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AGILE — AIRCRAFT 3RD GENERATION MDO FOR INNOVATIVE COLLABORATION OF HETEROGENEOUS TEAMS OF EXPERTS

Multidisciplinary Design Analysis of BWB Aircraft Through Collaborative Design Approach : AGILE EU Project

ICAS 2018 , SEPTEMBER 10TH 2018

Contributing Partners:

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Mark Voskuijl,	TUD, Netherland
Kirill Anisimov	TsAGI, Russia
Marco Fioriti, Luca Boggero	POLITO, Italy
Dominique Charbonnier, Jan Vos, Aidan Jungo	CFSE, Switzerland
Pierluigi Della Vecchia, Luca Stingo, Danilo	UNINA, Italy
Artur Mirzoyan, Alik Isyanov,	CIAM, Russia
Mengmeng Zahn	Airinova, Sweden
Benedikt Aigner	RWTH, Germany

European Commission | Innovation and Networks Executive Agency

DLR Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center

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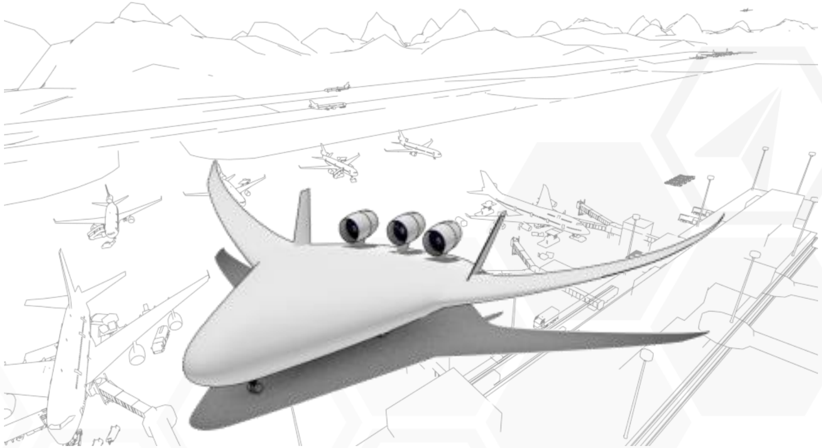
HORIZON 2020 PROJECTS

Multidisciplinary Design Analysis of BWB Aircraft Through Collaborative Design Approach : AGILE EU Project

Questions to be addressed

- Can we design a Novel configuration within short time?
- Can we design involving heterogeneous partners across different organizations through AGILE Development process?
- Can we solve some of the issues of Propulsion system airframe integration, Stability & control and Subsystems.
- Outcomes of such Model Based approaches



AGILE

Why collaborate?

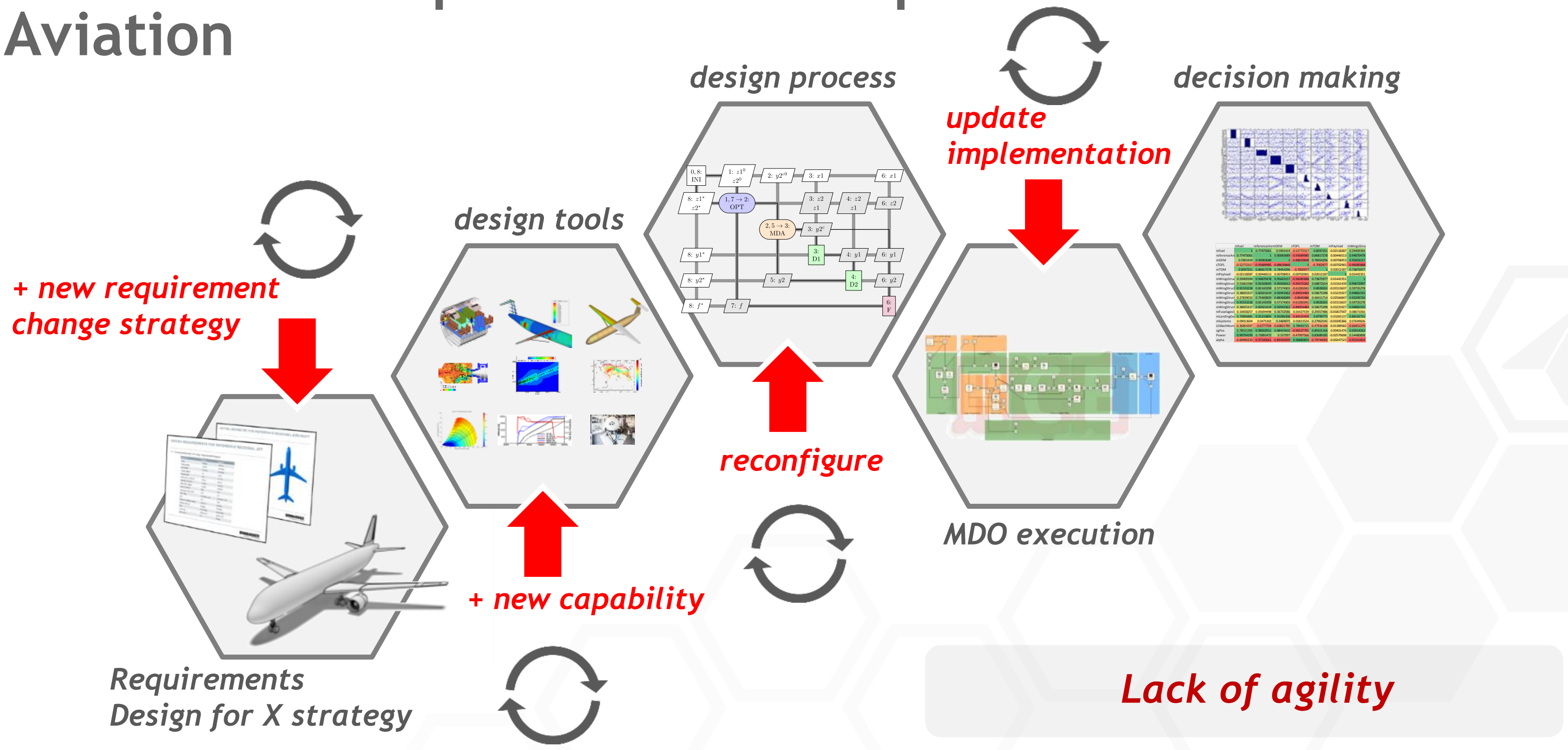
Aerospace problem is complex and resource intensive.

Experts or specialist exist. But distributed cross nation/organization and often there is no mode for collaboration

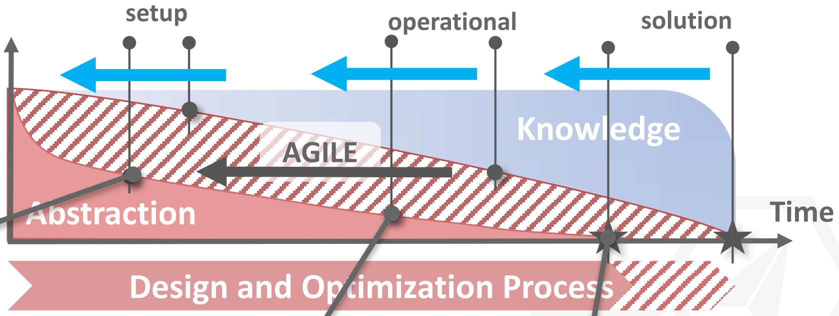
How to collaborate efficiently?

H2020 : AGILE project

Product Development and MDO processes in Aviation



AGILE Ambition



Objectives:

- *Realize the next generation of MDO processes*
- *Reducing aircraft **development time\costs***
- *Enabling Collaborative Aircraft Design*

Accelerate the setup of large scale collaborative distributed processes

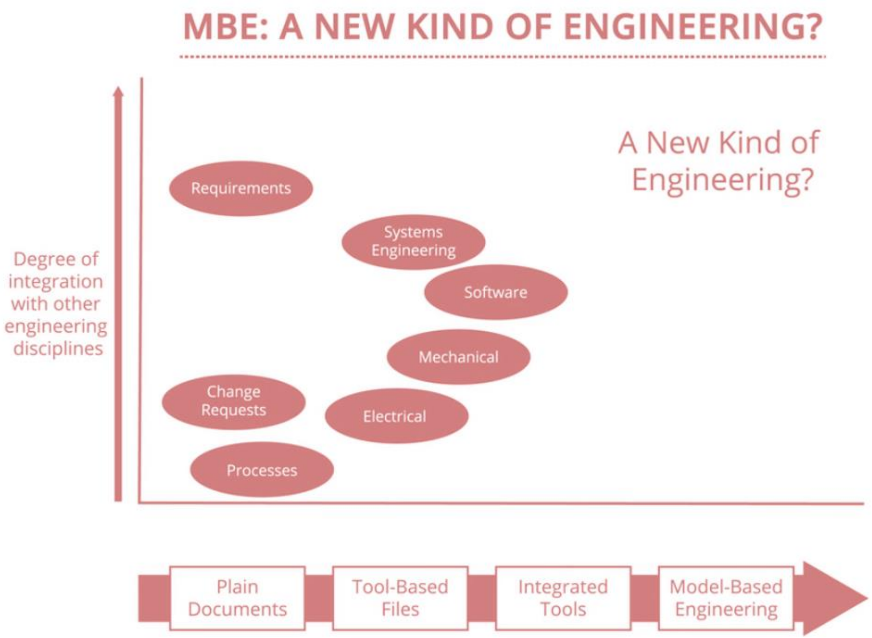
Support collaborative operation of design systems: people and tools

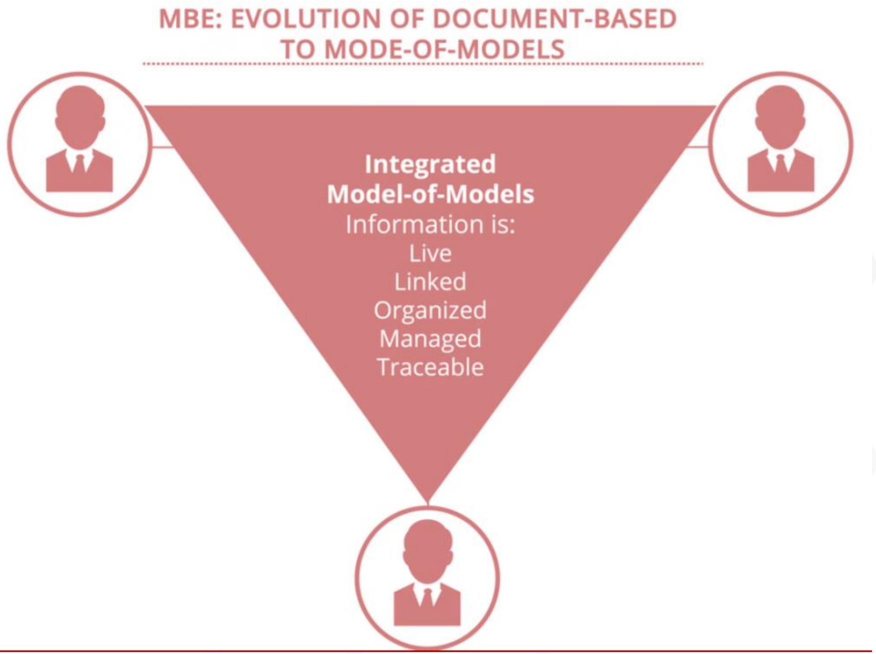
Efficient collaborative Optimization techniques

AGILE Configurations

AGILE

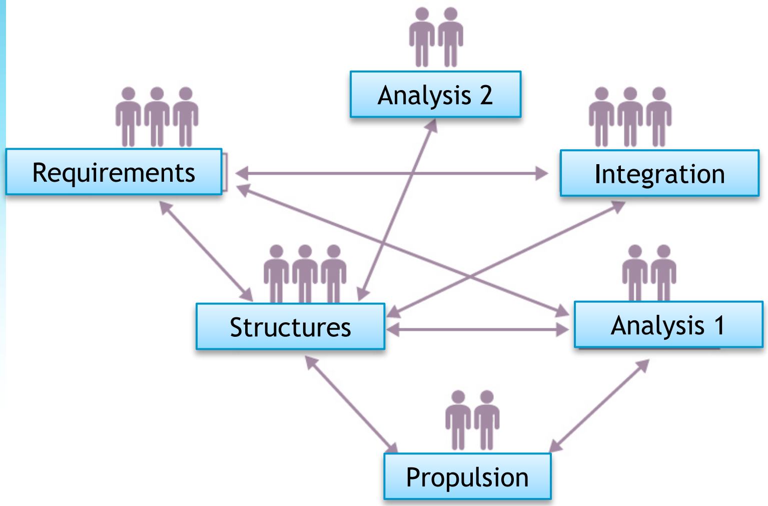
Model Based Approach of AGILE Paradigm





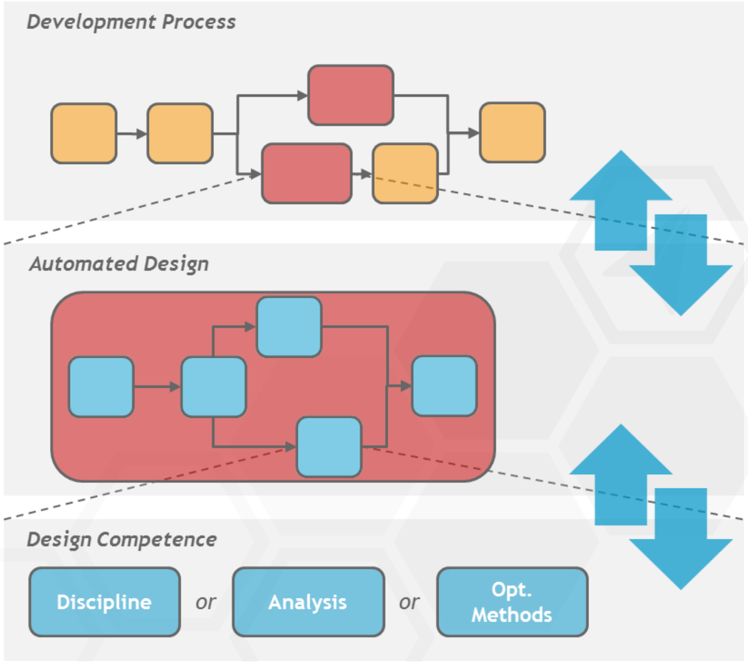
Source: MIT System architecture of complex systems

Collaborative Design by Heterogeneous Teams



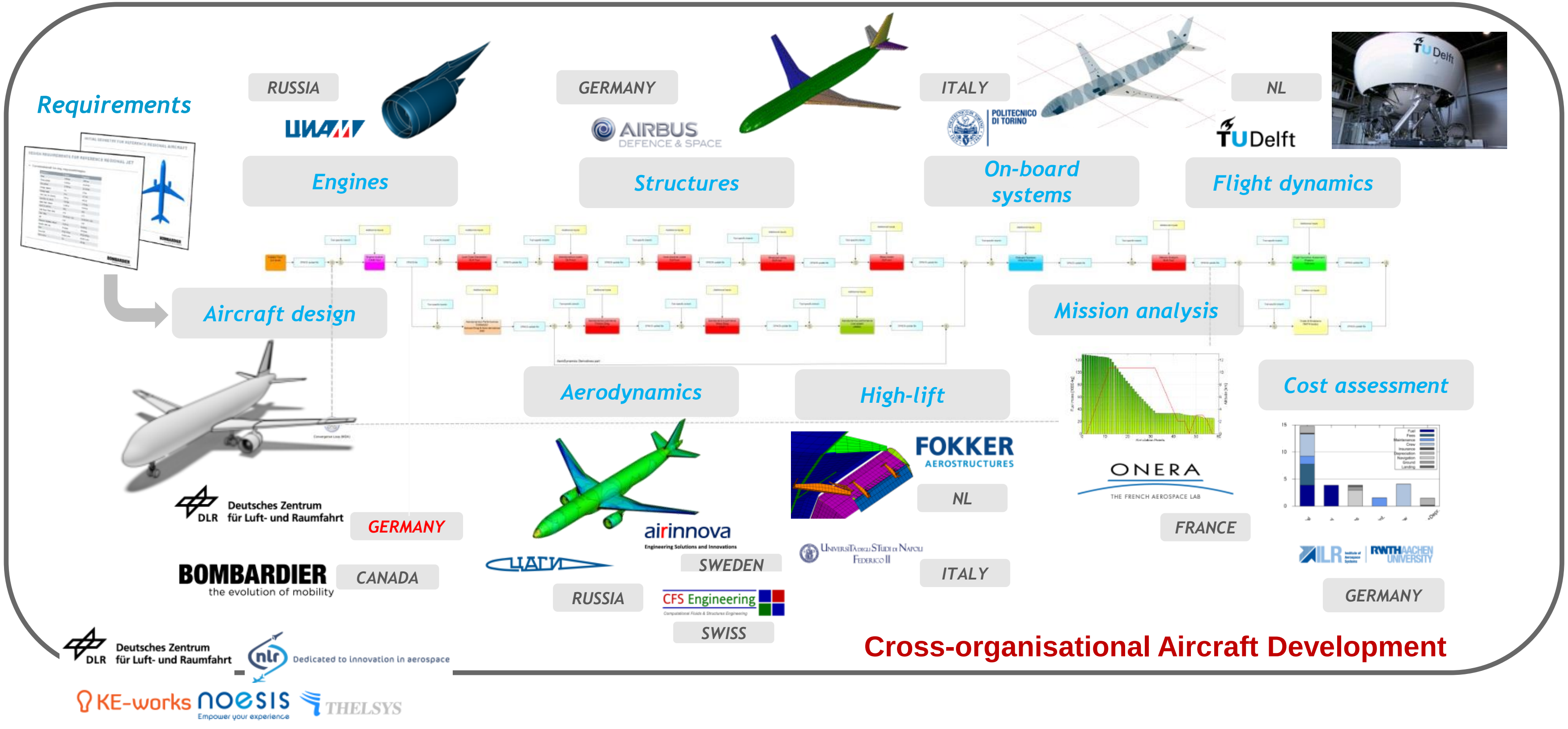
Source: MIT System architecture of complex systems

AGILE Architecture Layers



AGILE - Collaborative Process

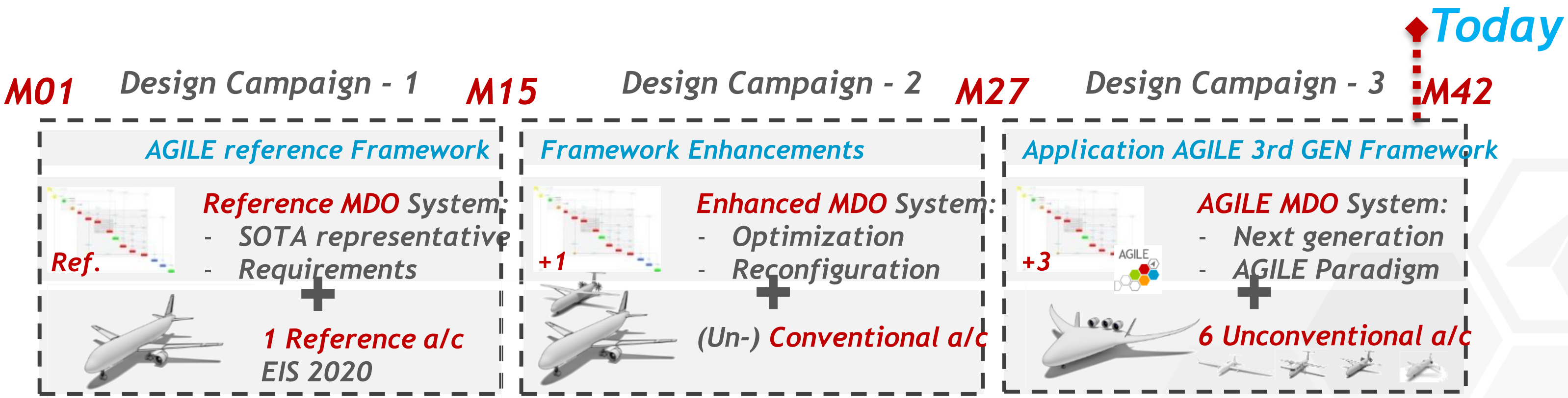
From TLAR to…flying!!!

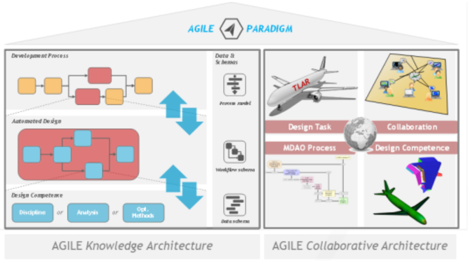


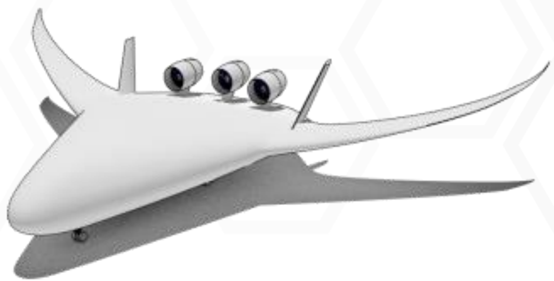
AGILE

Focus or Objective for the current research

To expand or test AGILE Framework for novel configuration

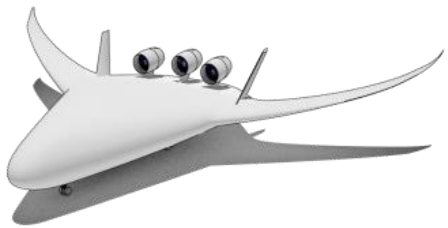






AGILE

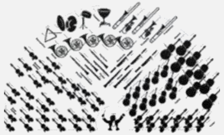
Blended Wing Body Aircraft Design Partners



Partner	POC	Main activities
DLR	Prajwal S. Prakasha, Pier Davide Ciampa	Architect and Integrator, Design, Mission simulation
CIAM	Artur Mirzoyan, Alik Isyanov,	Provide initial engine location, engine performance
POLITO	Marco Fioriti, Luca Boggero	Design of On Board Systems
RWTH	Benedikt Aigner	Assessment of lifecycle costs and emissions
TsAGI	Kirill Anisimov	Nacelle Design, aerodynamic propulsion investigation, Overall Aerodyamics
TUD (Focus)	Mark Voskuijl,	PHALANX – Flight dynamics toolbox
UNINA	Pierluigi Della Vecchia Luca Stingo, Danilo	High lift design L1\L3 CAD system, Overall Aerodyamics
CFSE	Dominique Charbonnier, Jan Vos, Aidan Jungo	High-fidelity aerodynamic analysis - CFD
Airinova	Mengmeng Zahn	High-fidelity aerodynamic analysis - CFD

AGILE Participative agents

Architect



Collaborative Eng.

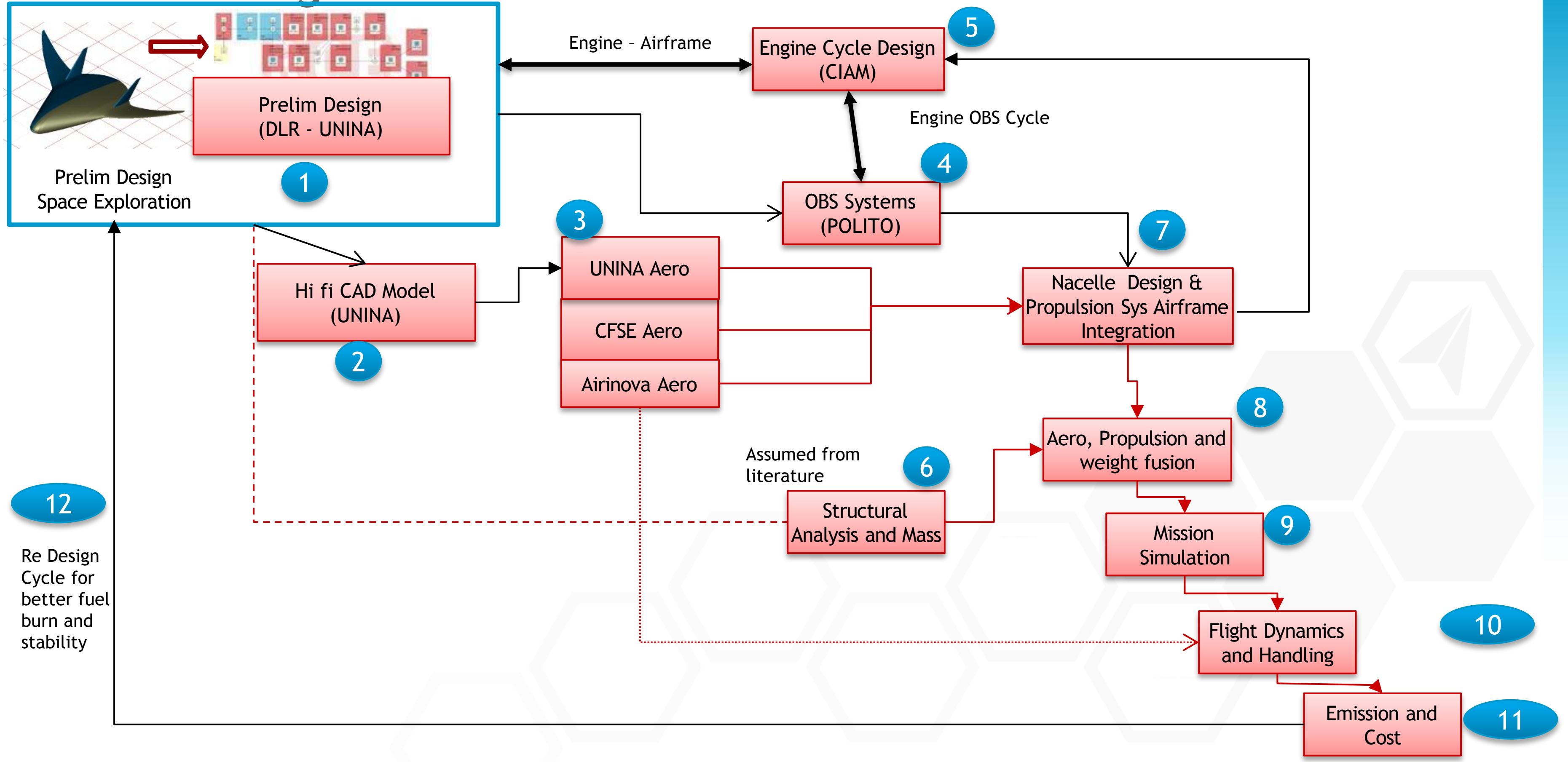
Integrator

Specialist

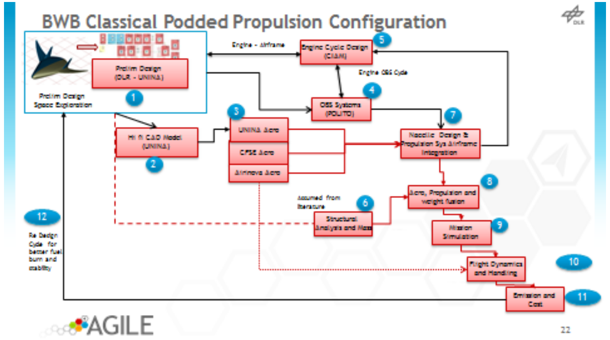
TLAR of Blended Wing Body

Category	Name	Unit	Description	Cond	BWB	Notes
Payload, range	#Pax	[-]	number of passengers	=	450	Triple class layout
	$m_{payload\ max}$	[t]	maximum payload	=	59	NACRE payload 17.1 t (180 PAX)
	range	[nm]	maximum range @ $m_{payload\ max}$	>	8500	NASA Sugar: 8500 VELA\NACRE: 7650
	m_{cargo}	[t]	amount of cargo	=	5	NACRE and VELA assumed 10 t (750 PAX)
performance targets	M	[-]	Mach number in cruise at ICA	=	0.85	NASA N+3: > 0.8 VELA,NACRE: 0.85
	H_{max}	[ft]	maximum operating altitude	>	43000	Same VELA, NACRE, NASA SUGAR HBW
	V_{appr}	[kts]	approach speed (@MLW, SL, ISA)	<	166	ICAO Code F: 141kt or more but less than 166kt
airport compatibility	b	[m]	maximum wing span	<	80	ICAO Code F
	TOFL	[m]	take-off field length (@MTOW, SL, ISA + 15deg)	<	2950	75% of airport, which possess at least a CAT II system can be reached with 2962m

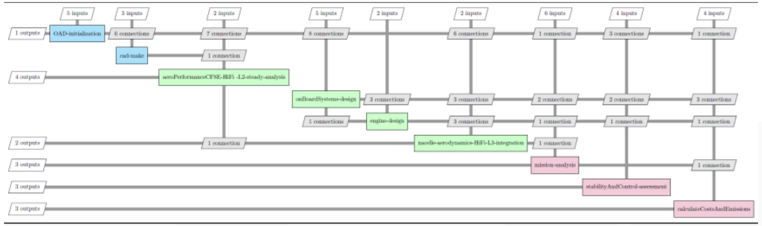
BWB Configuration workflow



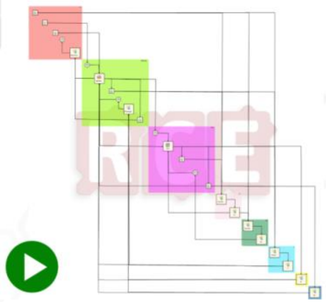
BWB Collaborative Workflow



Workflow : Informal Structure Diagram



XDSM



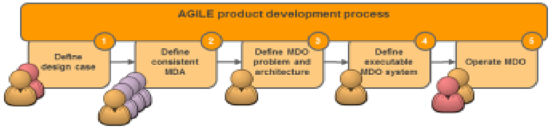
Workflow

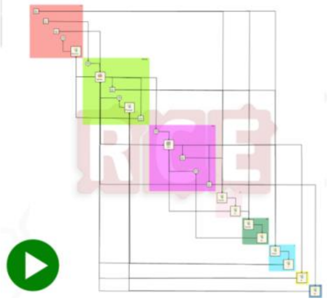
For more information,
Refer : Pier D Ciampa et al and Imco V Gent et al (AIAA 2017, AIAA 2018)

Central Data Model

KE Chain

AGILE PDP - MBSE

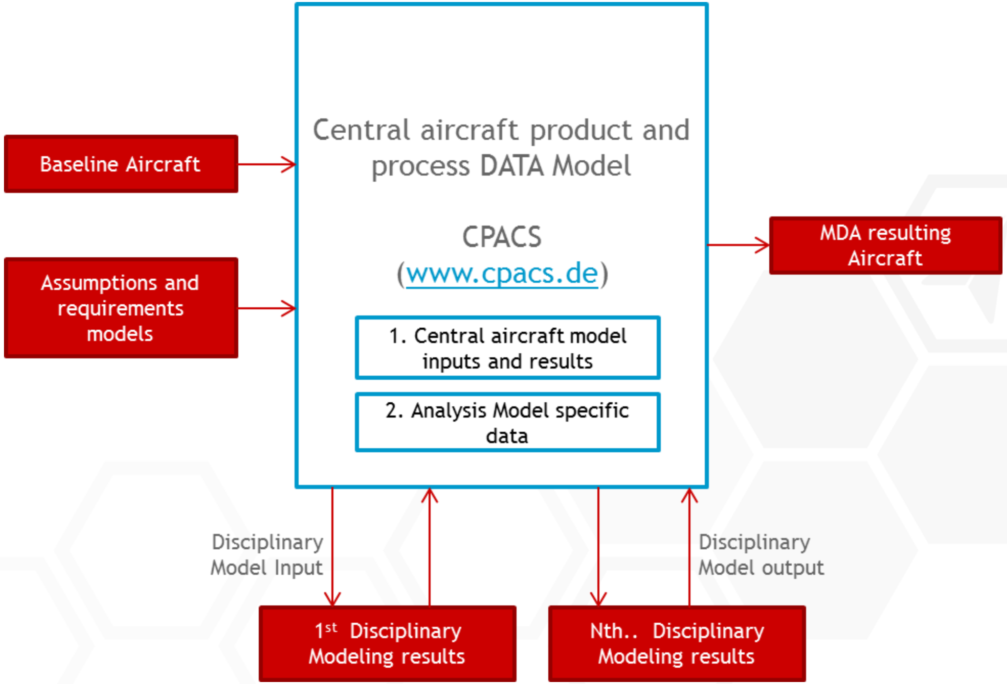




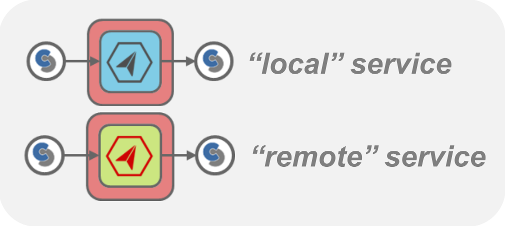
CMDOWS

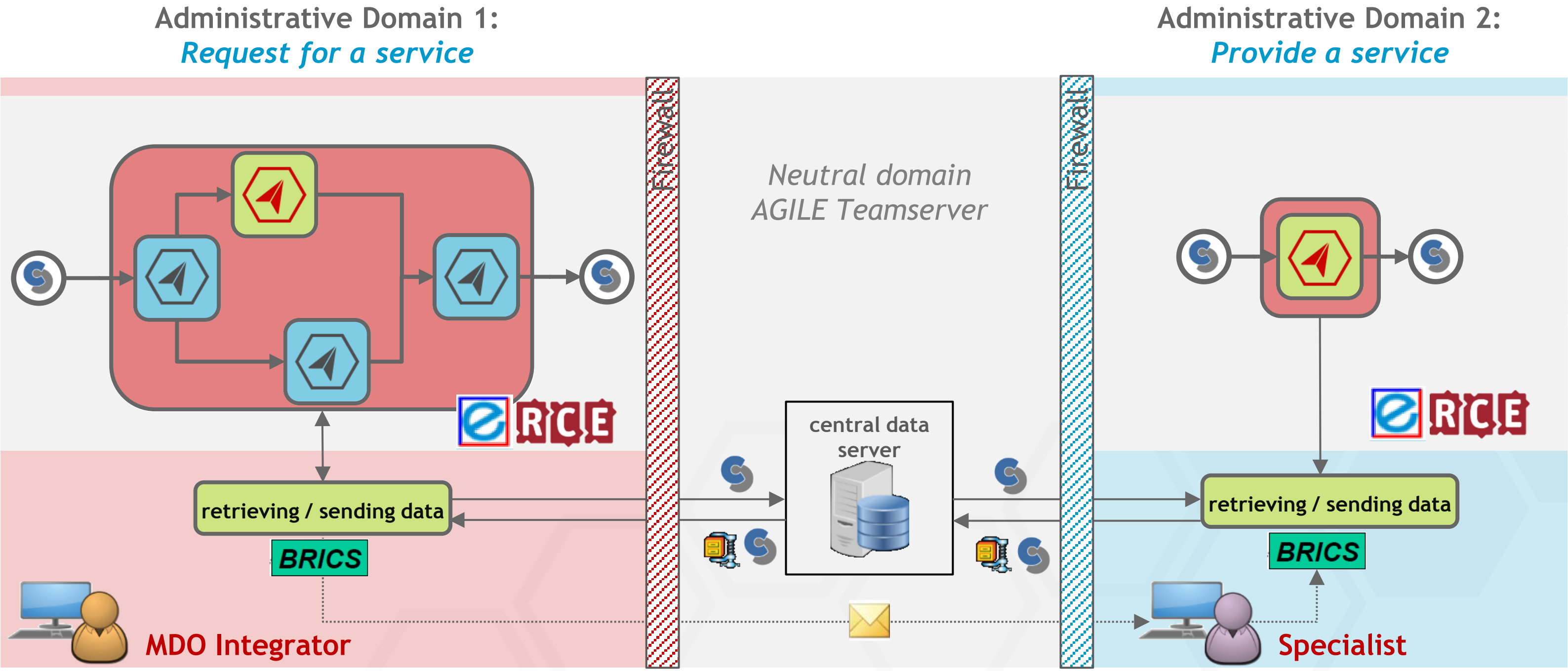
KADMOS

VISTOMS



Collaborative Architecture: principle





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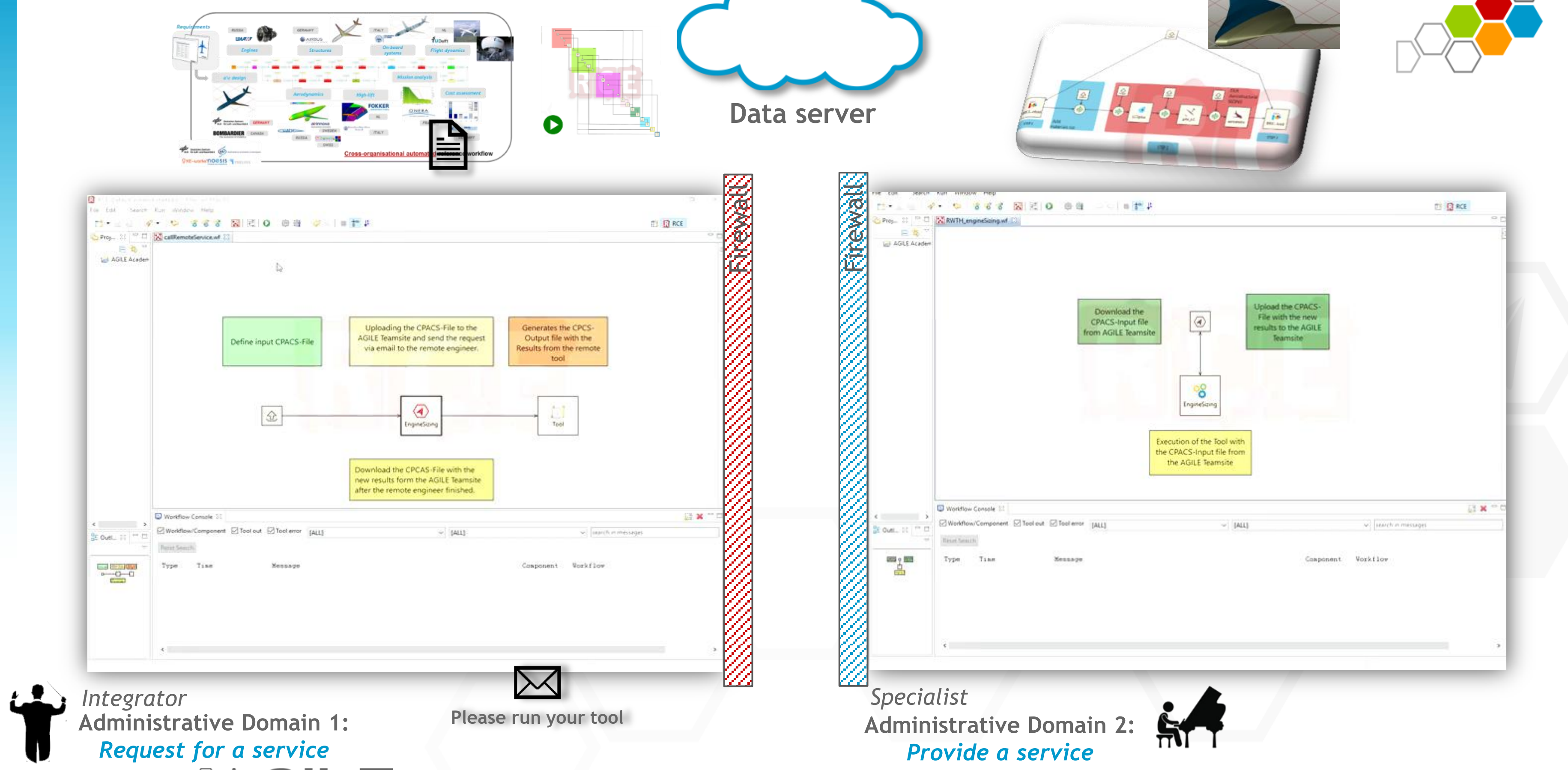
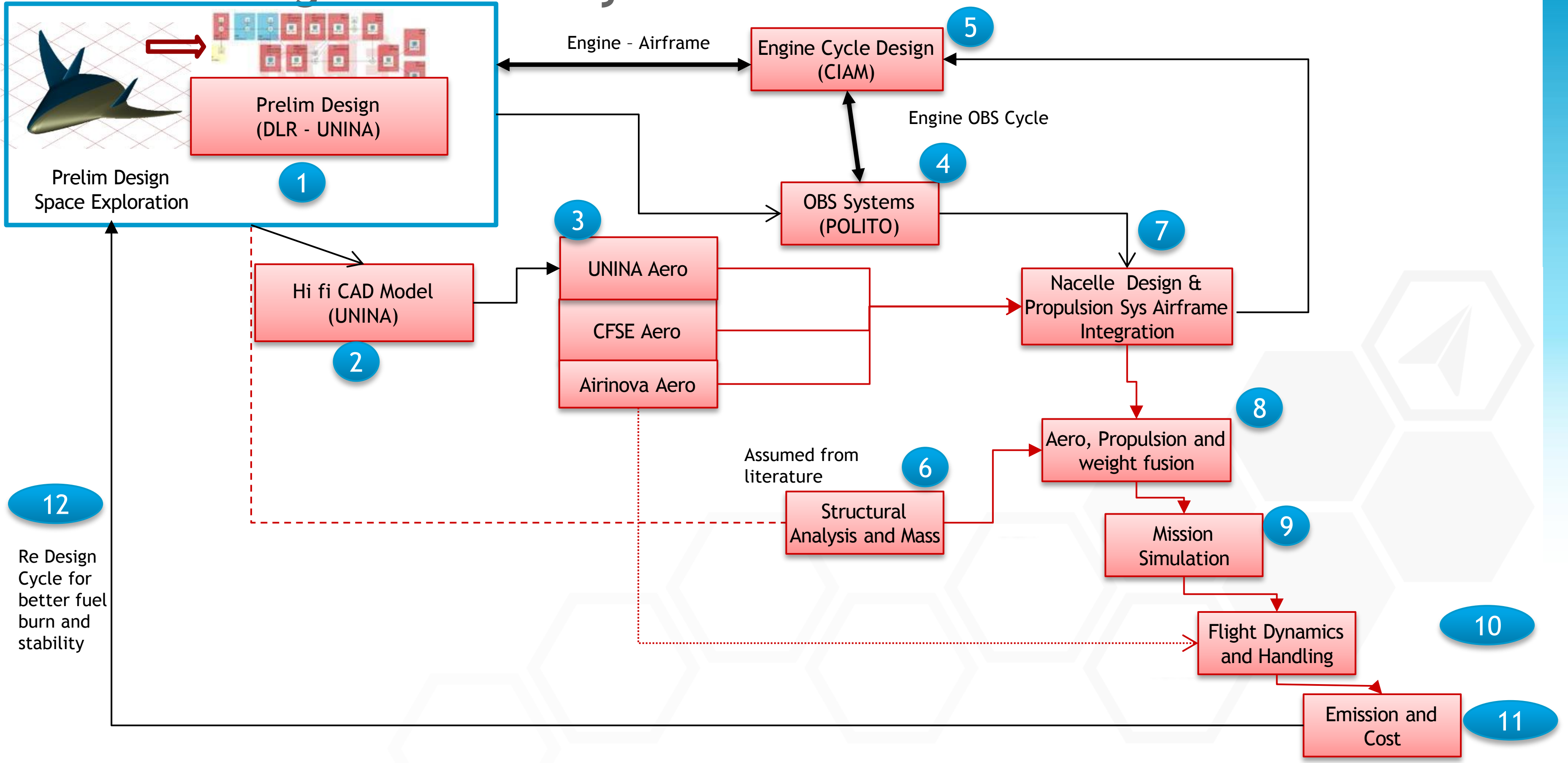
SOA execution principle

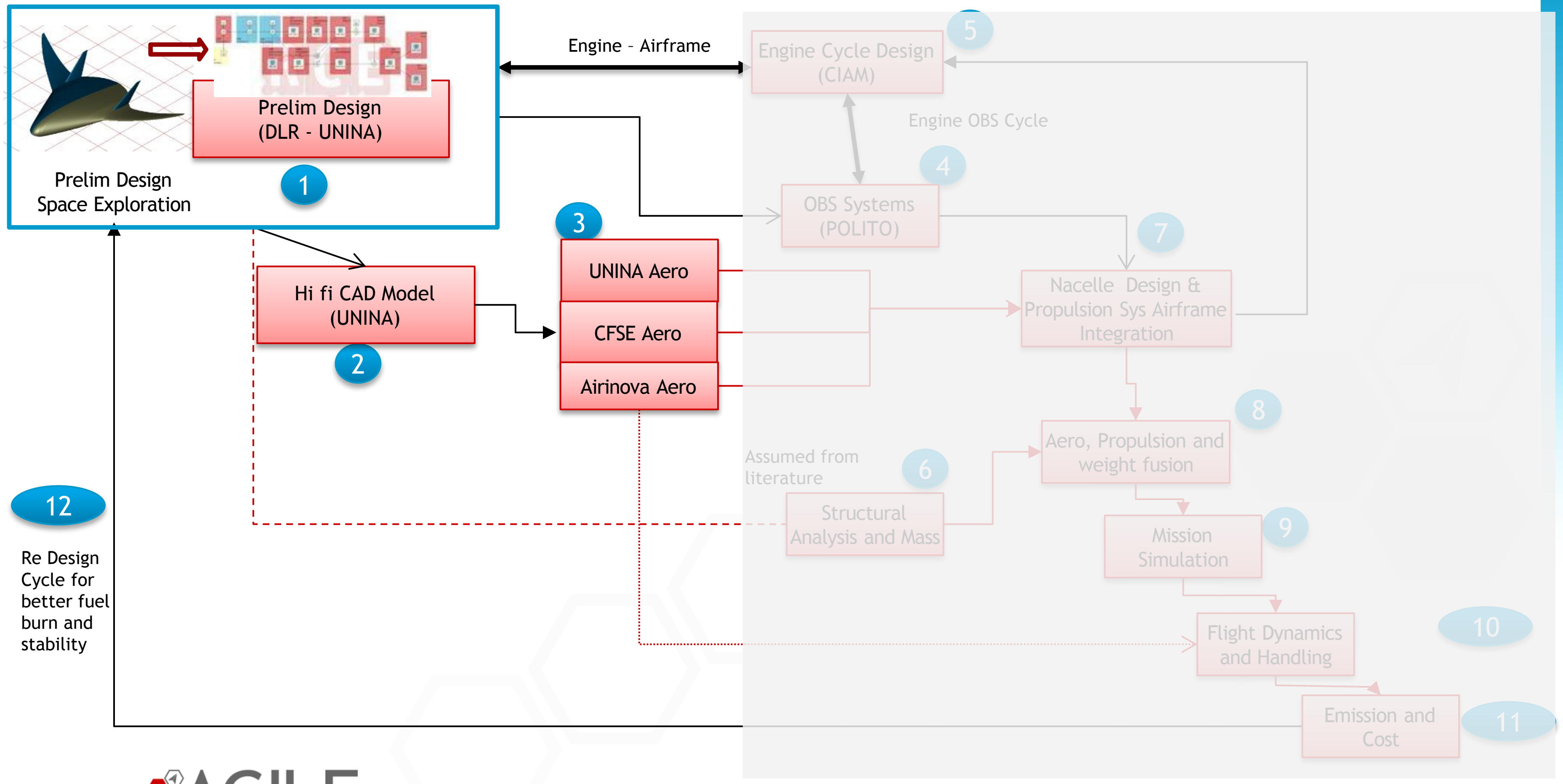


Prajwal Shiva Prakasha - DLR, ICAS, 2018

BWB Configuration Analysis Work Flow



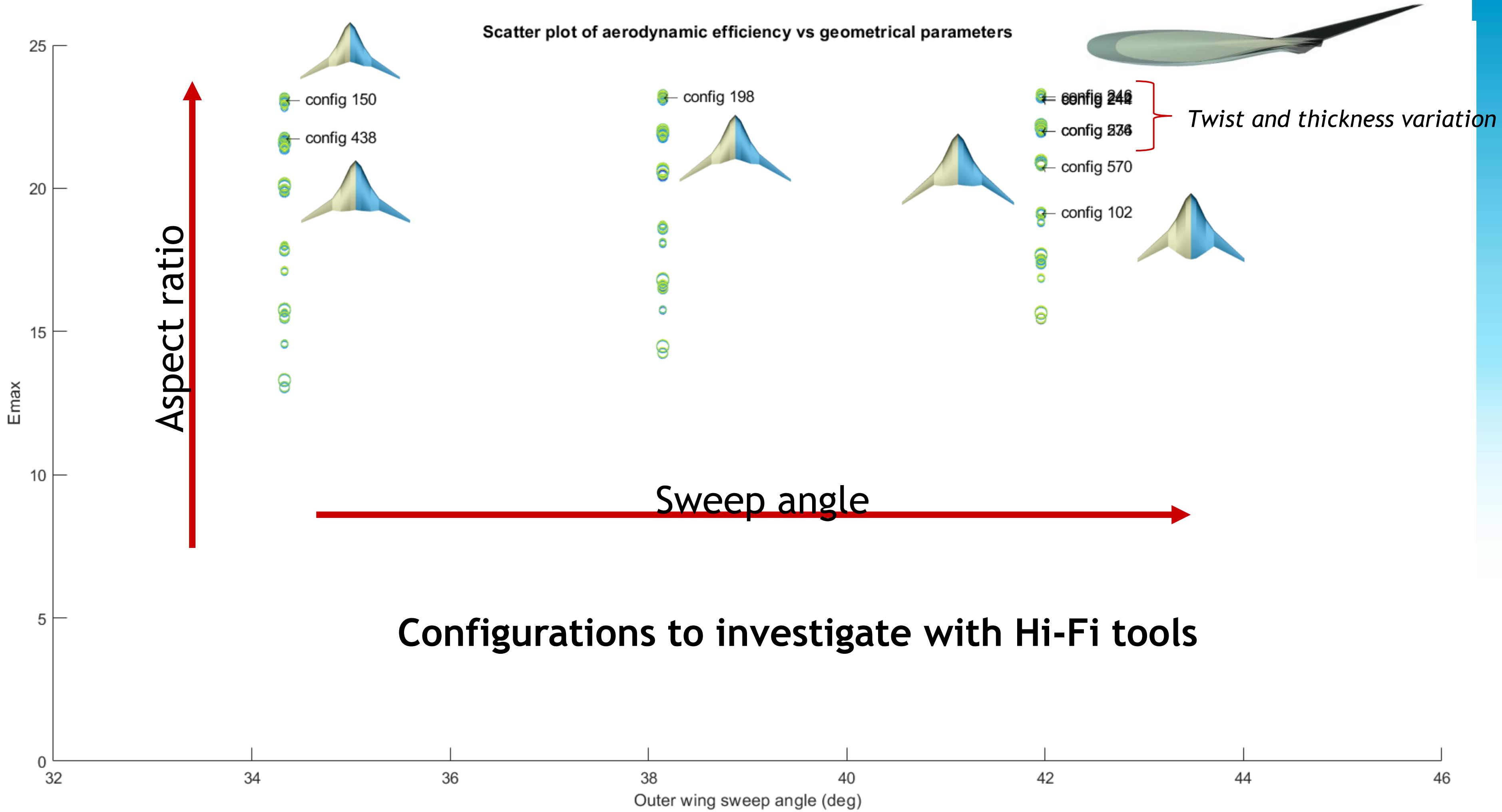
BWB Aerodynamic Design Space Exploartion and Evaluation



Low Fi **Design Space Exploration** by UNINA

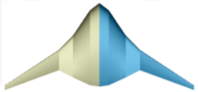
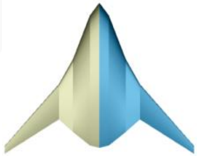
DoE – Target: E=21-24, CL=0.30-0.35, CL_{max}=1.55

AREA	SPAN	SWEEP (rel, outer wing)	TWIST (abs)	T/C (abs)	AIRFOIL
Baseline, +15%,50%	Baseline +10% b < 80m	-10% baseline +10%			
Root			0° +2°	16% (fixed)	Fixed
Kink			0° +5°	8% 10% 12%	Fixed
Tip			-5° -3°	8% 10%	Fixed
Combinations	2 x 2	3	2 x 2 x 2	1 x 3 x 2	= 576


Scatter plot of aerodynamic efficiency vs geometrical parameters
config 150
config 438
config 198
config 570
config 102
Twist and thickness variation
Aspect ratio
Sweep angle
Configurations to investigate with Hi-Fi tools
Emax
Outer wing sweep angle (deg)
25
20
15
10
5
0
32
34
36
38
40
42
44
46

UNINA suggests to analyze 10 configurations around the baseline, including variations of thickness, twist, sweep angle, aspect ratio

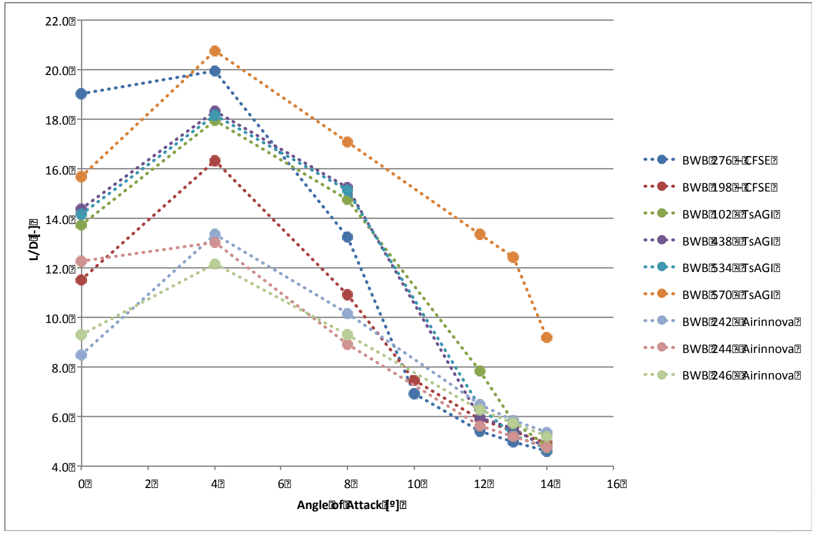
ID	Sw (m2)	b (m)	AR	Sweep (°)	t/c (%)	Twist (°)	Config.	Work
1	1174	80	5.45	42	[16, 8, 8]	[0, 0, -3]	242	
2	1174	80	5.45	42	[16, 8, 8]	[2, 0, -3]	246	AIRINNOVA
3	1174	80	5.45	42	[16, 8, 8]	[0, 2, -3]	244	
4	1174	80	5.45	38	[16, 8, 8]	[2, 0, -3]	198	
5	1174	80	5.45	34	[16, 8, 8]	[2, 0, -3]	150	CFSE
6	1174	80	5.45	42	[16, 12, 8]	[2, 0, -3]	276	
7	912	64	4.49	42	[16, 8, 8]	[2, 0, -3]	102	
8	1213	80	5.28	34	[16, 8, 8]	[2, 0, -3]	438	
9	1213	80	5.28	42	[16, 8, 8]	[2, 0, -3]	534	TSAGI
10	1213	80	5.28	42	[16, 12, 10]	[0, 0, -3]	570	

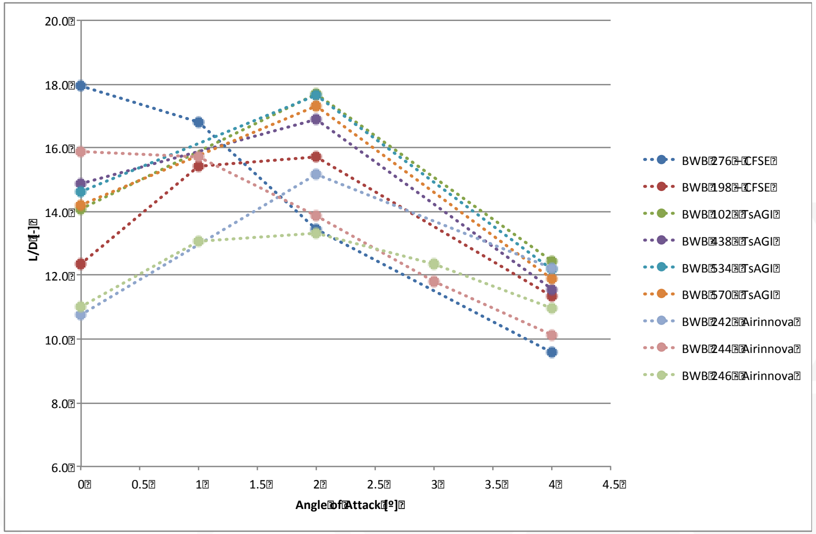
Hi Fi Aero Analysis Assumption from CFSE, TsAGI, Airinova

config.	Meshing tool	Mesh type	Mesh size [million]	CFD tool	Turb. model
242	Pointwise	hybrid, unstructured	20	Edge	S-A
244	Pointwise	hybrid, unstructured	20	Edge	S-A
246	Pointwise	hybrid, unstructured	20	Edge	S-A
198	ICEM CFD	multi-blocks, structured	12	NSMB	k-ω SST
150	ICEM CFD	multi-blocks, structured	12	NSMB	k-ω SST
276	ICEM CFD	multi-blocks, structured	12	NSMB	k-ω SST
102	TsAGI code	multi-blocks, structured	45	TsAGI EWT	S-A
438	TsAGI code	multi-blocks, structured	45	TsAGI EWT	S-A
534	TsAGI code	multi-blocks, structured	45	TsAGI EWT	S-A
570	TsAGI code	multi-blocks, structured	45	TsAGI EWT	S-A

Hi Fi Aero Analysis Results from CFSE, TsAGI, Airinova

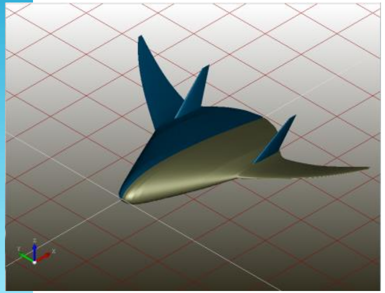


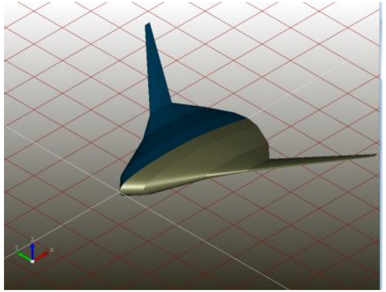
L/D comparison of the DoEs computed by L3 solvers (RANS) at take-off conditions, Mach=0.2, altitude 0 m



L/D comparison of the DoEs computed by L3 solvers (RANS) at cruise conditions, Mach=0.85, altitude 13200m

Best configurations





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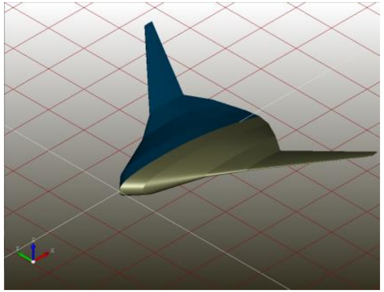

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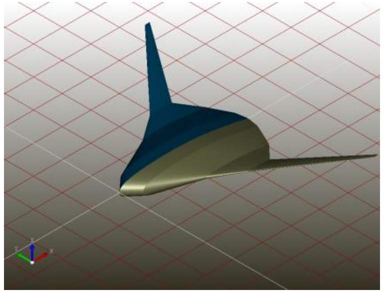
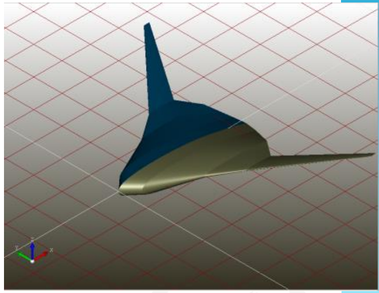


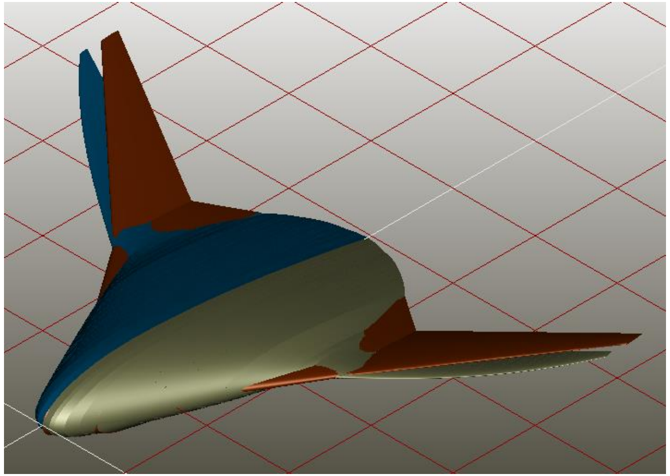
244



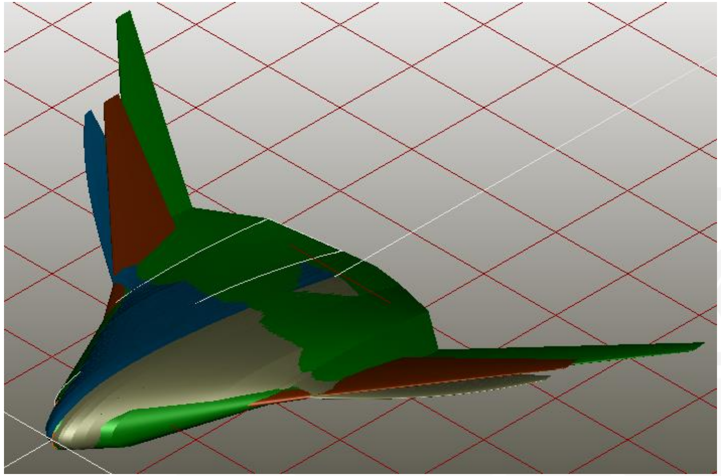
534

ID	Sw (m2)	b (m)	AR	Sweep (°)	t/c (%)	Twist (°)	Config.	Work
3	1174	80	5.45	42	[16, 8, 8]	[0, 2, -3]	244	AIRINNOVA
6	1174 (28% more area)	80	5.45	42	[16, 12, 8]	[2, 0, -3]	276	CFSE
7	**912**	**64**	**4.49**	**42**	**[16, 8, 8]**	**[2, 0, -3]**	**102**	TSAGI
9	1213 (33% more area)	80	5.28	42	[16, 8, 8]	[2, 0, -3]	534	

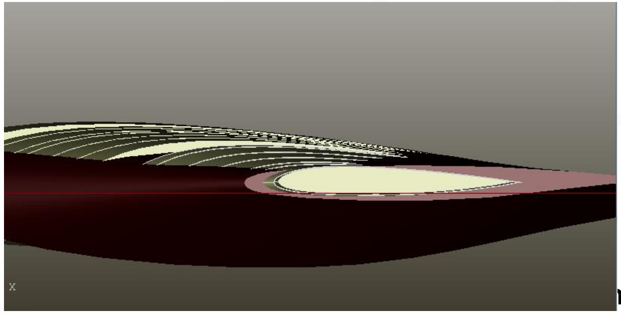
Selection of Baseline..



Baseline vs BWB 102

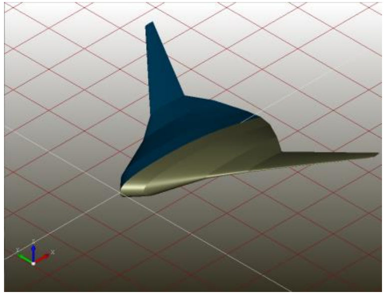


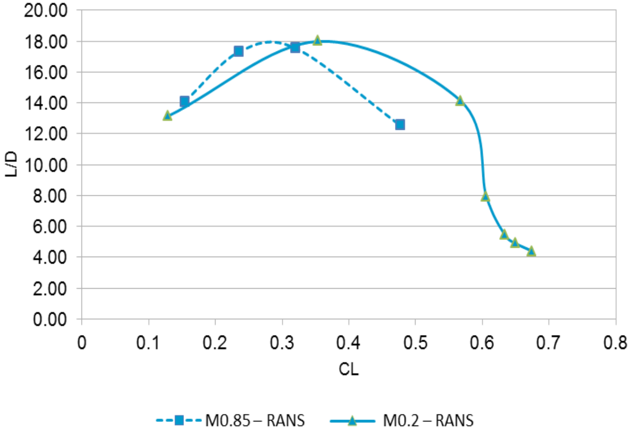
Baseline vs BWB 102 vs BWB 534



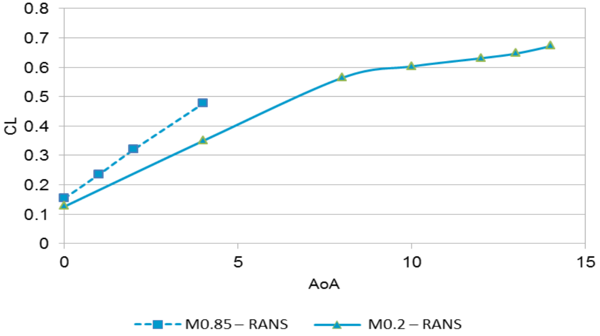
Optimum Baseline configuration

Collaborative Hi FI Aerodynamic Analysis

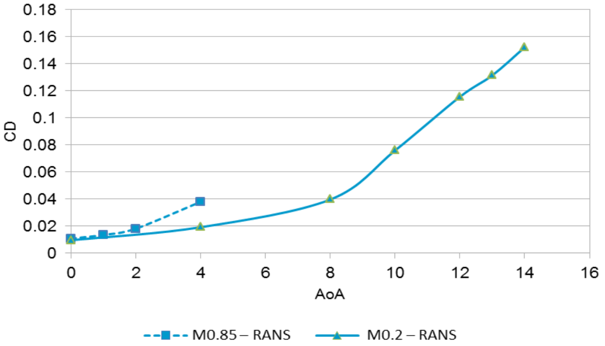




L/D vs CL for selected BWB configuration



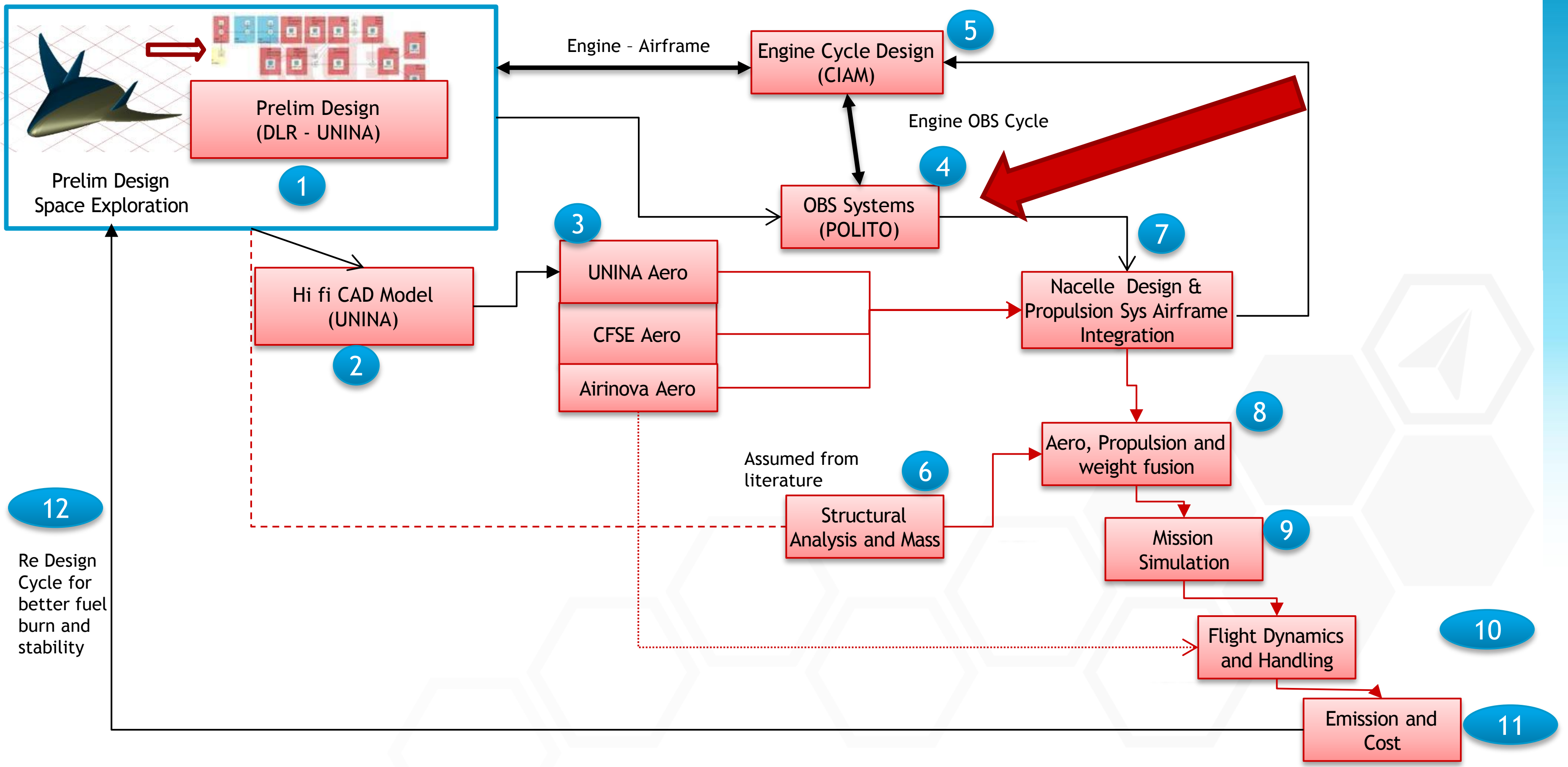
Lift Coefficient for selected configuration



Drag Coefficient of selected configuration

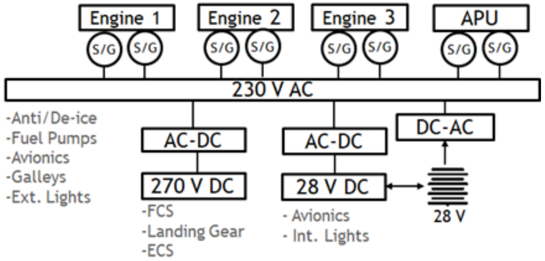
Issues: Low fi results are better but with Hifi.. The aero is not the best for bwb configuration. This demonstrates that collaborative approach works but need optimization based on first results. Aerodynamic Optimization with Nacelle and VTP in progress based on MDA presented. Geometric morphing and Hifi manipulation is still issue.

OnBoard System Design



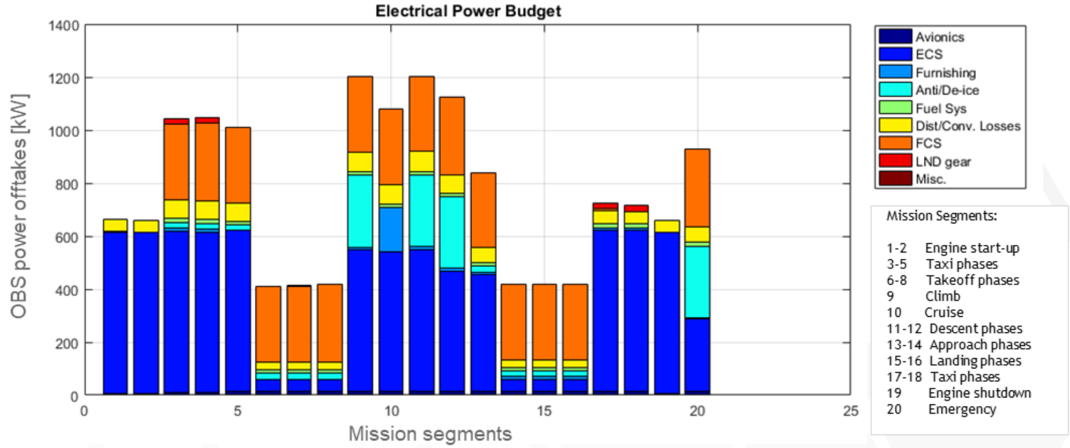
On Board System Design - POLITO - Results

- Designed using the tool ASTRID by Politechnico De Turino



All Electric architecture for OBS of BWB aircraft

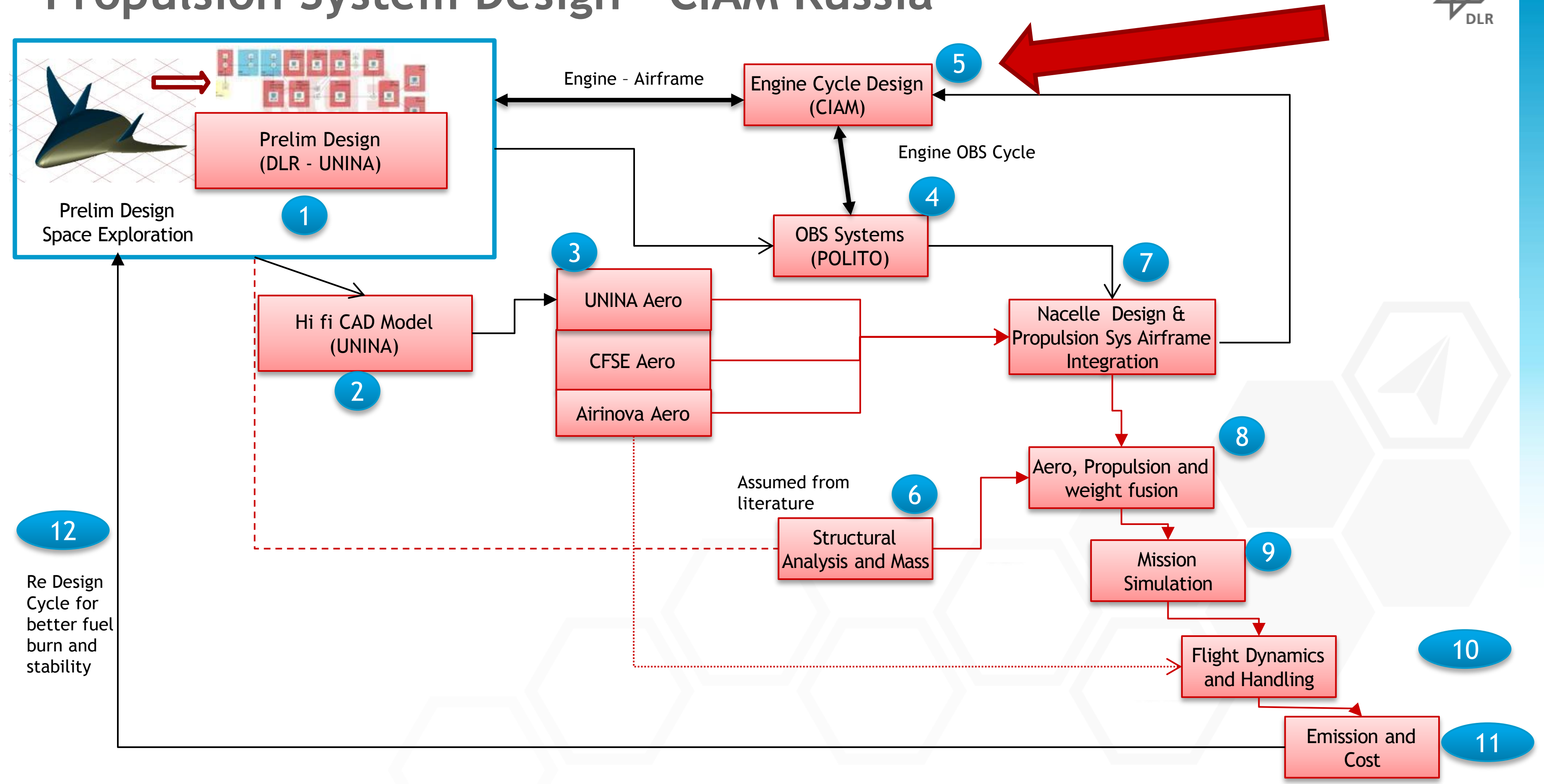
System Masses [kg]	AEA
Avionics	617
FCS	784
Landing gear	9268
ECS and anti-ice	2339
Fuel System	409
Aux Power System	772
Furnishing System	16622
Hydraulic	0
Electric	3978
Total Systems Mass	39364



OBS power offtakes calculated for each segment of the mission profile

More details : M Firoti et al, ICAS Conference 2018

Propulsion System Design - CIAM Russia

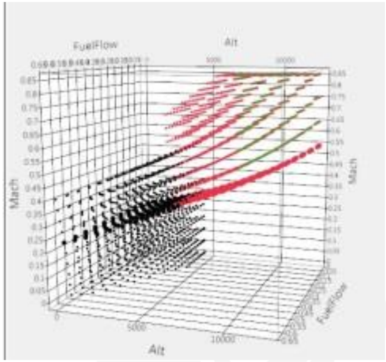


Propulsion System Design – CIAM Russia

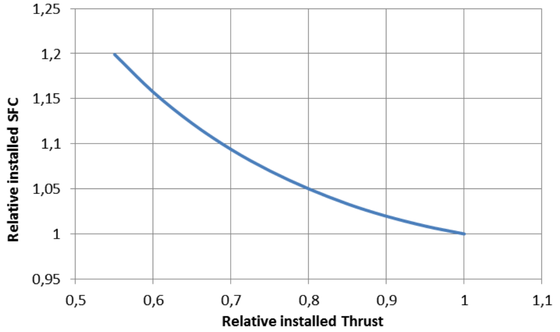
General Electric GE90-115B type
high-bypass ratio unmixed turbofan
Provide Thrust and Fuel consumption data

On Board system Offtake considered from OBS designers

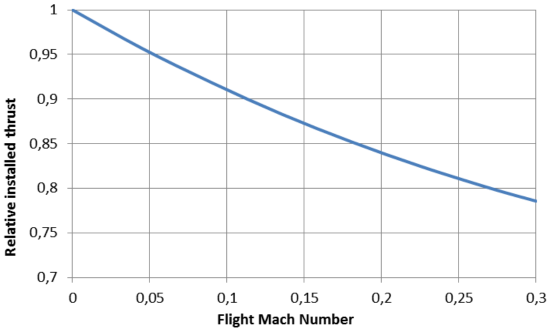
Flight Segments	Power Offtake per Engine, W
Normal Takeoff (NTO)	175098
Climb	501173
Cruise	449560
Descent	501320
Approach	349967
Landing	174637



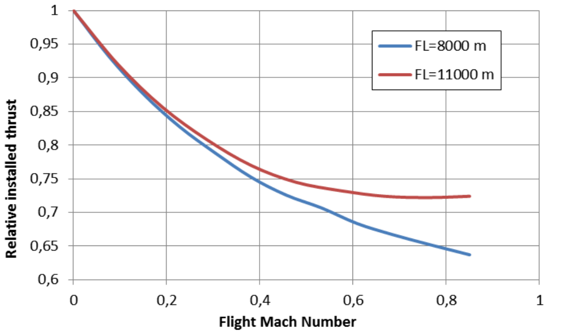
Engine Performance Map.



Cruise throttle performance at flight level 13100 m and flight Mach Number 0.85.

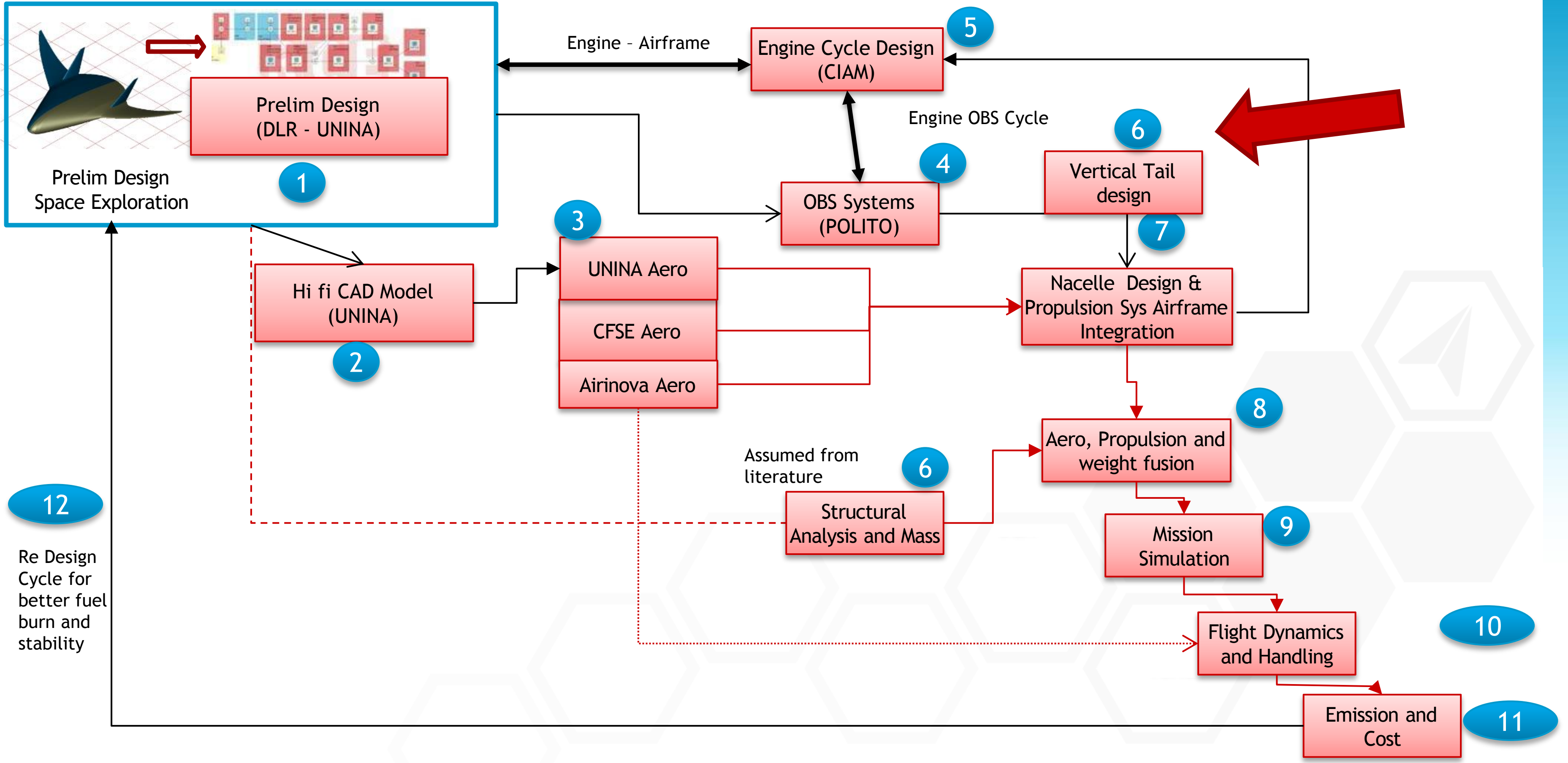


Change of relative installed thrust at Normal Takeoff.



Change of relative thrust based on Mach and ltitude for Climb Mode

Vertical Tail Plane Design - UNINA, Italy

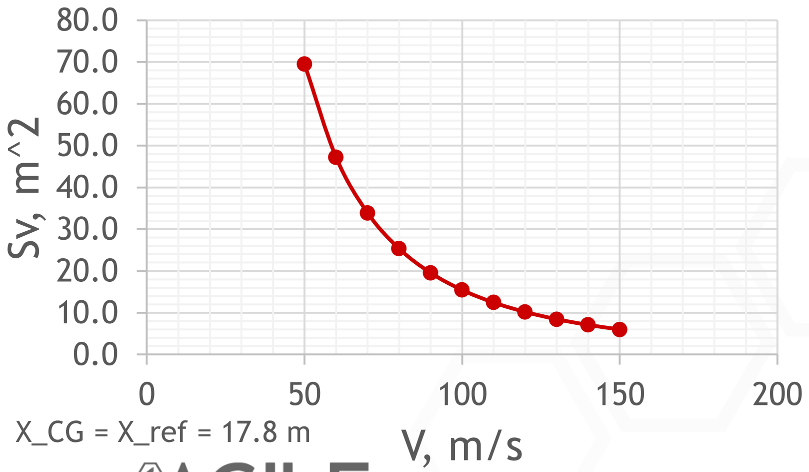


VTP planform area trend with VMC and CG

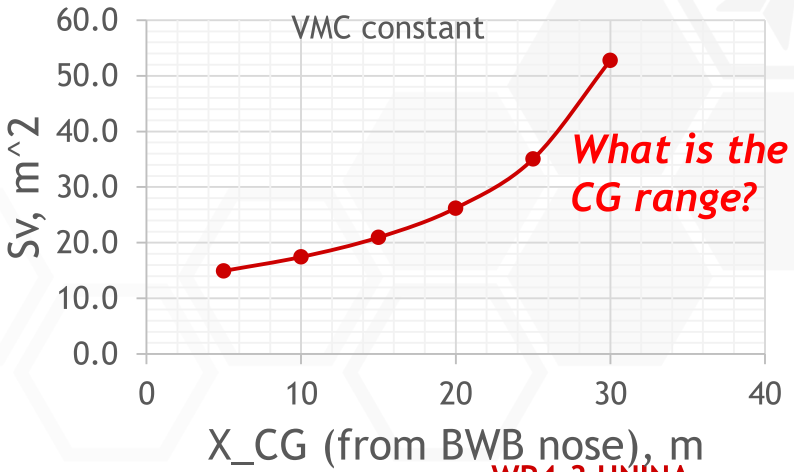
MTOW	435620	Kg
T0	1404840	N
no. Engine	3	
eng. arm	5.198	m
wing span	64	m
TOFL	2950	m
Sw	912	m2

Output data NOT dependent from VTP size

T/W	0.33	max
vert. arm	25.241	m
CLmaxTo	1.20	as TOP25
VMC	87.83	m/s
VMC	170.7	kts



X_CG = X_ref = 17.8 m



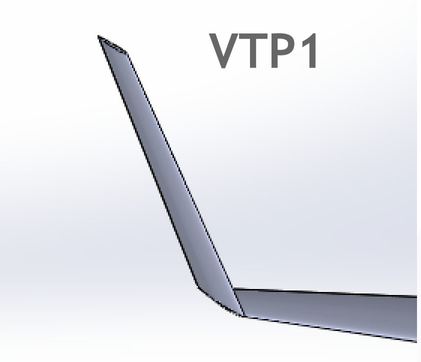
WP4.3 UNINA

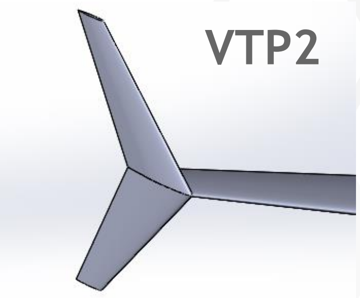
VTP sizing

2 solutions are proposed:

1. Winglet (wingtip end-plates) vertical stabilizers
2. Twin winglet (wingtip end-plates) vertical stabilizers

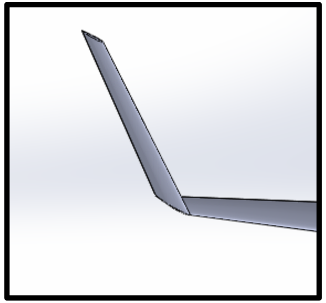
Notes	VTP1	VTP2	
Sv total	23.2	20.6	m2
Sv each	11.6	5.15	m2
aspect ratio	4	2.4	
sweep angle	40	40	deg
taper ratio	0.61	0.39	
tail span	6.81	3.52	m
Vol. coeff.	0.008773	0.008929	
CN_beta_v	0.0007	0.0005	/deg
tau	0.4	0.6	

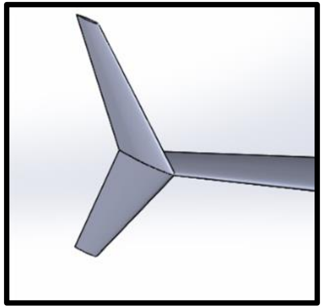




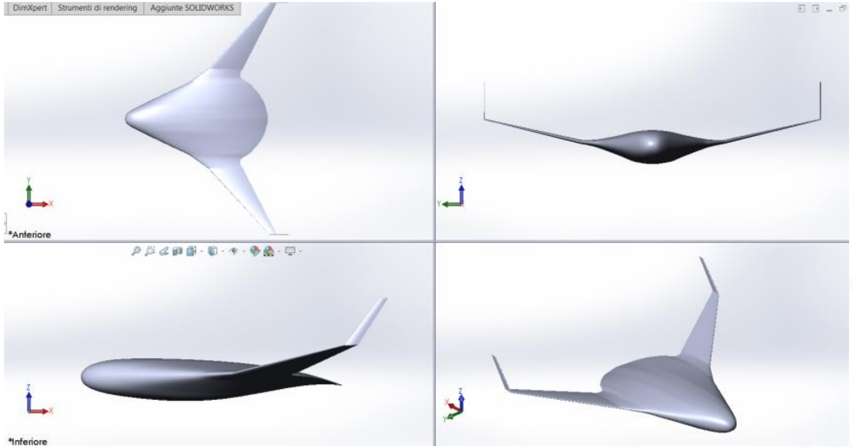
Cannot simply shorten the tail to preserve acceptable taper ratio, area, and aspect ratio! Multiple VTPs may be necessary…

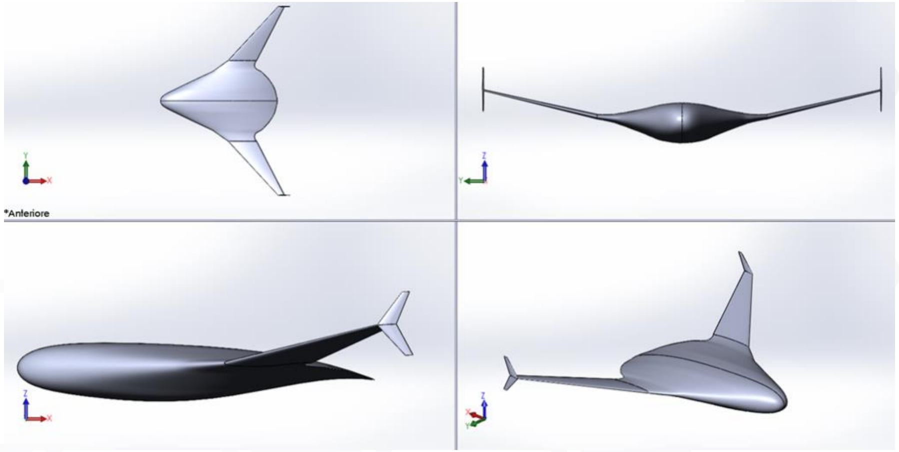
VTP
Configuration 1



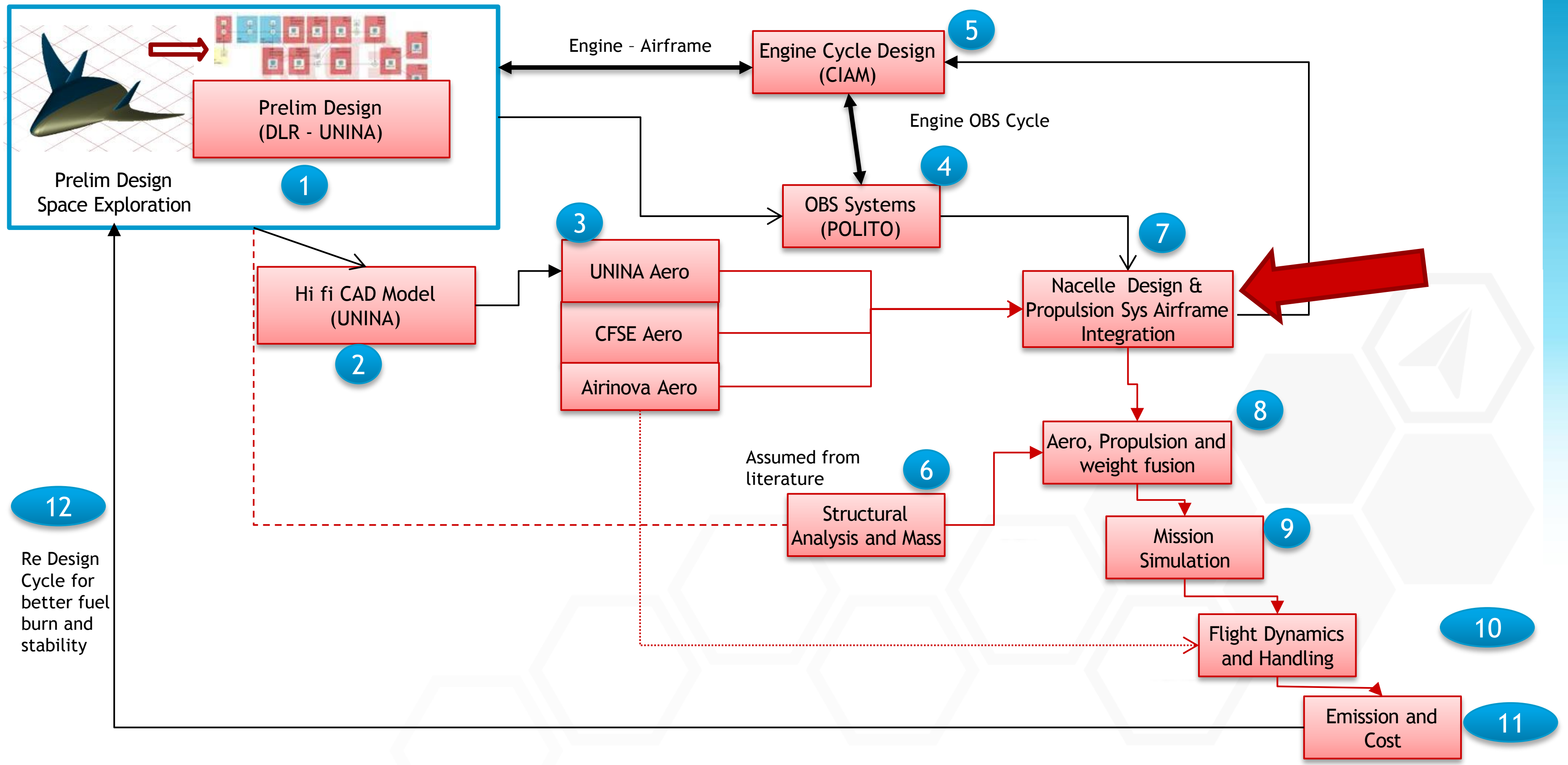


VTP
Configuration 2



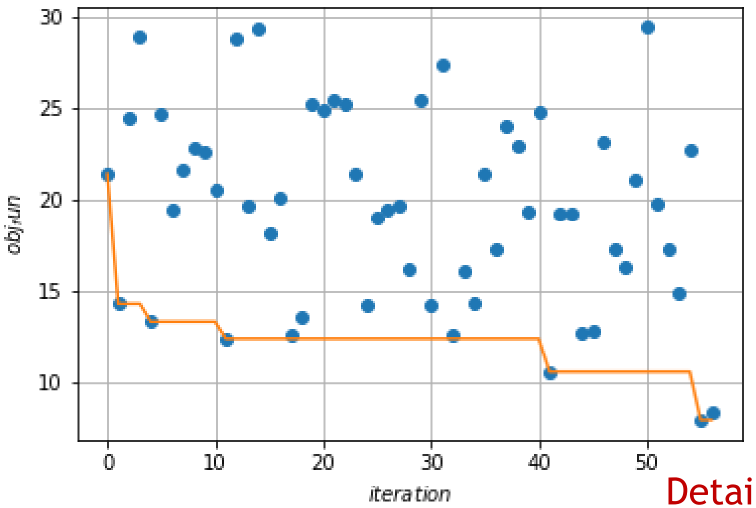


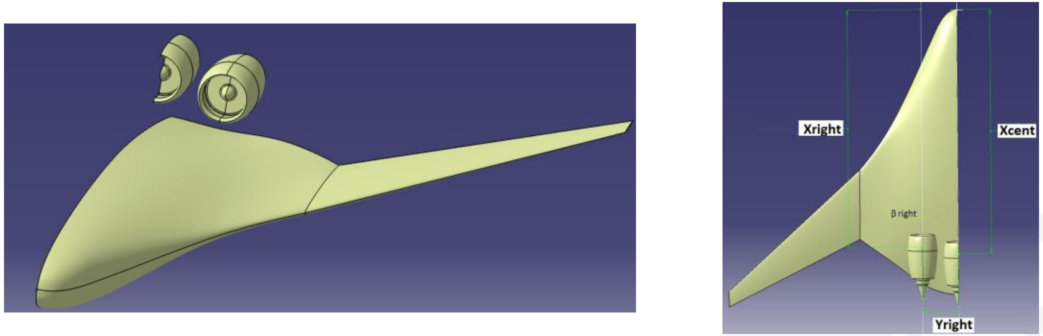
Nacelle Design and Integration - TsAGI Russia

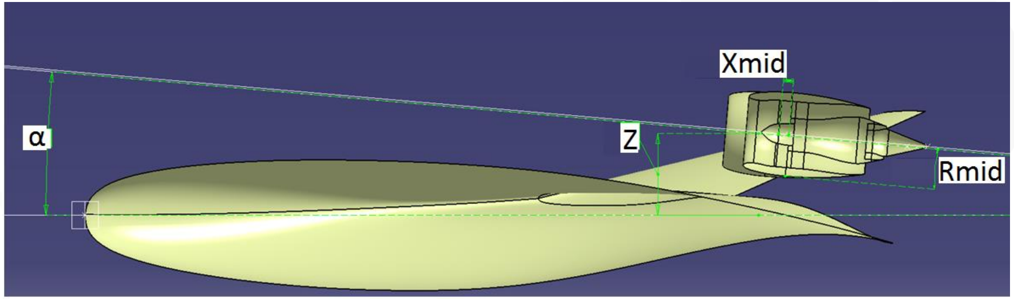


Nacelle Design and Integration - TsAGI Russia

Parameters (9): α, βr, Xc, Xr, Yr, Z, Rmid, Xmid, AOA
r- right nacelle
c- central nacelle
no index – all nacelles
AOA – AOA of aircraft
Object function: Fx+Eff. thrust
Constrain: Lift>=3 000 000 N



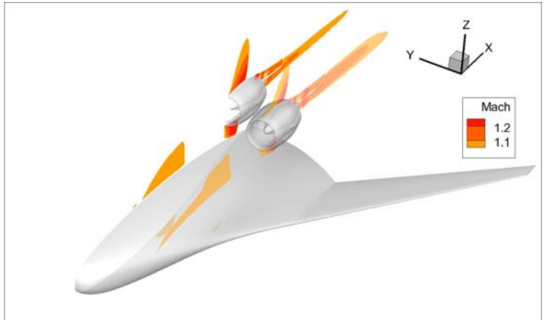


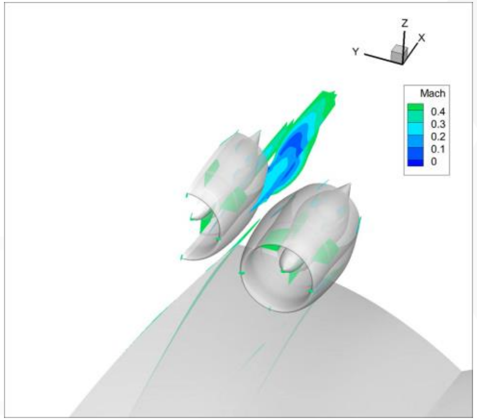


Detailed Presentation by Kirill Anisimov et all , ICAS 2018 (Tuesday)

Nacelle Design and Integration - TsAGI Russia

Geometrical Parameter		Base	Optimized
Central engine	α	5	4.26
	β	const	
	X	34000mm	34790mm
	Y	const	
	Z	4000mm	4153mm
	Rmid	2052.168mm	1902mm
	Xmid	495.605mm	1346mm
Outer engines	α	5	4.26
	β	0	0.988
	X	33000mm	33198mm
	Y	-5000mm	-5198mm
	Z	4000mm	4153mm
	Rmid	2052.168mm	1902mm
	Xmid	495.605mm	1346mm
Aircraft	AOA	2	2.33





Not optimum yet due to blended body non optimum airfoil sections

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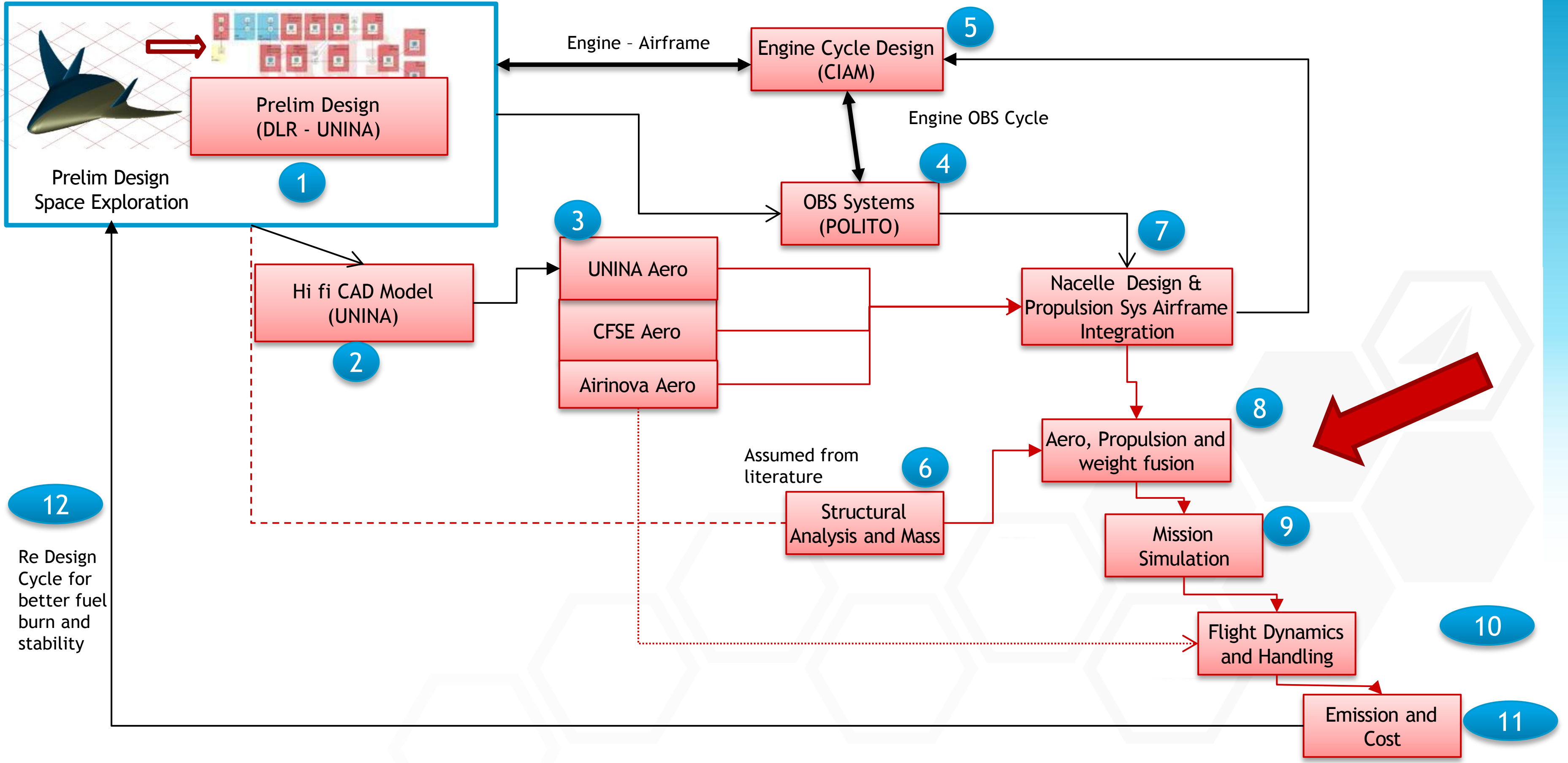
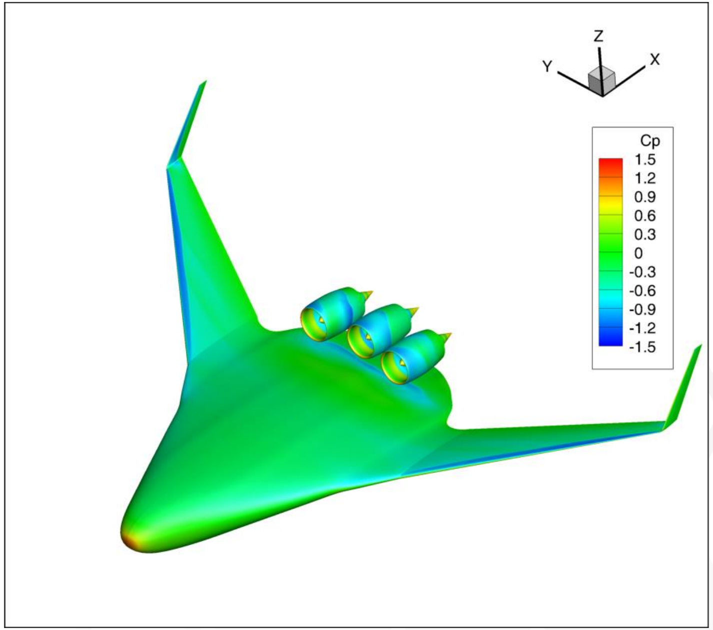
Weight, Propulsion and Aero parameters Fusion



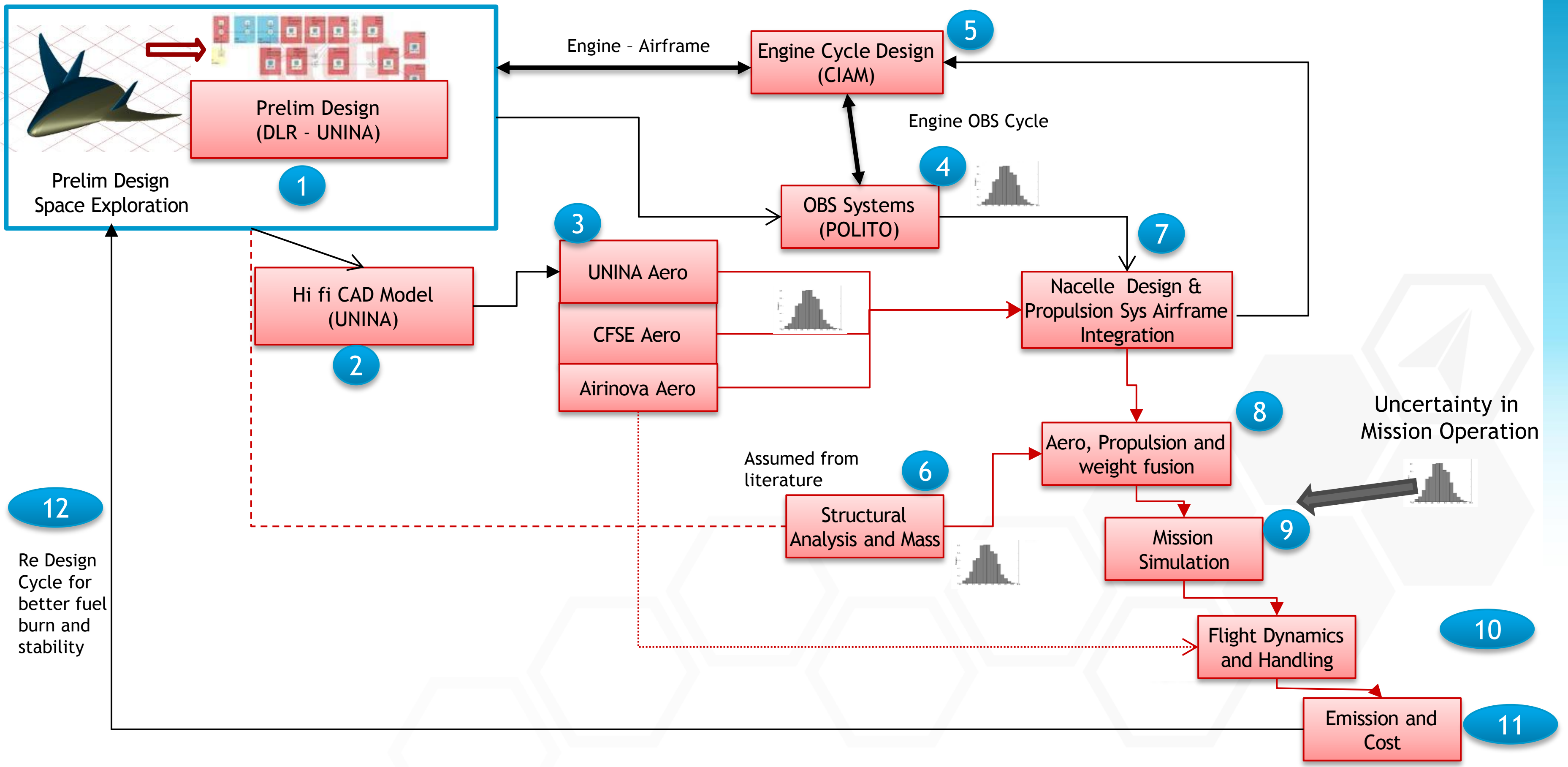
BWB Mass Budget

Mass Component			Mass in Kg	Source
	Sub component	Mass in Kg		
BWB wing and fuselage Mass			127644	Internal Project (Similar to Boeing BWB 450)
Total Propulsion system mass			26620.5	Internal Project (Similar to Boeing BWB 450)
System Mass				POLITO Estimations
	Avionics	617		
	FCS	784		
	Landing gear	9268		
	ECS and anti-ice	2339		
	Fuel System	409		
	Aux Power System	772		
	Furnishing System	16622		
	Hydraulic	0		
	Electric	3978		
Total Systems Mass			39364	POLITO Estimation - Section V.D of this paper
Furnishings			20214.7	Internal Project
Mass of other equipments			20828.2	Internal Project
Total Operating Empty Mass			234671.7	Summation of above masses
Payload Mass	Pax		45000	450 Pax @ 100kg/pax
	Cargo		5000	cargo requirement
Total Payload Mass			50000	
Total Zero Fuel Mass			284671.7	
Fuel mass			142621.5	Estimation from Mission simulation for 12000 Km range and allowable MTOM -
Total Max Takeoff Mass			427293	



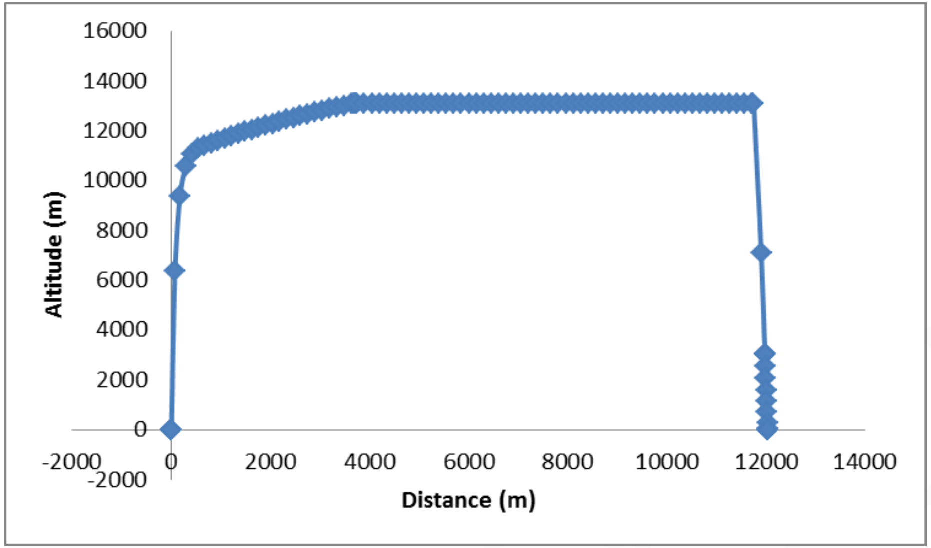
Note: A detailed structural analysis and weight estimation was not done due To limited Project scope and resource concerns

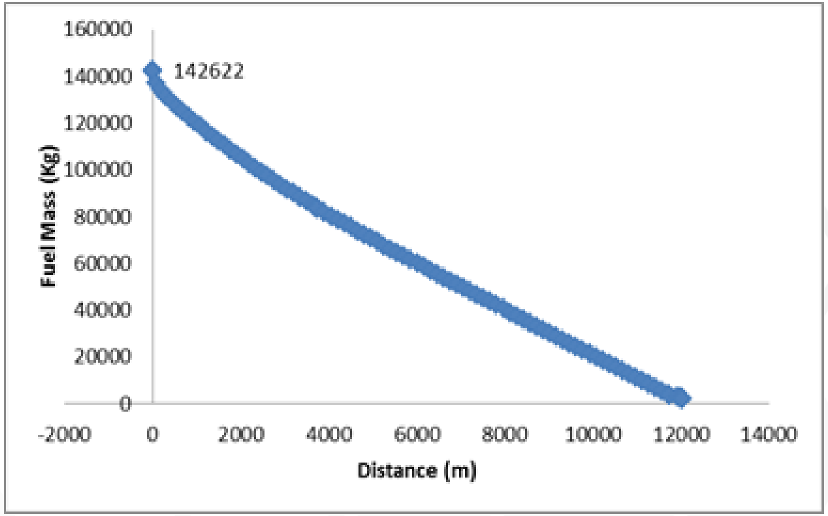
Mission Simulation - DLR



Mission Simulation - DLR

Fight altitude : 13200 m
Cruise Mach : 0.85 M
Pax: 450, Payload 50000 Kg
Mass , Aero and Engine parameters propagated

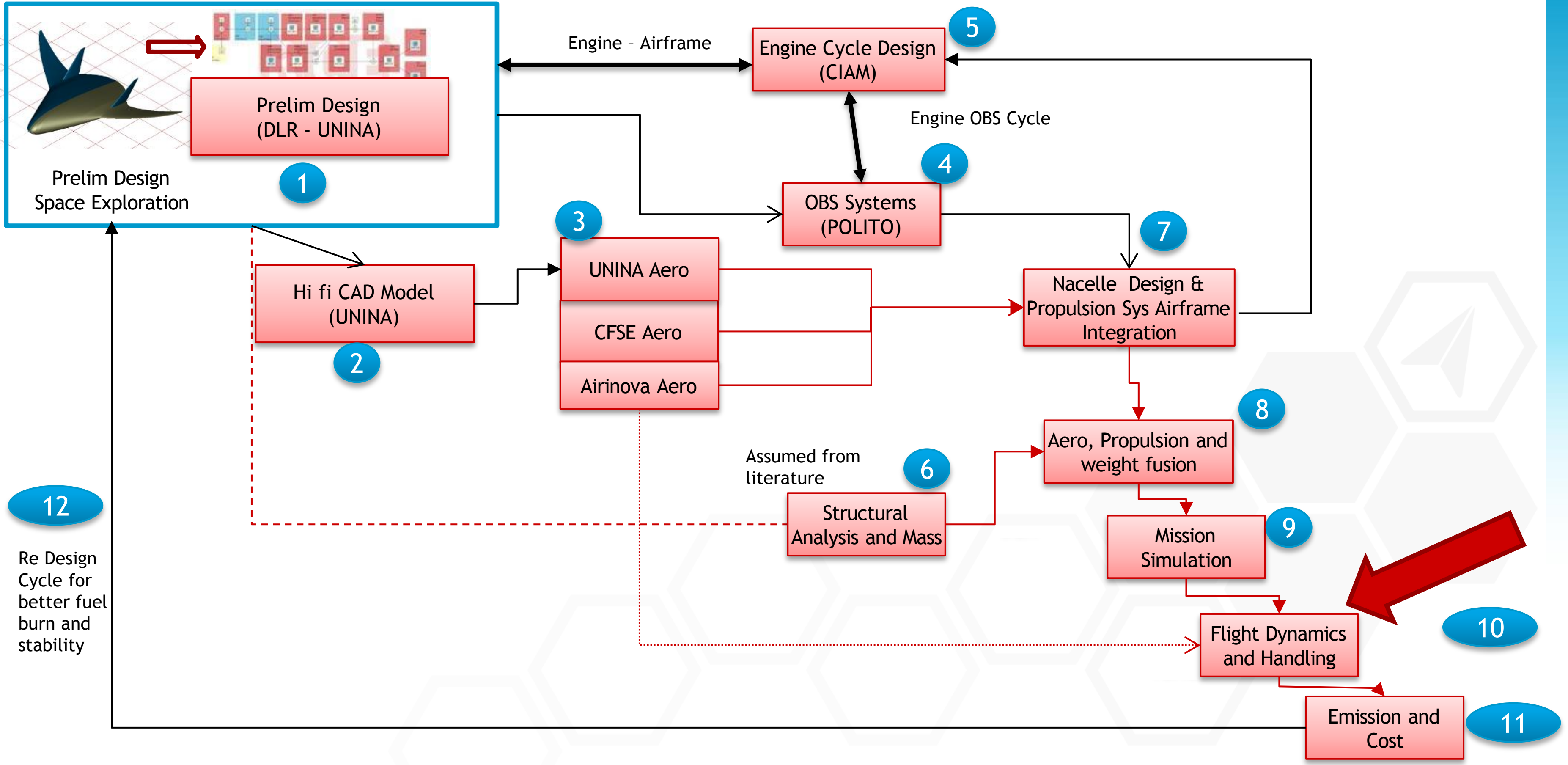




Fuel for 12000 Km mission : 142622 KG
Note: Aircraft ideally should fly 15000 km

Mission profile optimization is due for future work

Flight Dynamics and Handling - TU Delft and CFSE



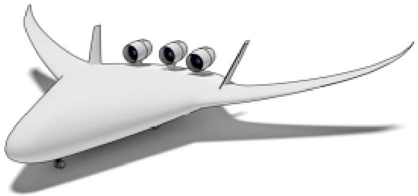
CFD and Database Parameters

Model features	Setting
CFD Solver	SU2
Equations solved	Euler
Type of mesh	Unstructured
Nb of Tetraheadron	6.5 M
Skin friction	Empirical (added post possessing)

Table 1: CFD Calculation parameters

Parameter	Value		
Angle of Attack	-2	0	2
Angle of Sideslip	-3	0	3
Mach	0.3		
CS deflection	-5	0	5
Damping derivatives	dp	dq	dr

Table 2: Aero Database parameters



Introduction - Simulation model (PHALANX)

TU Delft

Model features	Setting
Equations of motion	Nonlinear - 6 Degrees of Freedom
Aerodynamics	Look-up table (α, β, Mach, Re, p, q, r, δ)
Flight control system	10 control surfaces (elevons) saturation limits
	Daisy chain control allocation or weighted Pseudo Inverse
	second order actuator dynamics
	rate and saturation limits
Propulsion	Engine decks (Mach, H, throttle setting)
	First order dynamics

Table 1: PHALANX modelling features

Parameter	Value
Airspeed	Low speed V = 100 – 140 (m/s) H = 1000 (m) High speed V = 230 – 250 (m/s) H = 10000 (m)
Mass	MTOM: 435620 (kg)
Configuration	Clean
Class	III – category B / C

Table 2: Flight condition and configuration

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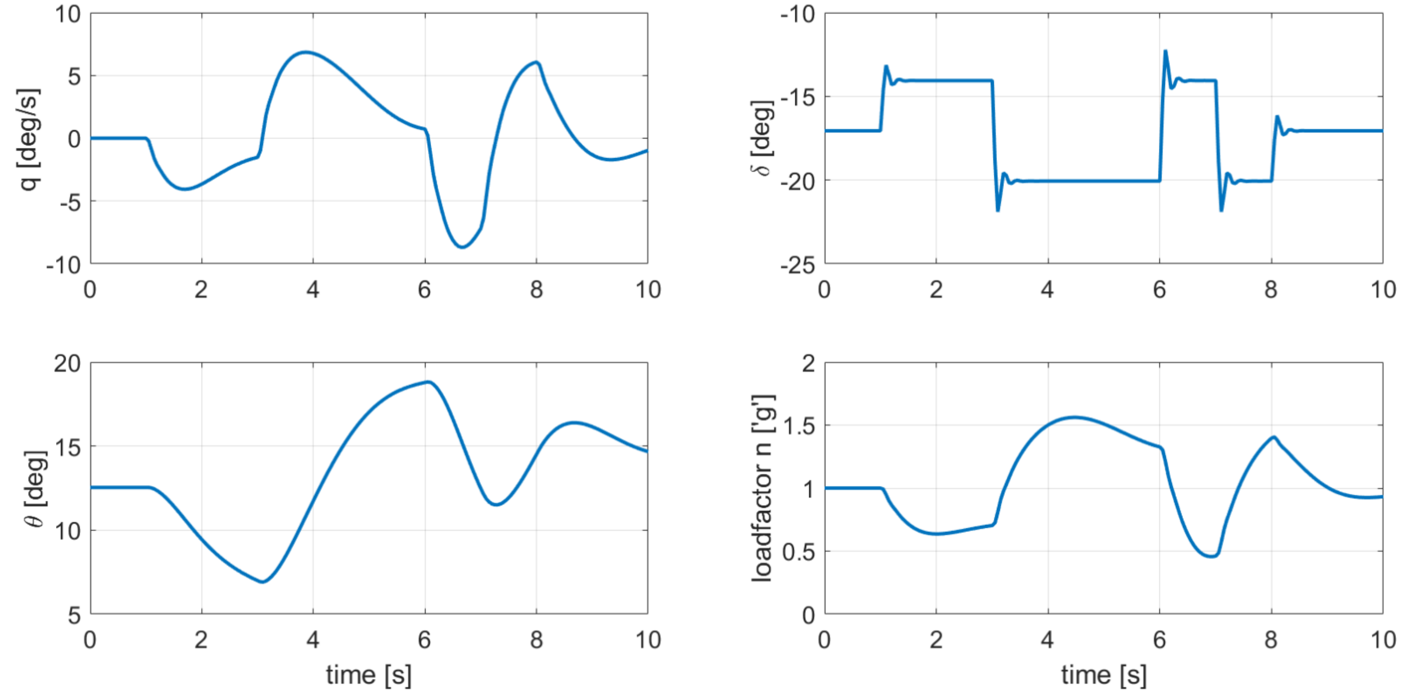
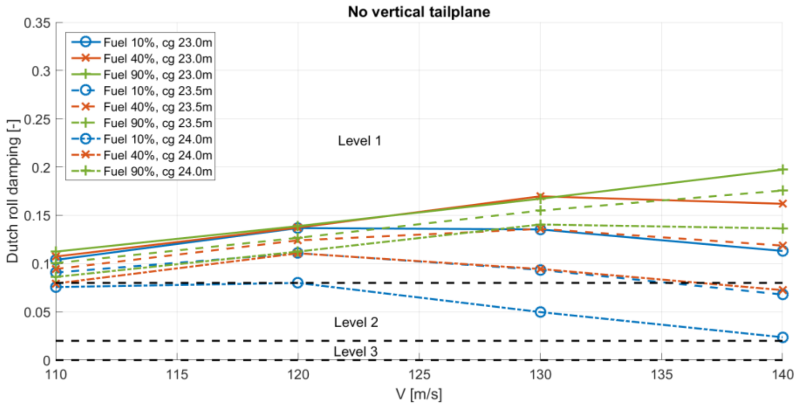
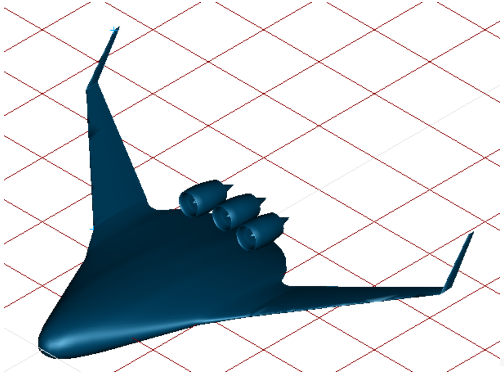
Control in maneuvering flight (2-3-1-1 pilot input)

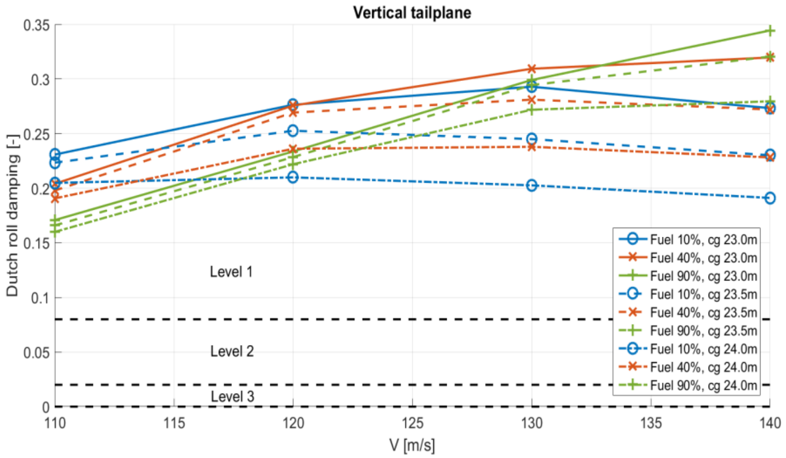


Static margin ~= 0.04, Altitude = 1000 (m), MTOM, (small aerodynamic database)

Low speed - Dutch roll damping (No VTP vs VTP)







The addition of the VTP increases the Dutch roll damping and thereby improves the predicted handling qualities from level 3 to level 2

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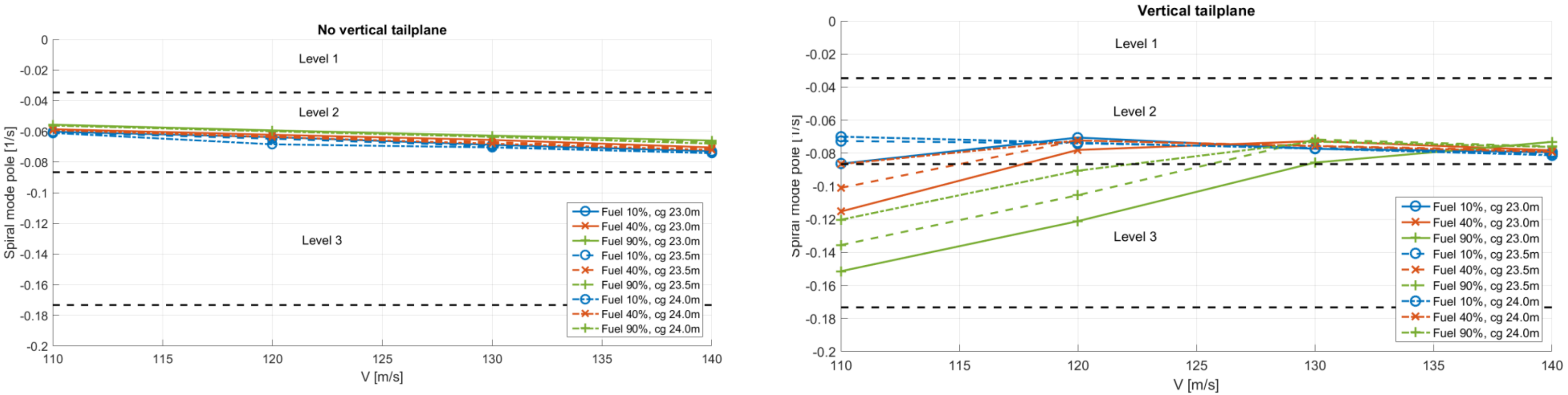
Low speed - spiral (No VTP and VTP)



The time to double amplitude for the spiral mode at low speed is reduced due to the VTP, resulting in level 3 flying qualities at low speed.

With VTP, all lateral directional stability parameters are in the level 1 or level 2 region with the exception of the spiral mode at the lowest airspeeds

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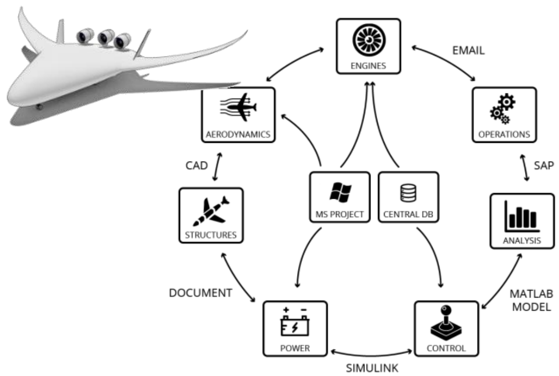
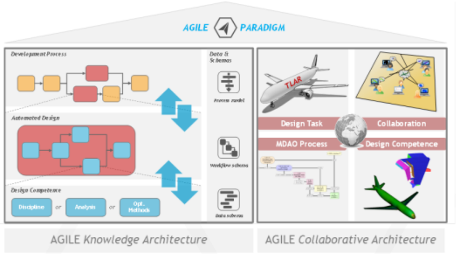
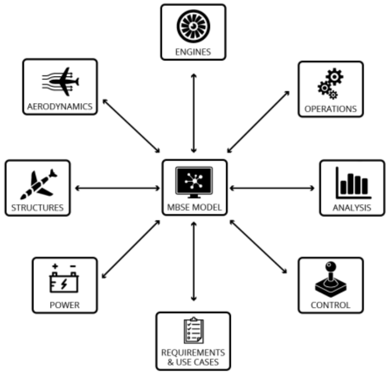
Flight Simulator for BWB

Overall Conclusion

- Issues: Aerodynamic Optimization with Nacelle and VTP in progress based on MDA presented. Geometric morphing and Hifi manipulation is still issue.
- Collaborative Design of novel configuration using AGILE framework is feasible
- Stability and Control, On Board System, Propulsion Airframe Integration analysis was carried out successfully
- Model based approaches significantly increased collaboration
- Models were reusable and reconfigurable, data traceable.







Thank you…

Prajwal.prakasha@dlr.de.. AGILE website: agile-project.eu

“ Ready play with the AGILE Technologies?

Check the** AGILE **open source developments!”

- AGILE website: agile-project.eu
- MDO system interface: mdo-system-interface.agile-project.eu
- CMDOWS interface: cmdows.agile-project.eu
- CMDOWS format: cmdows-repo.agile-project.eu
- KADMOS/VISTOSM package: kadmos-repo.agile-project.eu (or ”pip install kadmos”)
- RCE: rcenvironment.de
- CPACS: cpacs.de
- OpenLEGO package: github.com/daniel-de-vries/OpenLEGO

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