full scale demonstrator CS2-LPA-WP2.1/WP2.3 assessing the accessibility and capabilities of the repair equipment. The following actions has been carried out, generation of 3D FAL scenario, generation of 3D models of the repair solution, analysis of feasibility for different areas, risk identification and analysis of health and safety.

In Situ Thermoplastic Composites Repairs Patch Solutions on coupon and element level | RETPAIR Project

Noelia González Castro*, Pedreira, Albeto, Simoes, Beatriz, Rodríguez, Adrián, Pintos, Soraya, Coto, Ivette, Losada, Ricardo and Rodríguez- Senín, Elena

** AIMEN Technology Center, Spain*

One of the main objectives of RETPAIR project is the development of new high performance, flexible and cost-effective, automated and robotized net-shape technologies to rework and repair Thermoplastic Composites (TPC) parts to be integrated in the manufacturing line. Given the wide variability of repair scenarios, RETPAIR proposes different concepts, including in-situ repair by means of in- situ consolidation, for structural and non-structural applications based on automated and robotized layer-by-layer patch in-situ creation.

Automated Tape Laying (ATL) and Automated Fiber Placement (AFP) technologies will be investigated for structural and large size repairs, and a 3D printing Fused Filament Fabrication (FFF) for smaller repairs. For this latter technology, structural repairs with continuous carbon fibre filaments and short fibre filaments will allow to tune patches' strength for different repair requirements (structural and cosmetic). This process will allow to directly build layer-by-layer the repair patch over the damaged surface obtaining a high-performance solution for structural repairs without using further steps (e.g.autoclave in AFP).

The key parameters of the in-situ consolidation of Continuous carbon fibre -TPCs by automated laying process were investigated by depositing repairing TPC tape onto pre-consolidated laminates (damaged structure). In order to establish and understand correlations between the process parameters effects and mechanical properties (porosity, interlayer strength, etc), a number of parametric studies will be performed by manufacturing different types of samples and testing the interlaminar shear and single lap shear strength and fracture toughness.

Therefore, RETPAIR project has worked adapting existing technologies as well as creating new ones, in order to address the wide range of repair application scenarios (material widths, adjustable roll, adaptable laser heating). Developing novel TPCs in-house repair (rework) procedures by the development of new technologies based on automated and flexible manufacturing.

Exploring new approaches for Safe and Secure Systems in Aviation and Space

Chaired by:
Dr. Angela Vozella (CIRA)

Current approaches in UAV Operational Risk Assessment and Practical Considerations

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** Centro Italiano Ricerche Aerospaziali (CIRA), Italy*

The relevant capabilities of Unmanned Aircraft System (UAS) are creating new markets in many different sectors making UAM an emerging challenge to be faced. Besides the mid-air collision risk, highly automated, cooperative, passenger or cargo-carrying air transportation services in and around urban areas, entail risks on ground third parties such as buildings, traffic routes, and pedestrians .

The Joint Authorities for Rulemaking on Unmanned Systems (JARUS), supported by various National Aviation Authorities (NAAs) and stakeholders, have developed a reference framework, the Specific Operational Risk Assessment (SORA) to identify and qualitatively assess safety risks for UAS operations. It aims to provide a simple basic tool to operators, that can be easy to adopt and sound in guaranteeing safety in air (air risk class ARC) and on ground (ground risk class – GRC) . SORA GRC/ARC lookup table shows a logical background, but the annex G of the SORA guidelines that shall include supporting theories has not yet been released .

The last study AAM National Strategic Plan (2021-2030) conducted by the Italian National Authorities ENAC with the support of national stakeholder has addressed many different concepts of operations with their peculiarities , depending also on the variety of vehicles that can be used, differing in flight performance, and in crashing etc that SORA cannot take properly into consideration demanding to specific analytical analysis.

The higher the risk, both towards third parties on the ground and other aircraft in flight, the more stringent the requirements and the greater the need for technical investigations by the Authority.

Besides SORA, literature has been providing different methods to conduct a risk assessment , considering the very heterogenous "world of models" underlying each term of the simple risk equation. Models need validation and data representing the ground true to be validated. and operators need to know how to move in this complicated world. Each operator needs to understand which model better suits the application scenario under analysis, in terms of pertinence and thus can be acceptable by the authorities and needs to know which relevant data are available and can be used.

This work provides an overview of the current research trends on Ground Risk models, taking into consideration the different stages of operation planning , strategic, pre-tactical and tactical. It defines a logic pipeline that an operator should follow implementing some detailed analysis, exploring the data sources she/he should gather, as well as the required level of interoperability among models and related sets of data. It provides an instance of such logic flow on a case study set in Naples, considering two different potential operations from the Airport to the seaport and from two different points of the seaport. From such a reasoning, the work derives some key practical steps that could be considered by national authorities as "to do list" to easy the authorization process of an UAS .

How Human Factors can act as enabler for safety, efficiency, eco-efficiency and AI

Marcus Biella *, Anne Papenfuß, Jörn Jakobi, Patrick Lorrig, Steffen Loth

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Increasing safety is and remains a pivotal point for the air traffic management sector. Of course, it is also and especially important to mitigate possible effects on capacity. Equally - if not more important - is getting to grips with the consequences of climate change. Needless to say, not only digitisation but also AI in particular are drivers of a special kind.

How can human factors research make a difference in these areas? This presentation will present four examples of innovative work that highlight what can be achieved with Human Factors expertise.

(1) Towards zero emission airports

The German government has the goal, to transform the German economy into the world leading energy efficient one and strategically reduce energy consumption by 50%. The DLR aviation strategy takes main factors as digitisation and climate change into account and heads for an emission reduction aviation. Airports, with their high energy demand on air- and landside, have a significant potential to contribute to emission and energy reduction.

The DLR project THOR (Towards Zero Emission Airports) will evaluate different ways and possibilities to achieve emission free and energy efficient airport operations, which is set as a goal by airports around the world by 2050. Several DLR institutes joined forces to bring together their knowledge in specialized areas of airport operations and energy systems to generate an overall view and build an environment to evaluate and validate future operations in terms of emissions and energy usage.

The central goal for THOR is to generate a roadmap, describing promising technologies, processes and infrastructure, that are relevant to reach Zero Emission Airport Operations. Developed concepts and models will be evaluated, classified and summarized in terms of ecological, technical, operational, economic, political and societal aspects. The project will be the base for further research and development, that are required for deployment and implementation at airports.

(2) Safety and efficiency by remote tower operations (RTO)

In addition, current developments in the field of RTO and new possibilities for the future will also be presented.

(3) Enabling teams to collaborate in a safe and efficient manner

Furthermore, the collaboration of human operators from different organisations will be one factor enabling a performant air traffic today and in the future. Especially, good collaboration can contribute to the goal of a zero-emission air traffic by making operational processes more efficient. Within the DLR project Inter-Team-Collaboration (ITC), a team of human factors experts from different institutes investigated several methodological research questions regard analysis and evaluation of collaborative work processes. Concluding, the project derived guidelines, how collaborative work processes should be designed in order to enable human operators to collaborate in a safe and efficient manner, as well as being flexible and adapted to specific situations.

Results from five empirical studies build the basis from which overarching influencing factors on collaboration and guidelines for the design of collaborative work processes were derived. These studies had a broad methodological rand and covered a range of different uses cases from air traffic, in which collaboration across organisational borders is necessary.

(4) Recognising the limits of human performance in good time

The results from the EU project Human Performance Envelope (from Future Sky Safety P6) are currently being used to find conclusions about the performance of pilots in the field of condition recognition using physiological measurements. Measurements of physiological parameters in DLR's Flight Simulator AVES dedicated to measure stress and to analyse data through Deep Learning Applications will set the final tone in this report.

Overview of Safety Challenges associated with Integration of Novel Propulsion System Architectures for Climate Neural Aviation

Stefanie Degraaf, *German Aerospace Center*

Electrification of propulsion systems in aviation is one way to introduce the necessary step-change in emission reduction as anticipated in the ATAG Waypoint 2050 scenarios through technology. In particular, hydrogen-based fuel cells are being investigated for this purpose in research and development. On the one hand massive improvement in overall power density of fuel cell systems and the entire powertrain are needed, while modifying the enabling technologies towards the environmental conditions associated with the cruise altitude as well as hottest day and coldest day requirements. On the other hand, reliability and safety of such systems are of crucial importance.

The safety challenges associated with design and implementation of a hydrogen storage and distribution system on an aircraft are manifold. At the core of the problem are distinctive properties of the chemical substance hydrogen itself, such as high diffusivity and flammability as well as high reactivity under certain conditions. The consequence is the susceptibility of hydrogen to dissociation and diffusion, which leads to trapping. The permeability of hydrogen in combination with material imperfections will lead to hydrogen embrittlement, hydrogen-induced cracking and leakage. In case of leakage, hydrogen can ignite at a concentration as low at 4 vol% in air. This makes it more prone to spontaneous combustion and uncontrolled fire hazards, requiring stringent safety measures for its storage, distribution and utilization. Another critical phenomenon is the high-temperature hydrogen attack resulting in a chemical reaction of hydrogen with the carbon in certain materials leading to methane formation.

This work provides an overview of the challenges to be addressed during the safe design process recommended in ARP4754A for CS23 and CS25 certification. These challenges are clustered in the following categories: aircraft operation, hydrogen system architecture design and component design. In fact, this overview will be relevant for applications of both hydrogen fuel cell-based propulsion systems as well as hydrogen-based gas turbines.

Human Systems Integration in the design of future Aviation and Space systems: addressing Human-AI Teaming

Chaired by:
Dr. Ricardo Reis (Embraer)

Using Eye-Tracking for Adaptive Human-Machine Interfaces for Pilots: A Literature Review and Sample Cases

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1. Introduction

The need for an adaptive interface that changes its layout and elements according to the needs of the pilots is critical in such a demanding human-machine interface (HMI), where a lot of information is processed rapidly by the pilots. We argue that the use of eye-tracking technologies can assist HMI in adapting to prevent human errors such as failing to see important information, misinterpreting data, or failing to act. In this paper, we present a literature review of the use of eye-tracking in adaptive HMI for various cases of pilots (flight simulators, drone pilots, cockpit pilots), and we discuss two sample cases demonstrating the potential of using eye-tracking technology in adaptive HMI for pilots. 2. Use of Eye-Tracking in Adaptive HMI for Pilots

2.1 Flight Simulator Games Pilots

The utilization of eye-tracking technology was envisioned at an early stage in the game industry, particularly in first-person shooter games, to assist players in maintaining precise aim even when the target is in motion [1], as well as in the concept design of the first flight simulators to adjust the player's visual perspective [2]. Modern eye tracking technology is incorporated in various games [3-5], including the MS Flight Simulator, where the use of gaze-based interactions enables the pilot to fly the plane keeping their hands in the controls, while providing extended view for the in-game camera and improved spatial awareness. Additionally, using eye-tracking data, players could be guided to relevant areas of the cockpit [6].

2.2 Unmanned Aerial Vehicle (UAV/Drone) Pilots

Most works for UAV pilots focus on using eye-tracking technology to provide better control of the drone for people in need [7] or to be used in the auxiliary control of UAVs, which have various effects in improving the efficiency and accuracy of UAV operation and reducing the cognitive load of the pilot [8, 9]. Similarly, eye- tracking could be used to monitor the performance of drone pilots and detect abnormal statuses even in cases of multi-UAV operators [10]. Following these works, the use of eye-tracking data could initiate changes in the HMI of the drone pilot application to help pilots to overcome difficult situations, adapt to new challenges, and focus on data they have failed to monitor in time.

2.3 Use of Eye Tracking in Aviation

Data from eye-tracking have the potential to provide direct measures of pilots' information processing in the cockpit, including the information that is sampled by the operator over a given period (e.g., the distribution of fixation locations), and the time that it takes to process this information (e.g., fixation durations) [11]. Additionally, the analysis of the pilots' gaze distribution is used to measure how the pilots' task load influence visual behavior and performance [12, 13] and, generally, understanding of how the pilot processes the information in the cockpit while carrying out particular tasks [14].

3. Sample Cases

This section presents two sample cases demonstrating the potential of using eye-tracking technology for adaptive HMI for pilots. The former took place on a UAV simulator (DJI Flight Simulator) using an eye-tracking screen (Tobii screen eye-tracker). The pilots' fixation points were used to identify reactions and needs for adaptation. Pilots used the actual UAV controller, and the interaction analysis focused on adapting to critical situations (e.g., flying fast at low altitudes and avoiding obstacles). The latter was based on a UAV (DJI Mavic 2 Pro) that was operated in normal (i.e., not "unsafe" or critical) conditions to ensure the safety of the pilot and the UAV. The Tobii Pro Glasses 3 were used for raw data collection and the Tobii Pro Lab software for data analysis. Figure 1 shows an

example of a gaze plot, examining if the pilot focused on the critical information on the screen while flying beyond the visual line of sight (BVLOS); the analysis focused on pilots with various levels of experience and flights switching from flying in the visual line of sight (VLOS) to BVLOS.

Figure 1. Gaze plot from a UAV flight

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Enhanced integration of expert knowledge for the definition of aircraft design subspaces with the Advanced Morphological Approach

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The significant impact of the selected aircraft configuration on the final design and development costs implies the invaluable importance of the robust selection of rational concepts. In order to fulfill this demand, the Advanced Morphological Approach integrates Morphological Analysis and Structured Expert Judgment Elicitation for the purpose of obtaining relevant solution subspaces of aircraft concepts for a given mission. This implies the decomposition of a system into functional or characteristic attributes and their corresponding technological implementation alternatives. These are then evaluated by a selected expert panel, allowing to generate an extensive solution space. The current work describes the subsequent extension of the methodology, which allowed a better integration of the expert decision-making by going beyond the technology evaluation step. The experts are now involved in the problem definition and solution space analysis. Considering the increased subjectivity of such an approach, the robustness of the overall methodology is enhanced by integrating aspects of systems engineering, environmental analysis and scenario definition. From the numerical point of view, fuzzy solution clustering have been further introduced to the design process. The novel developments are demonstrated on the use case of the conceptual design of an innovative regional air transportation platform.

A step-by-step guide to include key electroencephalography (EEG) parameters in the study of human performance applied to air traffic control

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Electroencephalography (EEG) is a technique that focusses on the study of electrical activity in the brain. Over the years, it has become one of the most widely used neurophysiological techniques in the field of human factors. It includes the analysis of raw data (differences of potential) captured by different electrodes, the analysis of frequency bands, or the analysis of the areas that register greater activity depending on the task performed.

Among the advantages of using this technique is that it allows for the recording of continuous data, enables the detection of variations in the participant's state not recorded by other techniques (e.g., subjective methods) and, depending on the device used for recording, allows appropriate data recording without interfering with the main task performed by the participant. These advantages facilitate their use in conducting human factors experiments.

Many data collection devices, such as wireless headsets, are often accompanied by their own EEG data processing software. The problem is that in many cases the parameters obtained are difficult to interpret, as they depend on proprietary algorithms developed by the manufacturers. To overcome this problem, in this research, framed within the human factors project applied to air traffic control CRITERIA (ATC event-dRiven capacITy modEls for aiR navIgAtion), it has been decided to define a series of basic EEG parameters from the raw data, to be able to apply them later in the analysis of the data and to gain knowledge of the whole process followed to obtain them.

To this end, an intensive literature review was performed to identify reference EEG parameters that could be implemented in the analysis of brain activity data recorded while several participants performed air traffic control simulations in a high-fidelity simulator. Using different techniques and algorithms, the basis for a set of six EEG parameters considered fundamental for their use in the analysis of human factors applied to air traffic control is proposed. These parameters are stress, excitement, relaxation, boredom, engagement, and attention.

Once these parameters have been obtained, their use has been validated considering experimental data obtained from real-time simulations. As they have been rigorously defined from the raw data, they allow a clearer insight into the results obtained. This work describes the process to define these parameters, the first relationships observed among these parameters, and the experimental data related to some interesting metrics, such as the number of simultaneous aircraft in the sector or the task load that each participant faces, and their possibilities to be considered in further research.

More Haptic Aircraft

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This paper presents a comprehensive review of haptic feedback in aircraft control. It provides an overview of the results and experiences achieved in a previous research project dealing with pilot haptic guidance hardware design and testing. Furthermore, the paper examines the role of AI in pilot-aircraft interaction. The objective of the paper is to outline a roadmap for the future development of "More Haptic Aircraft" by addressing hardware design, software design, and implementation strategies. The hardware design section outlines the requirements and potential improvements for haptic interfaces, including considerations for portability and ergonomic design.

The software design section discusses aspects of human-machine interaction and human-AI teaming, focusing on the development of intuitive and efficient interfaces that facilitate seamless collaboration between pilots and AI systems. The implementation strategy section explores the concept of an optional system that can be retrofitted into existing aircraft, virtual flying environments that enable simulated haptic feedback, and the integration of haptic technology into flight schools and training programs.

Enabling Human-Autonomy Teaming in Aviation: A Framework to Address Human Factors in Digital Assistants Design

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Recent technological progress in the aviation industry has transformed people's interactions with technology. From simple tools, artificial agents have become full-fledged teammates characterized by high levels of autonomy in terms of decision making, adaptation, and communication. Expanding the current role of the machine could greatly transform the cooperative architecture, introducing new coordination requirements for human operators. Unfortunately, these transformations may bring new human factors risks related to the operator's understanding of the system, but also problems of vigilance or trust in the systems (i.e., the out-of-the-loop performance problem). In this context, researchers have investigated to what extent and under what conditions autonomous agents and humans can work collaboratively as a team.

Early approaches to human factors design proposed to focus on how to divide the work between man and machine. Fitts' famous "Humans-Are-Better-At, Machines-Are-Better-At" list inspired designers in new ways, but it has been criticized as too simplistic. Over time, human factors design has grown to encompass other factors that influence human performance, including cognitive, social, and organizational factors. Despite significant progress in this field, current methods for human factors analysis and design are either limited in their consideration of human-autonomy teaming, or too complex or time-consuming for non-experts to use. For example, coactive design or cyclical models are often labor-intensive and difficult to apply in practice. There is therefore a need for new lightweight design methods for Human-Autonomy Teaming to provide generative, insightful, and actionable descriptions of future incarnations of aviation systems.

To address this gap, the SafeTeam project introduces a novel method for function allocation and human factors design that leverages multi-disciplinary research to provide non-experts in human factors with an accessible, actionable, and accurate assessment of Human-Autonomy Teaming in aviation. Our proposed method is a combination of several human factors design methods and tools. It adapts a traditional hierarchical task analysis (HTA) to include color coded actors (human or artificial) and tags for task types, cognitive load, stressors, and interfaces. The HTA toolkit is applied in two phases, to model the (sub)tasks of the current system, and to design the task structure and function allocation of the future system. The HTA work is intended to be collaborative, iterative, and used to explore and discuss the qualities of the system design proposal. The HTA models are converted into tables where risks are identified based on the tasks and tags, focusing on human factors. In the third phase, the described design proposal is further analyzed with respect to several "enablers" of Human-Autonomy Teaming to address any identified risks associated with the design proposal. Each phase of the method is iterated as required. In the SafeTeam project, this method was applied to two different use cases concerning the use of digital assistants for (1) air traffic control, and (2) management of unstable flight approaches. Our proposed method was refined and implemented with the project partners to understand and design for the use case domains.

Our method contributes to human factors design and human-autonomy teaming in aviation in several ways. It provides a creative and collaborative way for non-experts to understand the activities in their respective application areas, and to explore and refine new design proposals in a

structured way. It also increases awareness and knowledge about human factors among non-experts, guiding them through implementation to ensure usable, efficient, and safe human teaming with autonomous systems in aviation.

Study and development of a real-time pilot monitoring system

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Two of the key challenges facing the aviation market today are rising operating costs, especially on short- and medium-haul flights, and the decreasing availability of pilots. Indeed, despite today's regulations for most airline flights requiring a pilot and a co-pilot on board the aircraft, to address these problems, there has recently been an increasing focus on the so-called Single Pilot Operations (SPOs). However, the SPOs in aviation can be achieved only by guaranteeing the same (or higher) safety and handling quality level regulated to date in the EASA parts. Therefore, a cockpit assistant with the potential to understand the cognitive workload of the pilot and his ability/inability to operate the aircraft is a fundamental need to foster this disruptive transition.

Our project aims to develop an autonomous Pilot Performance Monitoring system fully integrated into the cockpit. Our tool provides a continuous real-time output regarding the cognitive workload and the pilot's state of health during the flight mission. It is based on a multimodal approach that considers the most significant physiological signals, such as cardiorespiratory measures, eye tracking, fNIRS (functional Near Infrared Signal), and skin activity, through ad-hoc developed electronics. Together with aircraft data, these signals feed our AI algorithm, which estimates the pilot's cognitive load. The idea is to estimate individual capacity limits by correlating these parameters' variation with the mental load's increase or decrease through specific data labeling and further classification. This information is then provided directly to the aircraft avionics and the air traffic controllers on the ground so that the pilot's physical and mental condition is always monitored. This ensures the safety levels regulations require, even with a single pilot on board the aircraft.

Initial computer cognitive tests have already been completed on thirty healthy volunteers, providing the aforementioned parameters under three mental workloads and stress conditions. The most significant features have already been extracted from the signals, and three AI algorithms were implemented for the feature selection and classification process. We classified our dataset based on the five-level subjective rating obtained from the volunteers at the end of the tests.

To sum up, we decided to investigate the physiological multimodal approach and the potential of AI algorithms to foster the transition toward SPOs. This is a crucial topic for the aviation industry, which is continuously growing thanks to the exponential growth of the biomedical sensor market in the last few years. The availability of smaller, cheaper, and more reliable wearable sensors allows for investigating and developing technologies that could not be realized so far to enhance safety and push the aviation sector to the next generation of aircraft.

Increasing Predictability in the Response of an AI-assisted Stall Recovery System in Complex Stall Conditions by Expanding the Knowledge-base of AI

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The operational environment in the cockpit of commercial aircraft has become increasingly complex over the last decades following the introduction of digital systems in the cockpit in the late 1970s and early 1980s. This complexity primarily arises from an increase in automation systems and this becomes

particularly noticeable when such automation systems fail. The risk of disconnect between the pilot and automation even in normal operation is well known, with such disconnects following an automation-related failure having led to loss of control where the crew was unable to resolve the problem with the available information. Indeed, several aircraft accidents have occurred because of conflicting information that is either generated by the automation systems or caused by inadvertent activation of automation systems. Solving problems in such an increasingly complex environment is, therefore, critical to safety. However, this may become too demanding a task for the human pilot in case of failures such as data errors, or when additionally facing factors such as fatigue and stress. To mitigate this risk, an 'artificial expert' that is able to unravel incoming (mis)information can be introduced to help the pilot better understand the situation and, consequently, bridge the divide between the human and automation systems. Artificial Intelligence has the ability to create powerful functions that reduce the probability of loss of control and mitigate the risks of the consequences when such events occur. One way of doing the latter is by using a system based on Reinforcement Learning to assist in upsets such as stall recovery procedures. Despite AI's powerful abilities for application to this problem, one of the biggest issues in these methods for human-AI interaction is the trustworthiness of AI, particularly in potentially dangerous situations. In other words, its response is considered unpredictable in unforeseen circumstances. This also creates a challenge for certification of such systems. Therefore, there is a need to increase the trust in an AI system by decreasing its unpredictability in safety-critical applications without compromising the strengths of the AI approach.

This paper addresses the above challenge to increase trust in AI by focusing on the increase of knowledge of the neural connections in the Reinforcement Learning system to create an improved ability to respond predictably in unforeseen circumstances, specifically in the context of stall with data (sensor) failures. The knowledge of the Reinforcement Learning system to recover from a stall was expanded by training on a related task: learning how to force a stall. This novel method of training for stall recovery was realized by training a single neural network to generate a stall and subsequently recover from it. To show the effect of failing systems and unforeseen circumstances, data errors resulting from a blocked Pitot static system and combinations of failures were introduced during testing. Training was performed using a six-degrees of freedom simulation using an A320 aircraft model.

It is shown that a deeper knowledge of an AI system results in an increase in the ability to respond correctly (predictably and as desired) in unforeseen circumstances. This reduction is unpredictability can significantly improve the trust of humans in AI. Introducing the concept of an increase of knowledge by the example of teaching 'how to stall' was specifically chosen. This effective yet controversial method of allowing the AI system to know how to create a potentially dangerous stall opens up a discussion on whether it is safer if an AI system never learns dangerous situations or if an AI system should precisely understand these dangerous situations to enhance its understanding of the environment and create an intrinsic ability to ensure it avoids them. This paper uses the controversial method for creating an AI-based stall recovery assistant to provide evidence in context of this discussion.

Results show that a larger training space is important to be able to achieve correct emergent behavior and that by the proposed method the training space is naturally expanded by letting the system create its own tasks to recover from. A comparison was made with training approaches that introduced additional restrictions to the AI by using a dense reward function, strict termination conditions, and human-created task distributions. The results show that restricting AI is not always necessary and, further, that too many restrictions can lead to a system that learns only shallow features causing it to be unreliable in unforeseen circumstances. More importantly, increasing the knowledge by learning related tasks improves its response in situations it has not seen before and thus reducing the unpredictability of the AI system.

Towards Human Teaming with AI Systems for Aerodynamic Stall Recovery in Complex Aircraft

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An AI system has the potential to analyze an aircraft by its system and sensor outputs and with this be able to provide control instructions and/or recommendations when failures occur in real-time. Having AI in the cockpit can therefore help pilots by reducing the complexity of problem solving and guide them to appropriate actions in the prevailing circumstances. As automation systems are increasingly introduced in the cockpit, the task to resolve problems and recover from upsets when failures occur becomes significantly more complex. An AI system that assists pilots has therefore the potential to significantly reduce the consequences of loss of control.

Human-AI teaming in the cockpit is difficult, not least because the AI system only needs to make a small number of mistakes for a human to lose his or her trust in the system. To combat this, transparency is believed to improve trust into such systems. The most fitting form of transparency is explanation, which helps in the understanding of why a system operates in a certain way and why some errors occur. However, the risk of having explanations is that it can lead to information overload and automation complacency. In reality, explanations satisfy a need to be in control. Therefore, there is a need for some other way to achieve this sense of control, without causing information overload, whilst also rendering the system more trustworthy to humans. This paper introduces a Reinforcement Learning system that can assist pilots during stall recovery and provide a sense of control during this recovery procedure by interacting with the pilots on the strategy adopted for recovery from loss of control.

Although pilots are trained to recover from the stall, from a performance perspective, there can be different strategies adopted in the process of recovering from loss of control involving a stall to recapture the original (intended) altitude. Considerations include height above ground and whether a best climb gradient or best rate of climb is required. The latter consideration may be affected by factors such as the vicinity of high ground and the presence of other aircraft.

The Reinforcement Learning system was implemented to not only take data from systems and sensors as input but also the desired recovery strategy. This input may, on further development, be provided by an integrated terrain and traffic surveillance system. The present system was trained with a six-degrees of freedom A320 aircraft model. It was investigated if a Reinforcement Learning agent could distinguish between different stall recovery approaches and if these would be beneficial for the pilots to take control of. This analysis led to the design of different reward functions resulting in different stall recovery behaviors of the Reinforcement Learning agent. The insight of this analysis showed potential to create a system for multiple control options, for example, for stall recovery at best rate of climb and best climb gradient. Therefore, a single neural network was trained to perform both stall recovery strategies on command towards any desired altitude and airspeed.

The resulting learned strategies were compared with Reinforcement Learning systems trained with other reward approaches and tested at various altitudes and airspeeds. Aspects such as the time it takes to return to initial altitude, reducing angle of attack, and height loss were analyzed to assess the differences of training methods. To conclude, the system that learned to do all strategies at once, had a higher performance than any system that was trained for a single strategy. Therefore, the proposed approach can enhance the understanding of the environment for the AI system while also allowing pilots to have more control over how the AI system operates which can lead to an overall increase in trust, working towards human-AI teaming.

HAIKU, Human-AI Teaming, a human-centered approach

Simone Pozzi, Vanessa Arrigoni, Ricardo Reis, Anaisa Villani, Brian Hilburn, Jonas Lundberg

HAIKU explores six use cases across several aviation domains to generate guidelines for design of assistants for Human-AI Teams. The first year of findings will be presented and follow on research.

The Power of Synergy: SafeTeam unites human and automation in aviation's horizon

Pablo Hernandez, Paula Lopez

SafeTeams dives into the promising realm of automation in aviation, where the human factor shall take center stage.

Navigating the intricate complexities of this subject, our work zooms in on tangible case studies showcasing the technical maturity of digital assisting tools to support actual challenges of controllers, pilots and instructors. SafeTeam experts are collaborating to extract profound insights that will serve as guiding principles for the integration of digital assistants in aviation. Through seamless collaboration among academia, research bodies, large corporations, SMEs and civil authorities we foster a comprehensive understanding of end users' needs. Our ultimate aim? To empower civil aviation in swiftly and securely adopting these transformative technologies by decoding the intricate relation among human performance and digital assistant capabilities.

Together, we'll chart the path to a future where automation harmoniously intersects with the boundless horizons of aviation

European Policy Actions in the Field of Aviation

Chaired by:
Dr. Dietrich Knörzer
(former Senior Officer, Aviation Unit, DG Research & Innovation, European Commission)

European Aviation Research Policy towards Climate Neutrality by 2050

Jane Amilhat*, Michael Kyriakopoulos
** Senior Expert - Aviation Research Policy, Belgium*

The European aviation research and innovation policy is on track an ambitious path towards climate neutrality by 2050. The paper/presentation will present a holistic view of all relevant activities as well as focus on representative success stories and their path.

An agent-based model for technology adoption in Air Traffic Management

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Growing traffic demand and new market entrants are rapidly taking the Air Traffic Management (ATM) system to its limits, calling for disruptive solutions able to boost ATM performance. However, innovation depends not only on the development of new technologies, but also on the existence of

regulation and institutions able to foster the implementation of such technologies. In order to facilitate the exploration of different policy options aimed at accelerating the adoption of new ATM technologies, an agent-based model that represents the behaviour of the European ATM system has been developed. This model includes representations of the main stakeholders in the ATM ecosystem: regulatory bodies, technology providers, labour unions and technology adopters, including Air Navigation Service Providers (ANSPs), airlines and airports. New ATM technologies, policies imposed, behavioural biases (e.g., loss aversion) and exogenous variables (e.g., fuel price) drive the actions of the agents, leading to the emergent global behaviour of the system. A calibration and validation process involving historical data, gaming experiments and participatory simulations was performed. The model was used to evaluate various policies that included economic incentives and penalties in two scenarios: one based on past events and another focused on the future. In the past scenario, the aim was to demonstrate that the model accurately replicates the behaviour of real stakeholders. In the future scenario, the goal was to analyse the ideal combination of policies that would facilitate the rapid adoption of newly developed ATM technologies. The results allow us to analyse which individual stakeholders benefit the most from each policy and to identify the mechanisms that emerge and drive the path of technology adoption, finding that a combination of economic incentives (e.g., subsidies) and enforcement through mandates provides promising economical and operational results.

European Union aviation transnational Research and Innovation funding strategies

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One of the main objectives of the European Commission since the 70s has been to coordinate research policies and to enhance the transnational cooperation in order to reach efficiency in terms of funding and to match with Europe`s economic ambitions. It has been addressed through a centralized approach managed by the EC and a decentralized approach through the cooperation of Member States and Associated Countries. The EC identified the aerospace sector as essential for the economic recovery and for making a Europe based on innovation and knowledge. In the following years, aviation public and private entities, as well as national authorities and funding managers, realized that global competition could be only reached based on transnational cooperation. In this regard, the centralized financing has been successfully implemented under the EU R&i Framework Programmes with the support of the European Technology Platform ACARE (Advisory Council for Aviation Research and Innovation in Europe). However, the decentralized approach has been less success for the aviation sector, using initiatives such as Air Transport Net ERANET and the EUREKA network. This article attempts to shed some light by analysing different implemented methods and results, led by the European Commission and Member States with the support of Air Transport Net Coordination and Support Action (Air TN CSA) and ACARE Member States Group (ACARE MSG), to try to align Research and innovation aviation national funding programmes. Through the study of existing information of all MS and AS aviation national funding programmes and later interviews to the funding programme owners, it concludes which are the best practices, barriers and recommendations to improve the procedure in the next future. It also concludes how it is very related to the European intention of influencing on national aviation initiatives to maximize the real impact of R&i policies and strategies.

An approach to describe the business behavior of an airline, and to provide management solutions

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In recent years, airlines have undergone significant changes and at high speed, not only due to the deep transformations of the market and the world economy, but also of the sector itself. The appearance and consolidation of new Low Cost entrants has forced a change in the competitive strategies of the traditional airlines, both for the network operators and the point to point ones. In this new competitive scenario, combining profitability and a high level of service quality is a challenge that requires a very open mind to change and innovation, to reinvent itself if necessary. To implement this, it is very useful to define, as a practical tool, the break-even curve of an airline, which relates the three fundamental business variables: yield, Load Factor (LF) and unit cost. This break-even curve describes the basic business behavior of an airline and allows to see where it is positioned in relation to its competitors and the present market. From this situation analysis, airline managers can study the most convenient actions in order to increase their airline competitivity and place it in the position required by its business targets. The break–even curve is an effective management tool that facilitates the study of the decisions to be made, what must change, and illustrates the solutions. The paper provides the practical mechanism for using this tool, illustrated by some examples based in real data.

In order to successfully address the future challenges of the industry, in addition to the importance of the incorporation of advanced essential technology –state of the art–, the human factor will continue to be a crucial key factor in providing a good customer experience. The product of the air transport industry is a product of proximity.

Aircraft testing

Chaired by:
Prof. Ivo Jebacek (Brno University of Technology)

An event-driven link-level simulator for validation of AFDX and Ethernet avionics networks

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Aircraft are composed of many electronic systems: sensors, displays, navigation equipment and communication elements. These elements require a reliable interconnection, which is a major challenge for communication networks as high reliability and predictability requirements must be verified for safe operation. In addition, their verification via hardware deployments is limited because these are costly and make difficult to try different architectures and configurations, thus delaying the design and development in this area. Therefore, verification at early stages of the design process is of great importance that has to be supported via simulation. In this context, the present work presents an event-driven link level framework and simulator for the validation of avionics networks. The presented tool supports avionics protocols such as Avionics Full-Duplex Switched Ethernet (AFDX), which is a common protocol in avionics, as well as Ethernet, which is used with static routing in such scenarios. The simulator also uses realistic element models to provide accurate results. The proposed platform is evaluated in Clean Sky's Disruptive Cockpit for Large Passenger Aircraft architecture scenario. The speed of the verification is a key factor, so the computational cost is analyzed, proving that the execution time is linearly dependent on the number of messages sent.

Load flux determination on the spacecraft's primary structure

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The article describes the load flux determination on the spacecraft's primary structure. Each payload must meet with requirements that are specified by the lunch vehicle operator manual. In this user's manual, we can find the loads that the payload may be affected during the mission and it needs to be taken into account for the design and dimensioning of the spacecraft's primary structure. To verify the designed structure, it leads to a laboratory test of the spacecraft. These tests require not only the capability to support loads defined in the launcher user's manual but also the stiffness. If we apply the forces in the centre of gravity of the spacecraft that are specified in the form of load factors in longitudinal or lateral directions, then we need to verify if the load flux between the primary structure of the spacecraft and the connection to the launch vehicle adapter is the same as required. A piece of suitable equipment looks to be a strain gauge where the measured strains are directly proportional to the load flux. But there is necessary to verify if strain gauges are not affected by additional loads as a bending caused by non-zero stiffness of all parts. The results of this paper will be used for better understanding and evaluation of these kinds of tests and optimization of all measuring chains.

Experimental Structural Validation of a Landing Gear System for High-Speed Helicopter Applications

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The design and technological demonstration of a Landing Gear architecture were addressed for AIRBUS fast rotorcraft end application within the Clean Sky 2 Racer project. Numerical activities including advanced modelling approaches were carried out to substantiate the feasibility of structural concepts in compliance with industrial standards and CS-29 applicable airworthiness requirements. In order to demonstrate the goodness of design strategies, a true-scale prototype was manufactured and tested for demonstrating its capability to withstand static loads representative of the limit and ultimate cases expected in service. The paper will focus on the qualification of the Nose and Main Landing Gear systems. Sizing process was validated and verified by test whose results allowed for validating/calibrating the FE model. In such a way, the design database could count on a reliable tool available for analysing the effect of any further load condition change.

Vibration Response Correlation of a Main Landing Gear System for High In-Flight Dynamic Loadings

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The prediction of aircraft vibrations is necessary for identifying possible design optimization points of each on-board system. In this context, the authors investigated the dynamic response of a Main Landing Gear (MLG) conceived for a fast helicopter when exposed to flight vibrations arisen from the engine propellers. The research activity falls within the Racer program of Clean Sky 2 framework which aims to develop a novel high-speed rotorcraft. Relying on the Airbus Helicopters operative requirements, this paper deals to describe a numerical procedure for assessing the MLG dynamic response (resonance frequencies, accelerations amplitude, generalized masses) with respect to the expected in-flight vibrations levels. Because of various ways to simulate the typical excitation sources (burst sine waves and broadband noise), an equivalent combined load based on the normal modes and the corresponding modal mass distribution is employed for investigating the relevant effects on

structural endurance. The central themes focus on the modelling strategies and spectral analysis which led safely to the laboratory qualification. This method allowed for defining a reliable tool for the performance of sensitivity dynamic analyses in case of further design stiffness or weight changes.

Vibration Test Campaign performed on a Landing Gear System

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The landing gear system is one of the most critical subsystems of an entire aircraft. The need to design a landing gear with high performance, longer life and with a significant reduction in terms of weight, production and maintenance costs represents a real challenge for a sustainable future that Europe is heralding.

This article presents the results of the experimental campaign of vibration tests performed on the main and side landing gear system, in both extended and retracted configurations, to be installed on the AIRBUS Group/Helicopter high-speed helicopter demonstrator and it is part of the Project Angela within the European Research Program Clean Sky 2 Fast-Rotorcraft. The hybrid nature of the category in which the RACER belongs, not envisaged in the RTCA, required a tailoring of the standard during the definition of the loads to test the landing gear systems in a conservative condition.

The test campaign, conducted with RTCA DO 160-G tailoring, is part of a wider experimental activity aimed at the development, production and qualification of processes and materials that will allow the landing gear system to achieve the "Permit to Fly".

Super cooled large drop simulation at Icing Wind Tunnel Vienna

Hermann Ferschitz, *RTA Icing Wind Tunnel Vienna, Austria*

For flight through clouds, aircraft require de-icing systems to ultimately avoid crashing. The influence of freezing drizzle and freezing rain clouds on the aerodynamic of a wing is particularly high, as they sometimes have an effect beyond the protected area (runback ice). This danger and the necessary certification criteria for large aeroplanes have been defined in EASA CS-25, Amendment 18 Appendix O since 2016. Great efforts have been made to meet these icing conditions for necessar in flight-icing test simulation in large IWTs in the last decade. The generation of super large drops in large IWTs is associated with some difficulties. In the RTA Icing Wind Tunnel Vienna, a high-quality simulation of freezing drizzle was successfully demonstrated in the course of the H2020 resesearch project ICE-GENESIS with the support of the consortium partners. Further RTA has been researching the simulation of freezing rain since 2015 and is continuously developing this topic. With the help of new techniques, it was finally possible to simulate the requirements according EASA CS-25 Appendix O satisfactorily, which is unique to date. In this presentation the applied calibration methods and results will be elucidated. Furthermore, the technology that made the simulation of freezing rain possible will be discussed in more detail.

Development and Flight Testing of a Distributed Electric Propulsion Demonstrator

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The AeroSwitch concept combines a distributed electric propulsion (DEP) configuration with a set of propulsive control logics allowing the in-flight simulation of either a single-engine or a twin-engine airplane. This was initially motivated by the will of providing a flying school with a single platform capable of supporting training for both single-engine and multi-engine pilot rating. The concept was developed in a full preliminary design, leading to the Trybrid General Aviation aircraft, which was awarded the 1st place in the annual AIAA Graduate Student Aircraft Design Competition. To provide a complete demonstration of the practical feasibility of such a disruptive concept, a scaled radio-controlled model was developed to be fully representative of the Trybrid. This model, named SwitchMaster, employs a set of three thrust units, each composed by an electric motor and a fixed-pitch propeller, placed at the leading edge of each wing. The SwitchMaster was extensively tested on ground and in flight, fully demonstrating the effectiveness of the AeroSwitch concept in both its normal and failure modes. Furthermore, the flying model represents a fitting testbed to study the aeropropulsive coupling inherent to the DEP and develop innovative applications in the field of propulsion-controlled aircraft (PCA) such as trajectory steering, attitude control and stability, high-lift augmentation.

Current activities are aimed at providing a fundamental enabler for the above-mentioned studies, i.e. an accurate flight dynamics model. Indeed, predicting the effect of extensive wing blowing on the aircraft's flying qualities is difficult and flight data are not easily matched based on traditional methods. Particularly, the lateral-directional dynamic behavior appears elusory. Therefore, a second flight test campaign is currently ongoing, dedicated to model identification for the full longitudinal and lateral-directional dynamics. This aims at estimating the difference between the baseline (unblown) aerodynamics and the strongly coupled DEP conditions. Preliminary results show a promising behavior of the numerical model (an example is given in Figure 1) in capturing actual flight data.

Validation of a turboprop cabin demonstrator

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Turboprop aircraft are more environmentally friendly for short-haul flights due to less carbon emission. However, these aircraft generate more noise and vibration due to the propellers and engine, which in turn can have a negative impact on the passengers. Therefore, it is essential to examine and improve turboprop aircraft. Demonstrators are a good way to carry out investigations quickly and economically. The goal of the Clean Sky 2 project is to develop, validate, and evaluate a cabin demonstrator for turboprop flights. Validation is essential to verify that the demonstrator produces the same results as a real turboprop aircraft and that its function is correct. To validate the demonstrator, it is necessary to collect passengers' reactions during a real flight. These trials were already carried out in an ATR72-500 in November 2021. During two 70-minute flights, 94 subjects answered questions about their mood, symptoms, and environmental comfort e.g., regarding noise and vibration. The results showed that noise is the biggest discomfort factor, but this discomfort decreases over time. The discomfort rating of vibration also decreases. The next step is to set up the demonstrator, to verify it technically and finally to perform tests on subjects. For this purpose, a sample will be used that is based on samples recorded during the real flight. The conditions and questions will also be the same as from the real flight. Subsequently, passengers' reactions in the demonstrator will be compared with the real-flight data by replicating all possible environmental conditions from the real flights in the demonstrator. The goal is that the demonstrator data fall within the confidence intervals of the real-flight data. When the validation is successful, the cabin demonstrator can be used for different scenarios or other areas of application.

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Structural Analysis of a Large-scale Model for the Wind Tunnel Test of a Multiadaptive Flap

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Innovative studies on morphing wing structures with the highest potential to improve aerodynamic performance on large aircraft are running under the CleanSky2 platform to validate the morphing architectures on true-scale demonstrator through ground and wind tunnel tests. Research activities have been conducted to develop a revolutionary multi-modal camber morphing flap to enhance the aerodynamic behaviour of a new generation of regional aircraft within this challenging framework. Based on the CFD analysis, significant benefits in terms of CL max and stall angle increase were demonstrated for different flight conditions with morphing flap shapes. Investigating this new technology allows for changing the traditional double-slotted flap with a novel multi-modal camber morphing flap and increases aerodynamic performance. The additional lift generated by optimizing the flap's camber surpasses the requirements for takeoff and landing at a singular flap deployment angle, which is considerably lower than that necessitated by conventional flaps in both operational scenarios.

The design and validation of the intelligent architecture capable of different morphing modes required for low-speed (take-off/landing) and high-speed (cruise) conditions. To enhance the significance and applicability of the wind tunnel test campaign, a significant scale factor of 1:3 was selected for the test article. This choice allowed for a substantial increase in size compared to the actual aircraft. Additionally, the wind tunnel tests will be conducted at Mach numbers identical to those anticipated during actual flight conditions, ensuring a faithful representation of the aerodynamic performance of the morphing system. Given the inherent limitations in scaling the flap architecture designed for ground tests and flight operations, a complex and demanding task was to develop a test prototype incorporating an entirely novel and adaptable system. The objective was to ensure that this new system retained all the functionalities of the fullscale device. Therefore, a new architecture was specifically designed for inner and outer flaps to replicate the shape transition capabilities of the full-scale flap.

In this study, general layout of the mechanical model and FE analysis performed both inner and outer flap will be presented. A comprehensive structural analysis of the flap test article was conducted to ensure the safety and effectiveness of the conceived mechanical solutions. Linear static analyses were performed using the finite element (FE) method within the Ansys Workbench® environment. These analyses aimed to assess the adequacy of the mechanical solutions and validate the test article's structural integrity.

The latest approaches and challenges in rescue parachute system development and testing

Robert Grim*, Robert Popela

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Rescue parachute systems are becoming an inevitable part of the standard equipment of modern flying devices in a wide range of weight and speed categories. In order to meet the requirements of aircraft manufacturers to expand the flight envelope, it is necessary to continuously improve the rescue systems in all their elements. An essential prerequisite for improving systems is a detailed understanding of the function of the entire rescue process and all aspects that occur when systems

are activated. This cannot be done without comprehensive testing and, above all, obtaining detailed data to evaluate the canopy design itself.

The topic will introduce the procedure that is used to certify rescue parachute systems and will also provide insight into the breakthrough findings that led to the explanation for the difference in maximum speed for system activation in horizontal flight or vertical free fall. Another part will be an introduction to the principle of rescuing VTOL vehicles from minimum altitude at zero speed or when activated at their maximum design speed in the high altitudes. To achieve the required rescue capability, the system needs to be extended to a multi-element system, the parameters of which will be discussed. This is a topic that involves comprehensive knowledge of the maximum limits of the system, accompanied by a series of sub-tests that will also be pretested. Last but not least, an overview of the measured quantities and the equipment used in the tests will also be created. Much emphasis will be placed on the measurement of opening impact forces and the decomposition of forces into individual structures. The main aspects of the measurement technique will be demonstrated. An integral part is also focusing on the trend of future rescue system development and the use of unconventional design elements in real application

Keywords: ballistic recovery systems, parachute testing, opening shock load, limit load, load redistribution

Experimental validation of a numerical model for the simulation of a novel thermoplastic integrally stiffened panel's mechanical response

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Thermoplastic composites are increasingly used in components for aeronautical and aerospace structures due to the advantages that they present compared to thermoset composites and metallic materials. For this reason, they are incorporated for the manufacturing of components that may reach up to fuselage structure levels. However, fuselage structures are subjected to combinations of different loads, which include axial, bending, shear, torsion and differential pressure. The presence of this complicated loading profile makes the validation of advanced fuselage designs a highly demanding task, which is currently based on full-scale testing of the whole fuselage barrel. In this frame, the validation of fuselage designs through testing at lower levels of the testing pyramid, i.e., at stiffened panel level, is a novel approach that presents significant advantages regarding time and resources consumption.

Testing at stiffened panel using boundary and loading conditions that are representative of the operating conditions and load combinations that an aircraft fuselage encounters during its service life is a challenging endeavor, which requires the appropriate definition of the experimental testing methodology, and the careful selection of stiffened panel geometry, loading and boundary conditions. In this regard, development of Finite Element (FE) numerical simulations of the stiffened panel and the experimental setup is a powerful tool that can be used for the validation of their performance. Furthermore, validation of a FE model at stiffened panel level enables the development of numerical simulations at higher levels of the testing pyramid, reducing the cost and time required for almost right first-time fuselage designs.

In the present work, the numerical simulation of a novel thermoplastic integrally stiffened fuselage panel is presented. The simulation of the thermoplastic panel is performed using Finite Element analysis and comprises all its critical parts and technological details, i.e., the laminated skin, orthogrid structure, etc. The developed FE model also includes the simulation of an experimental setup, designed for representative testing of curved stiffened panels. The simulation of the mechanical response of the thermoplastic stiffened panel is validated through comparison with results of experimental testing in tensile and shear loading conditions.

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Small Air Transport (SAT) Technologies

Chaired by:
Dr. Vittorio Di Vito (CIRA)

The role of Electric Vertical Take-Off and Landing (eVTOL) aircraft in the advanced air mobility (AAM) and its integration into the multimodal system

Ismini Stroumpou, Danica Babic, Slavica Dožić, Massimo Fiorin, Milica Kalic

The advanced air mobility (AAM) and Urban Air Mobility (UAM) revolution is a broad concept enabling customers access to on-demand air mobility, from cargo and package delivery to healthcare, and emergency services through an integrated and connected multimodal transportation network. To implement these concepts, new, transformational aircraft designs and flight technologies should be integrated into the existing transport system, and airspace operations should be modified. While AAM may be enabled, several challenges (i.e., social acceptance and equity, safety, planning, airspace management, and others could create barriers to mainstreaming. However, in remote areas, AAM has the potential to reduce the time to access medical supplies and medical care for patients who are unable to travel. Electric Vertical Take-Off and Landing (eVTOL) has been used in the most diverse applications, as electric vehicles and having small size, they could land in small spaces and maybe in dense urban areas and/or areas difficult to be approached by terrestrial transportation rapidly. Although existing studies on the use of electric aircraft and more specifically electric vertical take-off and land (eVTOLs) and other emerging aviation technologies for aeromedical use are limited, an emerging body of research suggests that emergency medical AAM services may confront several technical and business model challenges. One of these challenges is the integration of eVTOLs in the multimodal system.

To tackle this challenge, the SIGN-AIR project has designed a use case based on eVTOLs. This case aims to identify the stakeholders participating in the multimodal chain and identify the data that they generate as well as the data that are necessary to bring as fast as possible the patient at the hospital in a safe way. Therefore, the Data Flow Diagrams (as a way of representing a flow of data through a process or a system) will be created to simplify the data exchange between stakeholders in the defined multimodal chain.

Additionally, this paper will examine: a) applications for a smart UAM system, b) the connection between vertiports and airports, and c) identifies potential impacts on stakeholders, environment and public acceptance. The possibilities of eVTOL integration into the multimodal chain will be illustrated by the case study on airport Swiss Aeropole, showing how such a transport mode can be part of the new system.

Synergy in Future Avionics: An Overview of Multiple Technologies for Small Air Traffic Segment in the COAST project

Jakub Lucky, Vittorio de Vito, Jan Beran, Tomas Kabrt, Tomas Vaispacher, Lubos Korenciak, Michal Dobes (jr.), Piotr Grzybowski*, Piotr Masłowski
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The paper describes research and development activities under Clean Sky 2 Cost optimized Avionic System (COAST) program. The main goal of this development was to deliver technology enablers at TRL 5 for affordable cockpit and avionics. The target segment for the technology enablers is aircraft with 1 to 19 passengers and small cargo aircraft belonging to CS-23 category.

The main aim is to provide overall summer during the whole COAST program development per individual technology. Sections are divided per each technology with their results and overall contribution to the program. The Clean Sky 2 COAST program covered the development of following technologies: Cockpit Architecture SAT avionic system architecture, Flight Management Tactical Separation System (TSS), Advanced Weather Awareness System (AWAS), Flight Reconfiguration System (FRS), Navigation and Surveillance Dual Frequency Multi-Constellation GNSS Receiver (GNSS), Low-cost Integrated Navigation System (NAV), Affordable Integrated Surveillance System (SURV), Platform technologies Compact Computing Platform (CCP), High Integrity Electronics for health monitoring (HIE), Integrated Mission Management System Integrated Mission Management System (IMMS). These technologies were part of several flight test campaigns which took place in the Czech Republic with Evektor company using EV-55 aircraft.

Design and validation of evolved version of the Tactical Separation System in the COAST project

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** CIRA, Italian Aerospace Research Center, Italy*

Small Air Transport (SAT) is emerging as suitable transportation means in order to allow efficient travel over a regional range, in particular for commuters, based on the use of small airports and fixed wing aircraft with 5 to 19 seats, belonging to the EASA CS-23 category. In this framework, Clean Sky 2 Joint Undertaking, in the European Union's Horizon 2020 research and innovation programme, funded the project COAST (Cost Optimized Avionics SysTem), which started in 2016 with the aim of delivering key technology enablers for the affordable cockpit and avionics, while also enabling single pilot operations for aircraft in the SAT domain.

In the project, some relevant flight management technologies to support single pilot operations have been designed, developed and demonstrated in flight, and among them the dedicated decision-making support system aimed to assist the pilot in the management of the separation task, under delegation of the separation responsibility to the pilot by the ATC. This technology, the Tactical Separation System (TSS), has been successfully demonstrated in flight in the year 2021.

Nevertheless, in order to properly integrate and enhance the individual enabling technologies for single pilot operations, in the COAST project a unique Integrated Mission Management System (IMMS) has been designed and implemented, as a relevant step forward towards advance support to single pilot's decision-making as well as towards more autonomous aircraft. The IMMS is able to automatically optimize the aircraft path by taking into account trajectory optimization needs that include at the same time consideration of traffic and weather, as well as best destination selection in case of pilot incapacitation.

To support the IMMS implementation, therefore, the Tactical Separation System baseline version has been properly evolved, leading to the Evo-TSS. The evolution has been needed in order to include specific functionalities that are required by the IMMS, namely the ability of collecting traffic information not only at tactical level (as per the primary scope of the TSS) but also at strategic level and to provide proper traffic clustering functionality, supporting the trajectory planning and re-planning by the IMMS.

This paper follows the one already presented in EASN 2022, where the basic aspects of the Evo-TSS design were reported. In this new paper, therefore, more details on the implemented Evo-TSS design will be provided, emphasizing the relevant design choices and outlining the implementation of the dedicated software in Matlab/Simulink environment. Then, in the paper the results of the prototype and laboratory validation campaign (fast-time in Matlab/Simulink environment) that successfully concluded in 2023 will be reported and discussed. Based on the positive outcomes of the described activities, the Evo-TSS main software and its evolved HMI will be integrated in the overall IMMS and demonstrated in flight in the dedicated campaign to be carried out in 2023.

In flight testing of the Integrated Mission Management System within the COAST project

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The pilot's situational awareness is the basis for planning a safe flight as well as executing it. Multiple possible threats must be analyzed, filtered, and included in the decision-making process. The most obvious threats from the pilot's perspective are weather conditions, terrain hazards, restricted airspaces, and traffic in the vicinity. Combining this information can only be performed to a certain degree before the flight, and during the flight, the pilot relies on multiple instruments available onboard for the purpose of possible route diversion due to threats. However, with multiple systems, it is difficult to combine threats, analyze them, and take proper action.

This paper presents the overall structure of the Integrated Mission Management System developed within the COAST project. The system is intended to provide the pilot with combined information on the threats mentioned above, aid in route planning, as well as analyze possible new threats so as to suggest if a path diversion is needed. Although tested previously in the Hardware-In-The-Loop laboratory stand, the article focuses on the real-life evaluation of the system which, for the purpose of demonstration, was integrated with the aircraft avionics. The presented results of tests scheduled for June 2023 show design advancements, flight parameters registered in-flight, as well as the pilot's suggestions regarding the system usage. Together, they verify the idea of presenting the combined data for increased situational awareness for SAT as a part of the Innovative Cockpit initiative within the Clean Aviation project.

Examination of the influence of the Integrated Mission Management System on the pilots' situational awareness within the COAST project

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This paper presents research conducted to examine the design of graphical elements for the Graphical User Interface (GUI) of the Integrated Mission Management System (IMMS) display for the flight planning process. As proven, commercial flight planning tools or weather data services have only a common part in displaying information. However, there are numerous significant divergences, including object color, shape, layer distribution, and transparency. During the flight management task, it is important to consider weather data that is often accessible separately based on

aeronautical information publication flight planning tools. Consequently, despite services offering support, a pilot has to refer to different sources. Displaying all relevant information on one screen requires a deliberate form of data presentation. For that purpose, surveys and research on the method of graphic elements and their presentation methods dedicated to the flight planning display were conducted on the target group of students/pilots studying at the Aviation Training Center of the Rzeszów University of Technology. Research on the GUI for the IMMS, including prepared templates and questionnaires, was designed. Based on this research, a conceptual graphical layout for the IMMS flight planning interface was proposed. Results were then applied in the application of the IMMS HMI (Human Machine Interface) and tested by the pilots.

The practical implications of the study are improvements in readability, understanding, and the manner of presenting methods of graphical flight planning elements related to terrain, weather, traffic, zones, and their influence on the final organization of the route, keeping in mind that this information may be combined in a single display. Integrating a system dedicated to the pilot allows for observing very equal to the current essential information originating from different sources at the same time. This research was performed within the Cost Optimized Avionic SysTem (COAST) project, under the Clean Aviation program, which aims to improve the flight path planning process in aviation. The article verifies the impact of the method of drawing and rendering graphic elements of the selected IMMS flight planning during the flight planning process.

Evolved version of Advanced Weather Awareness System in the COAST Project: latest developments and validation

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** CIRA - Italian Aerospace Research Centre, Italy*

Within the COAST (Cost Optimized Avionics SysTem) project, funded by Clean Aviation Joint Undertaking in the European Union's Horizon 2020 Research and Innovation Programme, several technologies are under development for cockpit and avionics of Small Air Transport (SAT) vehicles, since 2016. One of them is the Advanced Weather Awareness System (AWAS), aimed to provide on-board of the aircraft updated data regarding observed and forecast weather hazards, occurring over a geographical area centred on the aircraft position. The development of this system has been completed and it has been successfully tested in flight during the first COAST demonstration campaign, conducted in 2021. In the meantime, the development of the Integrated Mission Management System (IMMS) has begun: it is a new COAST technology, aimed to automatically optimize the trajectory considering several kinds of "obstacles", among which the weather hazards. In order to support the carrying out of IMMS, the evolution of the AWAS has been required and has been carried out in the project: several enhancements have been made to the baseline version of the system in order to generate additional information regarding weather hazards to be provided to IMMS.

The main features of the evolved version of AWAS have been already presented in 2022. In the current work, the latest (and final) developments are described, in addition to the tests carried out in laboratory to validate the prototype. Specifically, all the new functionalities have been tested, in order to verify the correct generation of output data required by the Flight Reconfiguration System (FRS), the core of the IMMS, and their visualization into the HMI (Human Machine Interface). Additional tests have been performed in order to ensure the proper functioning of the whole system in several situations, verifying also modifications carried out to the baseline AWAS functionalities, in order to improve the prototype performances. The positive results of all the performed tests allowed the integration of Evolved AWAS in IMMS technology, permitting its testing in laboratory in view of the validation in the last COAST flight demonstration planned in summer 2023.

Aviation Impact Assessment

Chaired by:
Mr. Volker Krajenski (DLR)

A Versatile Computation Platform applied to Environmental-Impact Assessments at Airport Level in Clean Sky 2

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To not only facilitate computational processes and improve their efficiency, but also to ensure quality and configuration management tasks are automatically and well taken care of, Royal NLR develops a versatile computation platform, the so-called GREENPORT2050 platform. This platform is developed in the Clean Sky 2 Technology Evaluator (TE) project GREENPORT2050. GREENPORT2050 quantifies the reduction in noise and gaseous emissions that Clean Sky 2 technologies for fixed-wing aircraft can bring up to 2050 at and around airports, and assesses the extent to which aircraft equipped with these technologies can be introduced and accommodated smoothly and safely into daily airport operations. Thereby it complements the other core assessments of those technologies in TE at aircraft and air transport system level. The GREENPORT2050 platform is implemented with modern widely-accepted and proven technologies. It integrates models for calculating noise, emissions, safety and capacity as single models or composite models (workflows). Easy access to the platform and its models and data is possible via a web-based intuitive visual User Interface running in the web browser, as well as a detailed RESTful Application Programming Interface (API).

Its implementation makes the GREENPORT2050 platform versatile. New or alternative models in the environmental and other domains can be embedded easily. The API can also be used to unlock models and results for integration with external systems. Moreover, the API enables an even broader access via the Internet to contribute to more transparency, efficiency, and knowledge sharing between various stakeholders and communities, such as science, government, and industry. Further, extensive access-rights management determines who has access to which data and who is allowed to run which models. Thanks to this implementation, the platform does not only increase the efficiency and effectiveness of performing the calculations, but also increases quality in terms of reproducibility, traceability, data integrity, and information security.

While the many-sided GREENPORT2050 platform is presently being used for the project's environmental-impact calculations, work at Royal NLR is already on-going to further enhance and expand it for a broader range of applications, even beyond ATM and airports. Illustrating by its use in GREENPORT2050, the presentation will provide a comprehensive overview of the platform's graphical user interface, implementation, features, future developments, and potential to a broad range of applications.

Environmental Impacts of Clean Sky 2 Technologies for Next Large Passenger Aircraft

Pierre ARBEZ, *AIRBUS, France*

The Clean Sky 2 Joint Undertaking is committed to alleviating environmental impacts of aeronautics and fostering the competitive advantage of the aeronautical industry and supply chain in Europe.

In particular, Clean Sky 2 has set-out an ambitious objective to reduce from 2014 state-of-the-art, CO_2, NOx, and noise emissions by respectively 20% for new aircraft entering into service in the 2030-2035 period and by 30% for the most innovative concepts joining the fleet after 2035.

This objective assumes a global fleet forecast to grow in accordance with a worldwide air passenger traffic increasing in the coming decades by 4 to 5% per year, considering that approximately 50% of flying vehicles might carry major Clean Sky 2 technologies by 2050.

In order to evaluate the environmental impacts and benefits of the most efficient combination of technologies integrated on new aircraft/rotorcraft concepts, the Technology Evaluator (TE) had been created as an integral part of the Clean Sky programme. It will enable quantification of Clean Sky's contribution to the ACARE Flight Path 2050 environmental objectives, particularly on CO_2, NOx and noise reductions.

To do so, assessments of the new concept aircraft being developed are performed at three levels, at mission, airport and air transport system levels. They are carried out using specific Clean Sky tools enabling Partners to build a global evaluation of the environmental benefits of the programme.

Among the various concepts addressed in Clean Sky 2, Airbus develops advanced Large Passenger Aircraft (LPA) planned to enter into service either in the period 2030-2035 or after 2035. These new innovative aircraft configurations implement the new Clean Sky 2 technologies to specifically address short-middle range and long range flight missions.

This abstract introduces a presentation of the environmental targets and results from LPA concepts, of their underlying key enabling technologies, evaluated and compared with 2014 reference technologies according to criteria like weight saving, fuel saving, maintenance or production improvement, overall aircraft system improvement and noise reduction.

These technologies are implemented into virtual aircraft models that enable the performances evaluation of these newly equipped concepts along defined flights. Their benefits and impacts are evaluated and then used for the final 'mission level' assessment handled by the Technology Evaluator.

The knowledge created in Clean Sky 2 Technology Evaluator will generate a new reference to the Clean Aviation Programme looking for similar environmental impact assessments of ultra-advanced concepts designed to contribute to the future net-zero carbon aviation. The presentation will illustrate this transition across Clean Aviation projects.

The basic scenario on aircraft noise assessment for analysis of new clean aviation technologies

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The Clean Aviation Program in Europe for the current decade is mostly directed at decarbonization of the aircraft and their operation. Hydrogen-fuelled and electric regional airplanes of various designs and principles, including commuters, are the priorities of this program. Noise reduction should be a complimentary pillar in producing new green airplanes still the same important as during the previous decades. The advances of the new technologies must be accessed in comparison with the current best results inside similar classes of aircraft.

On the basis of actual data for an average regional airport, the average annual range of aircraft noise impact was determined. For example, taking into account a regional turboprop aircraft, the accuracy of the computational model of equivalent and exposure sound levels were estimated from

noise monitoring data at the airports. The actual routes and profiles of take-offs and landings were included from the ADS-B database in the universal computational model of the movement of this type of aircraft, which is being developed and will be used to determine the impact range in the event of a change from the traditional power unit to electrically powered engines. Two aircraft types - ATR75 and DH8D – are operating at three exemplary regional airports and analysed in the paper. The recorded specific values of noise emission at selected measurement points lead to fine-tuning of the model in the case of a classic turboprop engine. After obtaining satisfactory results, the refined model will be used, taking into account the characteristics of the new type of drive unit. With an estimate of the accuracy of the model calculation for different configurations of electrically powered aircraft, it will be possible to assess the expected noise climate parameters change around the regional airport. The same approach is used for the hydrogen-fuelled airplane.

NOVEL AIRCRAFT EMISSION AND AIR POLLUTION SCENARIOS AT AIRCRAFT, AIRPORT AND FLEET LEVELS

K. Synylo*, O. Zaporozhets, A. Krupko, V. Makarenko, V. Tokarev, S. Karpenko

** NOISE ACH, Poland*

Improvements in aircraft and engine technology and subsequent fleet replacement hold the largest promise for decarbonizing European aviation. This includes the introduction of electric and hydrogen-powered aircraft on intra-European routes in 2035. The generation of commercial passenger aircraft to be developed in the next decade has a potential to realize a step-change in energy efficiency on the board during the flight. This task of efficiency assessment as for energy consumption as for the impact on environment may be divided into the following subtasks:

1. Overview of the available and promising technologies in terms of fuel/energy consumption, emission and noise. The benefits, challenges and limitations are planned to highlight.

2. A list of metrics and indications for analysis of fuel/energy, emission and noise interdependencies and trade-offs will be determined at airport and global scales. Additionally, significant factors like operational and technological will be taken into account as well as non-environmental interdependencies.

3. To collect, summarize and analyse the experience gained in the assessment of fuel/energy, emission and noise interdependencies at technological level for defined classes of aircraft.

4. The results of fuel/energy, emission and noise interdependencies for reference fleet and aircraft with novel types of fuel and propulsion system will be compared with ACARE 2050 noise and emission goals. In result possible technological gaps and efforts for overcoming difficulties will be defined.

The current status of emissions, the EU environmental targets for aviation, the gaps remaining and the measures needed to close them will be assessed. The current emission situation for all types of aircraft, determining their contribution to global emissions and projected trends, should be examined. The work planned for this task is divided into the following subtasks:

1. Fuel/energy consumption assessment according to the classes of aircraft.

2. Assessment of Emission Indices (EI&#39,s) for NO x , CO 2 , (U)HC, SO x , and non-volatile Particulate Matter (nvPM) for the classes of aircraft by using aircraft engine conditions (BFFM2, P3T3 method) or combustion modelling and fuel flow modelling tools.

3. Emission inventory calculation for cruise mode for the fleet and dominant groups of the aircraft. Assessment of Local Air Quality (LAQ) at airports (emission inventory analysis and air dispersion – at airport level) and Global Air Quality (GAQ) for air traffic routes (cruise emission inventory analysis and

its effect on global issues like climate change – cruise flight level): to assess LAQ and GAQ from NO x, SO x , volatile organic compounds (VOCs), non-volatile particulate matter (nvPM), carbon dioxide (CO 2) and other new specific pollutants/sources (full list will be proved during the research) that occur below 900m above ground level around predefined airport scenario from the dominant emissions sources by categories: a) aircraft emissions, b) aircraft handling emissions, c) infrastructure- or stationary-related sources, and d) vehicle traffic sources, to assess GAQ emission inventory and air dispersion will be calculated with the tools verified by CAEP for their accordance to ICAO Doc 9889: PolEmiCa (Pollution and Emission Calculations, designed by CEPA, verified during CAEP/12 working cycle) and AEDT 3.0 (a software system from US FAA that models aircraft performance in space and time to estimate fuel consumption, emissions, noise, and air quality consequences at the regional, national, and global levels) with BADA (Base of aircraft data, which provides theoretical model specifications and related specific datasets to accurately simulate the behaviour of any aircraft).

Air traffic scenarios will be defined with BADA including the novel EFACA aircraft designs. The management of airport LAQ and the relevant emissions is fundamentally targeted at achieving and maintaining compliance with local regulation on permissible levels of pollutant concentrations (standard limits). To understand the actual impact of these emissions, it is necessary to determine the pollutant concentration (mass per unit volume, which may be measured in ppm or mg/m 3) at the point where exposure takes place. In general, the LAQ is determined by comparison of the exposure concentrations with standard limits. An airport with a history of non-compliance with LAQ regulations can be subject to pressure from regulators and communities when planning permission for infrastructure expansion is needed. In contrast, the aircraft noise management primarily addresses mitigating adverse response from noise affected communities.

Compared to conventional aircraft, fully electric aircraft emit few or none of the pollutants that adversely affect local air quality. In particular, NOx and fine particulate matter will be greatly reduced due to the reduction in fossil fuel combustion. Fully electric or hybrid-electric aircraft could significantly reduce the emission of pollutants and GHGs in areas surrounding airports. Aircraft powered by a traditional jet turbine or turboprop engines can produce large amounts of pollutants such as NOx, volatile organic compounds (VOC), sulfur dioxides (SOx), and GHGs. Aircraft powered by piston propeller engines emit larger amounts of CO than jet turbine or turboprop aircraft.

The potential for hydrogen as a widespread clean energy source in the future also leads to interest in its use in aviation. Use of hydrogen, both as a source of propulsion power and on-board power, has the potential to reduce noise pollution, increase efficiency and reduce GHG emissions associated with the aviation sector as long as hydrogen is produced from a renewable source, from other potentially low carbon energy sources such as nuclear or from fossil sources with carbon capture and storage. While hydrogen has a much higher gravimetric energy density than kerosene, its volumetric energy density is much lower and both characteristics are critical to airframe design and performance.

Hydrogen combustion would produce about 2.6 times more water vapor than kerosene fuel. The products of LH 2 combustion are water vapor and nitrogen oxides, although the amount of nitrogen oxides produced can be kept to a minimum with proper design and operating envelope. For LH 2 , no unburned hydrocarbons, CO, or CO 2 are emitted. NOx emissions for LH 2 fuel are a 24% improvement over Jet-A, and again, H 2 O is a constant index with emissions changing only as a function of fuel flow into the engine.

On results of the analysis of the studies made by CAEP/MDG for the airport LAQ metric and for the Concorde EIA in US airports there are three simplified cases defined: for the assessment of queuing and low speed ground run prior to take-off the aircraft in stationary (moving speed equal to zero) conditions with two aside engine operation modes –idle and maximum: emission is considered for CO (nvPM) and NOx accordingly, engine jet performances are included due to their velocities and temperatures at engine exit, engine jet installations are defined by aircraft designs in consideration, wind direction is the same as the direction of engine jet, surface covering is a small grass, Pasquill atmosphere stability class D (E) for all cases. ·a moving source case is considered for the assessment

of taxing aircraft with engine in idle mode: emission for CO (nvPM) and engine jet performances should be defined for idle operation mode, wind direction is at angle 90° to the direction of engine jet, surface covering is a small grass. A moving source case is considered for the assessment of taking-off aircraft along runway with engine in maximum mode: emission for NOx and engine jet performances should be defined for maximum operation mode, wind direction is at angle 90° to the direction of engine jet and aircraft run, wing vortices should be included in consideration for preliminary dilution of engine emission, surface covering is a small grass. Multidisciplinary optimisation and fuel/energy, emission and noise trade-off studies will be joined for novel classes of aircraft at technological level and for scenario analysis of fleet operation in respect to aviation neutrality 2050 goals.

Current ANSP Practices Towards Reducing the Environmental Impact of Air Traffic Operations

Christoph SCHUETZ*, Emir GANI´C, Simon STAUDINGER

** Johannes Kepler University Linz, Austria*

Significant efforts have been made over the years to reduce noise impact as well as fuel consumption and pollutant emissions from aircraft operations. Different stakeholders such as airports, airlines, air navigation service providers, and regulatory bodies are tackling this problem from various perspectives in their sphere of influence. Most initiatives for the reduction of negative environmental impacts require substantial resources and are concentrated mainly on a strategic level. On a practical level, by changing airport operational procedures, ANSPs can achieve short-term improvements, which are less expensive to implement compared to solutions at the disposal of other stakeholders. In this regard, the optimisation of airport operational procedures with the aim to reduce noise impact and fuel burn has been well studied over the past decades, and various approaches have been proposed to ANSPs.

However, the implementation of possible theoretical solutions into ANSP practice proved not to be as widely spread as expected. Therefore, in this paper, we look at the state-of-the-art regarding current practices that ANSPs are following to reduce the environmental impact of air traffic on the population in the airport vicinity, including local air quality and noise emissions. In addition to investigating the available academic approaches, we analysed various information available in the official publications of different European ANSPs.We scraped websites for information material and technical documentation in order to apply natural language processing techniques to systematically analyse those documents.

Furthermore, we contacted different ANSP representatives in Europe to learn about their current practices as well as their future intentions to include environmental factors in their activities. As a result, we compared and classified the different initiatives in terms of processes that are optimised, pollutants reduced, and the primary purpose of the initiative. A special focus has been dedicated to the decision support systems and automated traffic planning tools that are used by air traffic controllers. Consequently, we identified possible improvements to the current solutions in place and formulated requirements and suggestions for the future development of such systems.

Way of future orbital and planetary robotics

Chaired by:
Ms. Wiebke Brinkmann (DFKI)

Development of a leveling and loosening mechanism for fine sediments on a test track for planetary robots

Jonas Eisenmenger*, Jonas Benz, Malte Langosz
** DFKI Bremen, Germany*

The history of planetary exploration shows an increasing tendency towards the use of robotic systems. Due to the difficult soil conditions on these planets, robots must possess a high degree of mobility. Thus, the robots must be extensively tested on earth before they can be sent on planetary missions, to guarantee a functionality even in difficult terrain. One of the challenges on a planetary surface is loose soil, which can cause the robot to get stuck and endanger the whole mission, which NASA had to painfully discover with their Spirit Rover getting stuck in soft sand on Mars and was not able to free itself. Therefore, during the preliminary testing, the robot should move over soil several times, with repeatable surface and soil characteristics each time to make different approaches comparable or confirm the results.

In the NoStrandAMust project, the focus is on testing the locomotion behavior of various robotic systems on different soils and driving behaviors in the context of the surfaces, to generate ground interaction models. Robotic systems developed at DFKI for planetary applications, such as four- to six-wheeled rovers and four- to six-legged walking robots, are being tested on a test track. The test track consists of four different substrates, from firm, smooth ground to lava structure to loose gravel and fine sand.

In order to achieve repeatable tests on the fine sand, the ground should be leveled and loosened before each run. In this way, increasing compaction of the soil as the number of experiments increases and an associated change in the soil properties can be avoided. As a result, the soil is as close as possible to the reality, where most of the ground has remained untouched until now.

For this, a leveling and loosening mechanism was developed, which will be integrated into the test track to allow repeatable experiments on the fine sand.

During the development different approaches for the leveling as well as for the loosening were reviewed. To test different concepts a test bench was designed and several experiments were executed. For the measurement of soil properties, a driven penetrometer was designed, which was used for the evaluation of the loosening abilities of the concepts. The experiment data was analyzed and in conclusion, a final design of the mechanism selected.

This paper will describe all these steps in more detail, show results of the experiments and the final design of the mechanism.

Design and testing of mechanical gripping tools for On Orbit assembling

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** Deutsches Forschungszentrum für Künstliche Intelligenz GmbH, Germany*

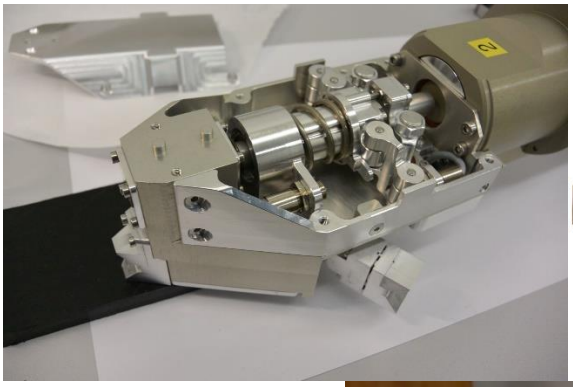
On-orbit servicing (OOS) and in-space manufacturing and assembly (ISMA) operations are becoming increasingly important in today's and future space applications. Almost all potential applications require the ability to interact with robotic systems. Therefore, extensive R&D activities have been advanced in Germany, Europe and internationally in recent years to develop compact general-purpose manipulator arms for orbital use (e.g., ROKVISS, CAESAR, DEXARM, PIAP). Tools that can be attached to the end effector and operated to perform the actual contact operations such as gripping, screwing, riveting are usually less generic and designed for specific operations, which limits their use on individual missions.

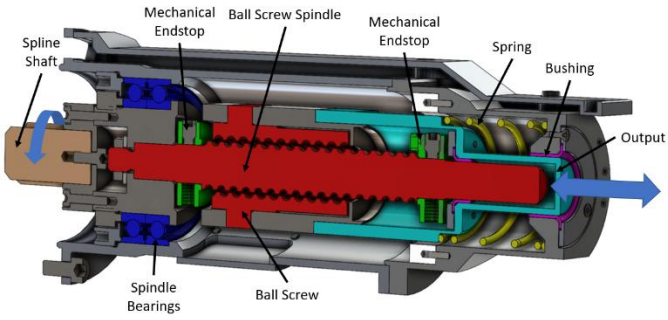
The subject of this paper is the description of the design of mechanical tools, driven by a Multi-Purpose-Tool (MPT) for orbital robotic systems, with manipulation capability. The MPT architecture was developed by AIRBUS Defence and Space GmbH (ADS) whereby the basis for the assembling process was derived from the satellite antenna manufacturing from the PERIOD project, which is part of the Horizon 2020 space research cluster of the European Union.

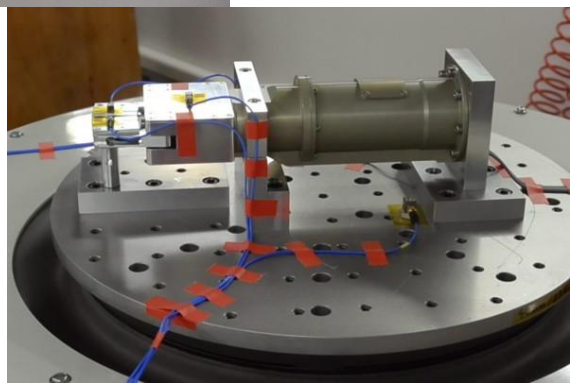
For this purpose, the development of robotic tool attachments and its partial qualification in the range of up to TRL 5 were aimed for 2022. Key driving factors for the tools were the design- and operational complexity to accomplish the assembly tasks. Also, interfaces necessary for grasping and safety requirements, such as securely holding the objects in the event of a malfunction or compensating for the positioning inaccuracies of the manipulator were considered and tested.

One of the tools described in the paper is the frame gripper, an asymmetrical mechanism with two rotational fingers for gripping triangular sheets. By avoiding the loss of a part at all costs, the frame gripper was accomplished by a redundant spring and a toggle lever mechanics disabling the mechanisms back drivability. The second tool presented is the cleat gripper, a two-finger gripper with adaptable jaws for the manipulation of noncritical parts attached of the sub antenna elements. To convert the rotary input movement provided by the MPT a ball spindle mechanism was chosen. Therefore, a generic drive unit (GDU) containing the spindle (Fig. 1, No. 3) being part of both tools was designed, lowering design complexity.

Verification has been carried out on component level so far with all tools and will also be described within this publication including vibration loads testing according to ECSS and Bartolomeo Payload hosting platform. TVAC testing and the external validation of the tools by our consortium member Airbus Space and Defence are scheduled for early/mid 2023, but not firmly planned as content part of this publication.







Enhancing Development of Modular Application-Specific Configurable Space Robots

Henning Wiedemann*, Priyanka Chowdhury, Wiebke Brinkmann, Jieying Li, Isabelle Kien, Malte Langosz, Moritz Schilling and Erik Michelson

** University of Bremen, Germany*

In many space activities, robotic systems are indispensable. However, existing systems are mission-specific and highly specialized ones, that cannot be re-used. In the MODKOM (Modular Components as Building Blocks for Application-specific Configurable Space Robots) project, the goal is to create a toolbox that allows to configure and re-combine a robot for certain tasks, out of specialized and standardized building blocks.

This publication presents a method to represent, store and handle all those modules to make them accessible also to non-expert users. Therefore, one of the main goals in MODKOM is to develop a software toolkit and user interface that helps to combine hardware and software parts to modular robotic systems. This paper elaborates the concepts, implementations and first results of this method. Alternative AI-supported methods for docking and mission planning are investigated additionally. Besides the software side, an initial set of hardware modules is presented.

The current state of this toolbox is applied in simulation and discussed by taking relation to the foreseen final real-world demonstration scenario, that will be used to evaluate the outcomes of MODKOM. This allows to have a first glance at how this toolbox will facilitate future robot creation by providing modules and standards that can quickly and easily be modified to meet new or changing requirements.

Tether Management and Docking System for Multi-Robot Rappeling into Lunar Lava Tubes

Jonathan Babel*, Leon Cedric Danter, Yogeshkarna Govindaraj, Gonzalo Paz Delgado, Raúl Dominguez, Frank Kirchner

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Subsurface lava tubes have been detected from orbit on both the Moon and Mars. These natural voids are potentially the best place for long-term human habitations, because they offer shelter against radiation and meteorites. Skylights, formed by partial cave ceiling collapse, provide an entrance to several of the previously discovered lava tubes. Multi-robot collaboration may allow us to reach and explore these unknown cavities, where sending astronauts without prior knowledge is an evitable risk. This work presents the development and implementation of a novel Tether Management and Docking System (TMDS) designed to support the vertical rappel of a rover through a skylight into a lunar lava tube. The TMDS connects two rovers via a tether, enabling them to cooperate and communicate during such an operation. Its hardware comprises an active winch and two interfaces, a passive HOTDOCK and a passive EMI. Although particular robotic systems are used to demonstrate the feasibility of the task, the device can link any robots equipped with the active counterparts of these standard interfaces. The height of the TMDS platform can be adjusted by two linear actuators in order to facilitate docking and transport. A framework independent interface provides control over the platform height and the velocity at which the winch releases the tether. The winch speed gets synchronized with the wheel speed of the rappeling rover to allow a controlled descent. The development of hardware and software components is part of the Cooperative Robots for Extreme Environments (CoRob-X) project. In January and February 2023, the approach was thoroughly tested in a three-week lunar analogue mission on Lanzarote, Canary Islands. The tests were divided into four mission phases (MP1-4): At first, the three rovers LUVMI-X, SherpaTT and Coyote3 collaboratively explore and map the area around the skylight (MP1). Subsequently, LUVMI-X ejects a sensor cube into the skylight to gather information about rock formations along the vertical walls and from the landing site (MP2). In the third phase, Coyote3

rappels down into the skylight assisted by movements of SherpaTT's manipulator (MP3). Once Coyote3 has reached the ground, it undocks from the TMDS and explores the lava tunnel (MP4). In this paper, we will discuss the results of our work, focusing on the successful rappel, sharing our experiences and lessons learned from the field test campaign.

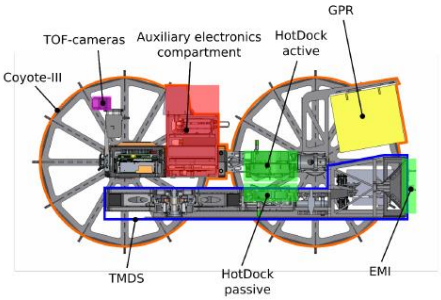

Figure 1: Coyote3 with docked TMDS underneath the main body in sectional view, important parts are labeled (credit: DFKI, Christopher Schulz).

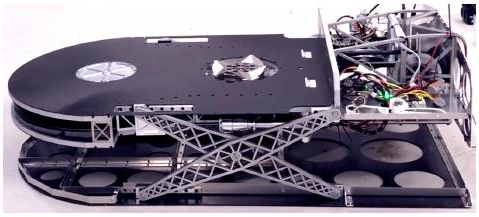

Figure 2: Tether Management and Docking System (TMDS) in lifted up state (credit: DFKI, Jonathan Babel).

Figure 3: CoRob-X Mission Phase 3: REU-1 and REU-2 performing Mobile Manipulation and Guidance Rappel (credit: DFKI, Meltem Fischer).

Figure 4: Shows the end of MP3 and beginning of MP4, where Coyote3 reaches the ground of the lava tube, undocks from the TMDS and starts exploring the cave (credit: DFKI, Meltem Fischer).

Context attentive robot reconfiguration for collaborative human-machine space missions

Isabelle Kien*, Manuel Meder
** University of Bremen, Germany*

With humankind's aspiration of extraterrestrial inhabitation, the need for robotic support is eminent. To master the emerging challenge of providing astronauts with assistive space robots possessing the required adaptability to new situations and tasks under the constraints of severely limited supply chains in extraterrestrial missions, the exploitation of existing hardware to its fullest is required. We propose the combination of a concept with an architecture to jointly support context-aware collaboration between humans and robotic systems for implementing effective resource utilization in space missions.

The underlying framework is an implementation of a flexible architecture that enables context awareness for robotic systems. It supports processing nodes for retrieval of context information from the raw sensor values as well as further inferences. Context information spans across three entities and describes the current state of the environment, the astronaut and the robot itself. This information then can be used to infer the human's current intention as well as influence the behavior to be executed next. Additionally dynamic changes in the data processing chains are handled by the framework to facilitate an adequate adaptation of the system to situational events.

The second concept is the composition of space robots from building blocks, which is supported and made accessible by a software toolkit. The modular design-approach enables online self-reconfiguration of robotic hardware and software components. In combination with dynamic mission planning, based on ontological descriptions of available resources and functionalities, robots are able to adapt their physical and computational appearance dynamically during a mission according to different tasks and goals.

By incorporating these two developments in a joint deployment we envision to raise the efficiency of robotic systems in human machine interaction through the usage of self-reconfiguration as a reactive behavior in order to adapt to a specific task, recognized or derived from a human's intention. Transfer of the proposed idea back to Earth may help to abate resource dissipation caused by deploying specialized monolithic systems with a narrow range of capabilities through utilizing the adaptivity of reconfigurable robots.

Digital Tools for future Aircraft on the horizon

Chaired by:
Mr. Andreas Kötter (Capgemini)

Implementing Lifecycle Standards to Automate Cost-Benefit Analysis in Aerospace Product Design

Massimo Panarotto, Ola Isaksson*

** Chalmers University of Technology, Sweden*

The need to improve performances, cost-efficiency and sustainability is pushing the aerospace industry to consider new and disruptive concepts, both in the technology (e.g., electric, hydrogen and hybrid) as well as in the business domain (e.g., small regional transportation). However, the cost-benefit comparison between these radical concepts is difficult today, since the alternatives present different parameters, scales and modelling logics.

This paper presents a framework and a web-based tool (Club Design) to enable automated cost-benefit analysis of design and business alternatives within the aerospace propulsion business. The

framework is the result of a decade of research within the aeronautical and space sector. The technical novelty of the framework is the combination of existing lifecycle standards (ISO 15288 and ISO 10303-243 – MoSSEC) to enable a 'batch run' cost-benefit analysis of aerospace design concepts (e.g., different concepts for the propulsion system) onto different business scenarios (e.g., long-haul flights, small regional aircraft, and shortage of fuel/electricity).

The results point at the value of implementing lifecycle standards in a web-based tool to promote cost-benefit analysis already from the early phases of product design (and from system design down to sub-systems and components). Also, the tool implementation can increase industrial accessibility to new ways of working.

A system of systems framework for strategic cargo airlift using agent-based modelling

Nikolaos Kalliatakis*, Tobias Dietl, Prajwal Shiva Prakasha, Thomas Zill, Nagel Bjorn

** DLR- German Aerospace Center, Germany*

In times of emergency, the rapid movement of cargo assets around the world is highly critical. Upon a natural disaster or other crises, foreign and domestic governments seek to offer prompt humanitarian aid and disaster relief (HA/DR) material to the afflicted area(s). Similarly, in wartime scenarios, militaries are responsible for the swift, international movement of supplies, vehicles and troops to support bases and operational areas. Despite the cargo sizing and content differences, both military and HA/DR missions have stringent time horizons and seek to minimize costs and cargo throughput. Such requirements constrain these missions, whereupon fleets of aircraft with extraordinary payload-range capabilities are adapted to conduct these movements. The extreme demands of airlift result in high utilization rates on certain aircraft, hastening fatigue and precipitating a rapidly retiring fleet [1]. To solve this problem, this work proposes a framework for coupling aircraft design, fleet planning and operational logistics to the airlift performance. This is done via a simulation tool which encapsulates the complexities of strategic airlift. Through measures of effectiveness (completion time, cargo throughput, cost, etc.) and measures of performance (utilization rate, travel distance, etc.), inputs corresponding to design are directly linked to the output mission performance. The framework is designed to be multi-use, by having parameterized tool inputs, it can be applied in both low and high-fidelity design loops. To ensure a holistic analysis is conducted, the simulation models the shifting cargo requirements and aircraft maintenance problems that commonly occur through an airlift as stochastic events. The subsequent dynamic operation environment is then handled through agent-based modelling, enabling flexible flight scheduling and swapping between aircraft. An illustration of the framework's capabilities is then explored by varying the multiple inputs in a DoE so that a sample trade space is obtained. Using the framework, the determination of future top-level requirements is better facilitated. A framework overview is displayed in Figure 1.

Quantum@Airbus: Bring Aerospace into the Quantum Era

Gerd Büttner, *Airbus*

Airbus' nearly exponential growth in processing capability has required the computational platforms. We are also investigating new software-hardware interfaces for faster processing, distributed parallel computing, neural networks and Quantum Computing!

The focus of Airbus is to work with partners on the development of algorithms and applications, including first tests on existing small scale hardware. This is mainly done in the frame of Government funding contracts like Horizon Europe with the EQUALITY project.

Digital Twin and flexible energy streams, new sustainable tools for quality optimization in the Aircraft industry

Ragnhild Eleftheriadis*, Andreas Kötter

***** *SINTEF Manufacturing, Norway*

The aircraft industry is a cutting edge for safe and sustainable growth in the field of aerospace in Europe. Sustainable and flexible tools in energy sector can bring benefits for quality assurance of the produced aircrafts, which is important for pushing the boundaries after the COVID-19 pandemic. In this paper we will have a closer look at combining such concepts as digital twin and energy stream tools in order to optimize the use of renewable energy resources that will be a game changer for this industry in the future. The sector at hand has a long implementation time frame due to the high-quality standards of the aircrafts and long-term optimization of new technological solutions, as well as validation of products and processes.

Development and high focus on Industry 4.0 around year 2011 gave the aircraft industry a possibility to adapt more digital solutions. This made a huge impact on the progress, and more prospects in the quality domain. Digital transformation and implementation of Industry 4.0 is closely related to application of approaches such as Zero Defects Manufacturing and Six Sigma. The COVID-19 pandemic with a lot of aircrafts and factories in "lock down", have shown how fragile this industry can be. Suffering from downtime, planes on the ground, lack of qualified technical personnel on industrial sites, as well as war in Ukraine increases importance of sustainable manufacturing of various products, including those in the defence sector. As a result, there is a high demand for solutions that would allow to scale up production in a short time, in a safe and secure manner, while adapting new solutions and technologies.

In an ongoing EU project, digital twin solutions for the energy market are being developed. Corresponding conceptual models connected between each other on an aggregator platform are supposed to help manufacturing to adapt to the energy market through increased use of renewable energy resources at the lowest possible cost. The solutions under development are combining control systems and algorithms for market penetration to predict when which type of energy resources is the most beneficial to be used. Proposed solution can be later adjusted to be used in various industries, including the aircraft one, in order to decrease energy consumption, save the costs, as well as increase the overall quality of the produced goods and services.

Aircraft a possible application area of digital tools and hydrogen solutions?

Rico Löser, *Fraunhofer Institute for Machine Tools and Forming Technology, Germany*

In order to achieve the targeted climate neutrality in the EU by 2045, a broader application of green hydrogen in combination with digital solutions is required. Hydrogen technologies currently still play a subordinate role in the field of aviation. It's not just about using fuel cells in the powertrain of aircrafts. Their potential mainly is along the whole production chain of aircrafts, especially while looking on key elements above all systems for converting renewable energies into hydrogen (electrolyser) or converting it back into electricity (fuel cells).

From a starting point of current research projects in the field of hydrogen by the Fraunhofer IWU, like "Referenzfabrik.H2",which aims to enable economical, high-rate production of electrolysers and fuel cells and "HZwo-DigiTwin", in which a new scalable digital twin as a joint test and validation platform for operational management strategies of fuel cell systems will be developed, potential application for the aircraft will be discussed.

Furthermore, the presentation will be finished with an overview of the digital tool Xeidana (eXtensible Environment for Industrial Data ANAlysis) developed by the FraunhoferIWU, by showing new possible fields of application in aerospace derived from current applications in the areas of inline quality control, automation and condition monitoring.

UAM Vertiports - mobility of the future Design & development of a modular vertiport

Enrico Massel, *Sogeti, Germany*

Vertiport is a research project, funded by the City of Hamburg, to funded by the City of Hamburg, to develop a modular design for an develop a modular design for an eVTOL take-off and landing site for eVTOL take-off and landing site for passenger and freight services of the passenger and freight services of the Advanced Air Mobility. The focus is on the topics of community, sustainable, independent and adaptive.

Innovative electrical devices for New Horizons in Aviation and Space: from materials to application

Chaired by:
Prof. Patrizia Lamberti & Dr. Monica La Mura (University of Salerno)

Innovative strategies in composite manufacturing for electrically conductive coatings in aerospace

Hetal Parmar*, Pierpaolo Carlone, Patrizia Lamberti
** University of Salerno, Italy*

The article aims to develop innovative strategy in composite manufacturing using VARI route. Main application of this metallized composite material system can be in external and/or internal aircraft parts for lightning strike protection. Cold spray coating technique was successfully applied to attain deposition on hybrid thermoplastic-thermoset composites. The DC conductivity measurement highlighted the improvement in conductivity of the thermoset matrix carbon fiber reinforced composite. To validate the experimental findings, a COMSOL based simulation was attempted for lightning strike on the metallized composite materials system.

Electrical aircrafts for short range flight services: an analysis focused on the state-of-art of the ON board innovative battery recharge

Marco Barozzi *, PATRIZIA LAMBERTI, MONICA LA MURA, VINCENZO TUCCI, ELISABETTA SIENI, RAJI SUNDARARAJAN
** University of Insubria, Italy*

The worldwide race for the reduction of greenhouse gas in 2050 requires a great effort in the reduction of the use of oil fuel in the vehicles, and then also in the aircraft propulsion. The idea of introduction of Electric Aircraft, EA, for short range service is challenging in the terms of battery development and ground service to manage recharge using renewable sources. Without the design of more efficient and clean process for the management of the energy the introduction of short-range EA might be only a shift of the greenhouse production with a small worldwide effective result.

The first EA have been designed with small size, with 1 to 5 seats and were equipped by available technologies batteries.

In recent year the worldwide producers proposed the development of electric propulsion aircrafts for short range flights with up 180 seats and a flight distance of around 500 nm, e.g. A320. These type of EA with 180 seats mount 28MWh battery pack that requires energy to be recharged by the at ground services. The required power for grounding service related to the recharge battery in the conventional time of 30 min is 1 MW for 820 kWh battery. In 2022 it was evaluated that energy density between 400 and 750 Wh/kg are usual in short-range flights. Then the challenge is on batteries of new generation able to store energy with high density.

The new technologies based on Lithium-ion battery, e.g. Lithium-Sulfur might arrive at 2600 Wh/kg, could improve the on ground service required to manage EA fast recharge. In this frame NASA proposed improved solid-state battery technology. Other groups instead modify electrode introducing carbon fiber functionalized. This review will analyze both the battery state-of-art in EA.

STRATIFIED MATERIALS FOR AIRCRAFT STRUCTURE: THERMAL EFFECT OF LIGTH IMPACT BY NUMERICAL SIMULATIONS

Ellisabetta Sieni*, PATRIZIA LAMBERTI, MONICA LA MURA, VINCENZO TUCCI, GIULIA MIGNEMI, MARCO BAROZZI

** University of Insubria, Italy*

the structure might arrive to fuse the metallic coating that in general is in aluminum. In recent year, Carbon Fibers Reinforced Composites (CFRC) panels are studied as structural parts as an alternative with respect to metal. Metal layers are able to dissipate the current related to the lightning that impacts on the structure, whereas the multilayer CFRC panels are less conductive and then have a limited possibility to dissipate current.

This study presents a time varying thermal simulation coupled to electromagnetic simulation considering different lightning currents representing the short stroke, i.e. an impulse, or the long stroke, i.e. a square pulse. In order to compare different materials, e.g. CFRC with epoxydic resin with or without conductive nanocomposites, different layer size and number, covered or not with aluminum, the temperature increment due to the lightning impact will be evaluated using Finite Element Analysis. This way an estimation of the influence of the different materials composition will be studied.

Graphene Devices for Aerial Wireless Communications at THz

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Recent advances in wireless communications and IoT open huge and promising perspectives for new applications for industrial facilities automation [1], [2] and intelligent and autonomous vehicles (IAVs) including unmanned aerial vehicles (UAVs) [ASCB22]. Many Industrial IoT applications currently rely on either wired connection or Wi-Fi, but fail to meet the ubiquitous service availability and the stringent criteria for latency and outage; whereas cellular technology possesses expensive licensing. 3GPP is actively working on New Radio in unlicensed bands for incorporating ultrareliable low-latency communications (URLLC) into 5G and 6G communication networks. UAVs can strongly benefit from sensing and positioning capabilities offered by 6G systems in unlicensed bands at THz. The ultra-high throughput and enhanced sensing capabilities provided by THz communication could may offer several opportunities [3],[4], opening the door for new services, such as advanced swarms of UAVs, where UAVs may need to exchange large amount of data to handle an increasing number of sensors

to provide integrated sensing, localization and mapping. However, THz technology is not yet mature enough to be commercially viable. This study aims at investigating the possibilities of end to-end THz communication systems, as enabled by the novel graphene-based technologies.

Because of excellent electrical, thermal, and mechanical properties, graphene has been regarded as the most valuable metal substitute material since its discovery. It can be used in multiple applications of interest for the aerial wireless communications, such as high-speed electronic devices (e.g. transistors for single-device amplifiers, mixers, phase shifters, frequency multipliers) and tunable metamaterials for both innovative antennas (e.g. reconfigurable multiband antennas) and photonic-inspired components (e.g. absorbers, mirrors, detectors, polarizers, lens). The optimization of graphene-based components will provide significant energy savings, making the THz technology green and sustainable.

This study targets graphene-based electronic components and antennas in order to support integrated THz communications and sensing for future 6G networks for application in the IAVs and UAVs scenario. We will present the opportunities and challenges arising by the wide deployment of graphene technology as the enabler for integrated sensing and communication (ISAC) at THz. We will show the benefits of graphene technology to provide energy-efficiency and reliable coverage, which are fundamental for UAV operation.

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Simulation-based design of a microbolometer for THz imaging

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The terahertz (THz) radiation falls into a relatively unexplored range of electromagnetic (EM) radiation due to technological limitations which have, until now, limited the development of systems functioning with good performance at room temperature. Nevertheless, since THz radiation does not interact with many materials and is not harmful for people and things, it can be exploited to perform effectively the detection of materials enclosed in packaging that conceals them to the eye, such as harmful explosives [1]. For this reason, THz imaging has been, in the beginning, explored for airport security scanning. However, other possible applications related to aeronautics and aerospace can

be imagined. For example, THz imaging can support the inspection of coatings for the monitoring of the structural integrity.

The detection of THz radiation can be performed indirectly by relying on the bolometric effect, i.e. by monitoring the temperature increase related to the exposition to THz EM waves of THz-absorbing materials. Several bolometers have been proposed to operate in the THz range. Micromachined bolometers have also been explored, working as resonant sensors made from microfabricated structures such as cantilevers, bridges, membranes, plates, and trampolines, which resonance frequency changes due to the THz-induced heating of the absorber material [2]. Increasing the sensitivity of the bolometer typically increases the time required to reach the thermal equilibrium of the heated device, and therefore results in a slower response time. It is therefore desirable to design the device by finding the optimal tradeoff between the resonance frequency shift (Δf) and the thermalization time (τth).

In this work, a resonant microbolometer design is presented [3], based on the sensitivity analysis performed by means of finite element simulation. The finite element analysis (FEA) proposed, investigates the performance variation in response to the design parameters variation, and the factorial design of simulations allows computing the response surface of the Δf and τth for the optimization of the microbolometer geometry.

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