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Design Analysis of the Ancient Italian Frigate "*Terribile*"

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Abstract. In 1861, the frigate "*Terribile*" has been the first ironclad of the emerging Italian Navy and her history is interesting from technical point of view and historical events. In fact, as the industrial revolution unfolded in the 19th century, the age of wooden hulled sailing ships gave way to that of steam powered iron ones. Moreover, due to the development of armament and armour, many changes took place in nearly every aspect of warship: design, operation and tactics. The present paper completes a previous investigation on the historical events that led to the construction of the frigate "*Terribile*" and the design principles followed during the transition time of 19th century. Based on the availability of the original lines plan, some aspects are further examined and discussed, starting from main ship ratios, up to structural considerations, hull outfitting and hybrid propulsion. Finally, the general arrangement is also examined, showing ship details generally not always known in the historical records.

Keywords. Italian Navy, Ironclad, 19th Century, Warship.

1. Introduction

In the 19th century, the industrial maritime revolution led to a change in warship design and military doctrine. During the transition period, iron slowly replaced wood, assuring increased hull girder strength and longer ships; steam engines started to replace wind propulsion, assuring both greater speed and wind independent manoeuvrability. From the operation and tactics point of view, this caused the end of the ship of the line. Moreover, battlefield techniques changed significantly due to the introduction of new destructive weapons, adopting shell guns having a tremendous destructive power of explosive shell compared to solid shot: shells detonated upon a ship's side leaving an irregular hole that could sink a wooden vessel, could ignite her by means of sparks from the explosion and the iron shell fragments could decimate the enemy crew. To react to these new weapons, the French and later the British responded with the construction of floating iron cased batteries.

The Italian Navy also followed the same way, providing the design and construction of the frigate "*Terribile*" and her sistership "*Formidabile*", but their history was rather complex. Historically, "*Terribile*" was the first ironclad for the Sardinian navy. She was built in France in 1860 as will of the Prime Minister Camillo Benso Count of Cavour and, subsequently, she was transferred to the emerging Italian Navy after unification. The France shipyard Forges et Chantiers de la Mediterranee was selected to have showed

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enough experience in the construction of the first ocean-going ironclad "*La Gloire*", launched in 1859. Probably, it was also the result of a geopolitical agreement between Savoy and France. Initially, Camillo Benso required two coastal defence ships, capable of littoral operations close to the shore, sacrificing speed and range for armour and armament. But the quick change of pace during the half of 19th century and the untimely death of Count of Cavour, convinced the Italian Navy to modify "*Terribile*" as a frigate, reducing the number of guns and increasing coal weight and range. Unfortunately, the result of these modifications was questionable and in 1866 a parliamentary commission of inquiry ascertained that "*Terribile*" stability, seakeeping and manoeuvring performances were not very successful, [1], [2].

Design aspects, including armour, armament and stability, were analysed in a previous study, [3], confirming the ship officer evidence about roll angle amplitude in severe sea and flooding of battery deck through gun holes due to the reduced free board, because of the increased weight of the ship due to the armour. Moreover, it was observed that she wasn't designed for high seas operation but intended to act as coastal defence. The present paper extends the analysis to further design aspects, starting from main ship dimensions, up to structural considerations, hull outfitting and hybrid propulsion, giving a picture of the design approach of the time. Finally, the general plan is examined, providing ship details generally not always shown in the historical records.

2. Ship main dimensions and characteristics

The Société Nouvelle des Forges et Chantiers de la Méditerranée shipyard in La Seyne, France was selected for the construction of "*Terribile*" whose longitudinal view is showed in Figure 1. The shipyard was specialized in the construction of warships, having the primate of the construction of "*La Gloire*", the first ocean-going ironclad. In June 1860, "*Terribile*" was laid down; she was launched on the February 16th, 1861, and completed in September of the same year. Her main dimensions and characteristics are summarized in Table 1, based on the drawing dated November 20th 1861 "*Plan des Batteries Cuirasses a Helice Terribile et Formidable*", from private record, whose values match generally well with historical records.

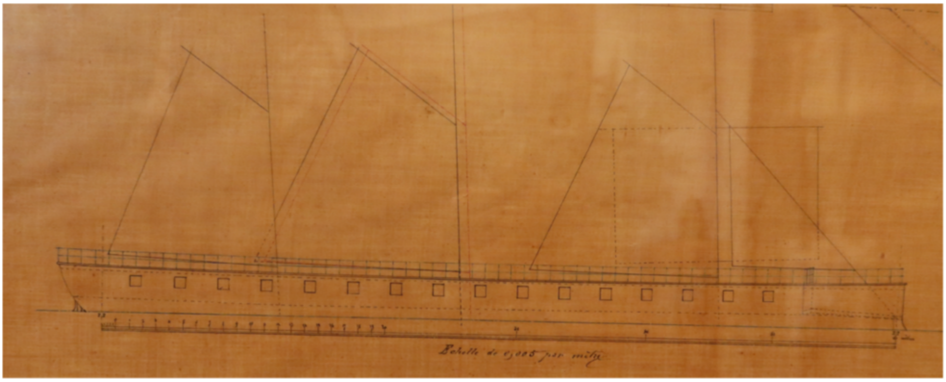


Figure 1. "*Terribile*" longitudinal view.

Table 1. "*Terribile*" main parameters.

L_{OA}	=	65,30 m	D battery deck	=	6,10 m
L_{WL}	=	64,00 m	D main deck	=	8,25 m
L_{BP}	=	61,00 m	Displacement	=	2.725 t
B (moulded)	=	13,60 m	Z_B	=	2,107 m
B_{max}	=	14,44 m	X_B	=	30,84 m
T_{fore}	=	5,20 m	X_G	=	29,35 m
T_{aft}	=	5,70 m	BM_T	=	3,68 m
T_m	=	5,45 m	Centre of sailing plan	=	9,88 m
T (on keel)	=	5,25 m	Effective Power	=	450 HP

Ship body plan seems to be basically designed along the same lines as her wooden predecessor, with the difference that she was iron hulled and protected by 114mm of iron that ran along her entire length and extended from battery deck to the main deck (about 1.5m below the design waterline).

3. Stability

In Fasano et al. (2024), [3], the stability of "*Terribile*" was analysed, referring to the two conditions of ship with armour and without armour. To this aim, a 3D CAD model of the naked hull was created based on the original lines drawing. The armour was treated as an additional weight considered as hull appendage that does not contribute to the buoyant volume of the vessel, although it was partly immersed. However, the armour, which is not, strictly speaking, watertight, provides buoyancy, reducing about 13 cm the draught, and increases the water plane area, leading to a value of the metacentric radius almost equal to the ship without armour, as summarized in Table 2.

Table 2. Effect of the presence of the armour on the transverse metacenter.

		Without armour	With armour (additional weight)	With armour (buoyant volume)
T_M	(m)	4,65	5,45	5,32
Δ	(t)	2225,19	2725,19	2725,19
KB	(m)	2,79	3,23	3,19
A_w	(m^2)	642,4	650,9	706,44
I_x	(m^4)	7978,5	7946,7	9864,2
BM	(m)	3,66	2,93	3,71
KM	(m)	6,45	6,16	6,9

Therefore, it seems that at the design stage it was preferred to keep the same metacentric radius of the ship without armour, to guarantee the same characteristics. But probably, it was neglected the effect of the added weight to both ship period and inertial forces that caused the problems as attested by many ship officers during the parliamentary commission of inquiry [1], [2]. It must be noted that the same stability problems were also observed in "*La Gloire*" [2], that was defined as a not good sea-boat because, rolling boldly, she was an ineffective gun platform [4]. Stability concepts during the XIX century were still little investigated and the concern about stability issues is demonstrated by the actions taken in 1864 during the voyage from New York to Italy of the ironclad "*Re d'Italia*", ordered in 1861 to the American shipyard William H. Webb,

[5]. To increase ship stability in view of the voyage through the Atlantic Ocean during the winter season, part of the armour, for an estimated weight of about 250t, was not assembled and used as ballast by stowing it along the bottom, lowering the centre of gravity of the vessel.

4. Propulsion and machinery

Speed, endurance and range were guaranteed by a "hybrid" propulsion, consisting of sails and steam engine capable to drive the ship by both wind and steam. The engine was a first source of propulsion, whose advantages were clear: it offered, in addition to the increased speed, some means of maneuvering in unfavorable winds and during naval combat. The conservative approach to keeping the sails albeit the engine was typical of design choices of the period, due to the not yet consolidated technology and the need to increase ship endurance. Only at the end of the XIX century propulsion by steam engines totally replaced sails, offering to the warships the availability of a free deck and the installation of innovative routable gun turrets.

The "*Terribile*" was schooner rigged with 460 m^2 of sail area, distributed on three masts (fore, main and mizzen mast), located respectively at 24%, 57% and 87% from the forward perpendicular.

According to the standard of the time [6], the height of the masts was evaluated as a function of moulded breadth. Due to the obtained result, generally they were carried out in two or three trunks. However, the height of "*Terribile*" masts was no more than 23.5m (rather than 35-40 m as for standards) and they were carried out in a single trunk, as appear in the ship's drawings. The reduced dimension of the masts probably depended on her hybrid propulsion and initial operational profile as coastal defence ship, demonstrating that sails were designed for only a secondary role. On the other side, the mast diameter was evaluated as a function of its length and the "*Terribile*" values generally comply with the standards, as shown in Table 3:

Table 3. Main mast dimensions.

Tree	H (m) upon main deck	H_{Tot} (m)	d (mm)	H rules (m)	d (mm) 1° trunk rules	d (mm) Single trunk
Fore	20,5	23,5	500	34 – 40,8	400 – 560	470
Main	20,5	23,5	500	34 – 40,8	450 – 510	470
Mizzen	19,0	21,0	400	34 – 40,8	430 - 490	420

Finally, it must be considered that only the fore mast was placed on the bottom structure, while the mizzen and main masts were supported by the battery deck (the lather equipped with a pillar to transfer weight and stress to the bottom structure).

The propulsion system consisted of one single-expansion marine steam engine that drove a single screw propeller, producing a top speed of 10 knots at maximum power, with a range of about 1.300 nautical miles at the top speed. No information is available about ship speed when powered by both sails and steam engine but considering sail area and musts' dimensions, the main source of propulsion was steam.

The engine room shown in Figure 2 was placed amidships and was about 16m long and 5,1m high from the bottom to the battery deck. The power plant was comprised of 4 boilers with 4 furnaces each and 2 back-acting engines, capable of delivering 450 hp to the shafting, considering any losses. The "*Terribile*"'s back-acting engine laid transversally to the ship, with two horizontal cylinders due to the larger ship breadth compared to the engine room height [7]. This solution is the same as the French frigate "*La Gloire*". The boilers were fired by coal stowed in four tanks: two of about 60 m^3 located forward the boilers and the other two of about 110 m^3 and 160 m^3 located respectively port and starboard side of the boilers. Therefore, considering a whole capacity of about 390 m^3 and a coal density in pieces 0,8 t/m^3, the total coal weight was about 310 t; this value agrees with the values of similar ships and literature. Four cowl vents equipped with buffle ensured the air supply for boilers, while the exhaust gases were piped across the large funnel (2m diameter) located exactly over the boilers.

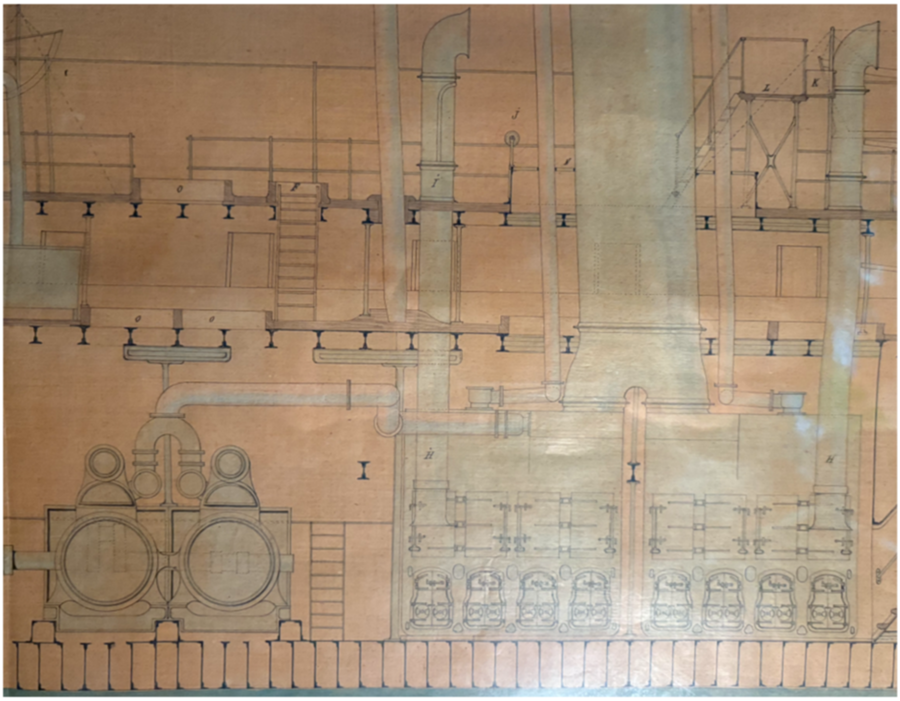


Figure 2. "*Terribile*" engine room.

The engines were connected to a single shaft about 22m long, having a diameter of 300mm; it was composed of two intermediate shafts (7m long each) and a propeller shaft of 8 m, located into the stern tube having a diameter of 500 mm. These dimensions complied with the rules of the Italian register of shipping RINA (edition 1950) [8], as shown in Table 4.

Table 4. Summary of the shaft main components and dimensions.

Item	Original value	RINA requirements
Propeller shaft length	8 m	-
Propeller shaft diameter	300 mm	245 mm
Intermediate Shaft length	7 m	5 – 7,5 m
Intermediate diameter	300 mm	195 mm
Stern tube length	4,8 m	4,5 – 7,5 m
Bearing length (intermed.)	400 mm	240 – 360 mm
Bearing length (stern tube)	3 x 800 mm	1200 mm

5. Structure

The "*Terribile*"'s midship section (Figure 3) gives the opportunity to appreciate, through some structural details, the transition time of her age and the needs in terms of structural strength of warships.

The structure of the bottom and side (keel, frames, beams and cladding) was mainly made of iron, while the three decks (main, gun and lower deck) were made of wood, with thickness decreasing from the upper to the lower deck. The drawing shows the detail of a stringer iron plate ① on each deck connected to the side and web frames by L-shaped angular beams ②. Moreover, two additional strakes ③ were placed to strengthen main deck and battery deck, at about 1/6 of the half breadth from the midplane. These stiffeners strakes increased deck strength but also guarantying a certain ability to resist the impact of explosions. Moreover, the drawing in Figure 6a shows a 12 meters long platform deck aft the collision bulkhead, comprised between the ceiling of the bottom and the lower deck, useful for ship's crew to rapidly reach the engine room.

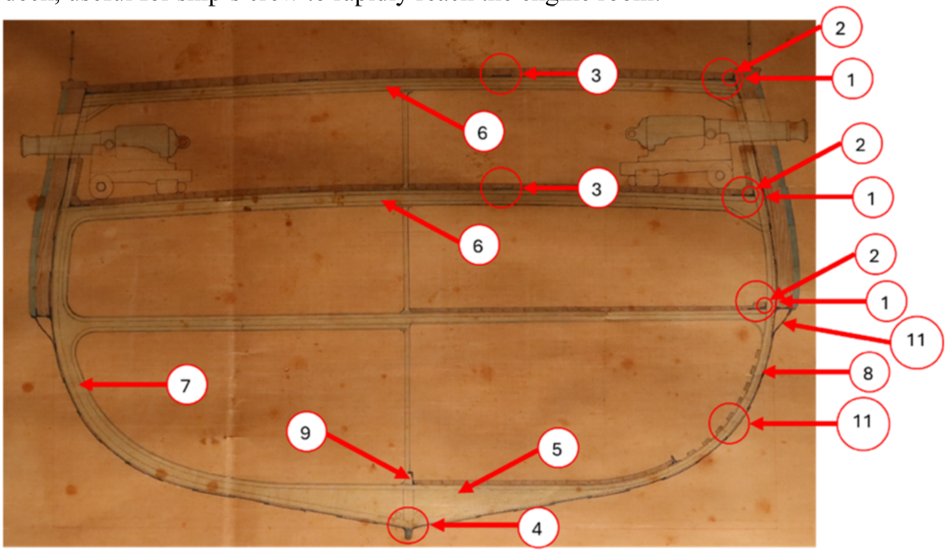


Figure 3. "Terribile" midship section.

"*Terribile*" was transversally framed (as the system was derived from wooden ships), with an iron bar keel ④ supporting the transverse frames. The spacing was 40cm, but the framing system was peculiar: at each frame, solid floor ⑤ supported the bottom and strong deck beams ⑥ supported main deck and battery deck. The side was supported by side frames ⑧ and each two spaces by L-shaped web frames ⑦. Such a framing system provided enough strength to those parts of the ship that, together with the armour, had to resist the destructive power of explosive shells. A continuous iron center girder was placed over the solid floors ⑨. Pillars were placed along the midplane to halve the span of deck beams. The ceiling of the bottom was continuous along the midplane and replaced with battens along the sides ⑩.

The iron shell plating was riveted by overlapping contiguous edges. The armour was made of iron plates 11.4cm thick backed by 38.1cm of teak intended to cushion the shock of a hit from enemy shells. This frame was supported by an iron plate placed at the same height of the stringer plate of the lower deck. In turn, this iron plate was supported by the side shell plating, which was tapered to connect to the armour ⑪. This detail shows that the "*Terribile*" armour was considered as an appendage of the hull (like for wooden ship), contrary to the British warship "*Warrior*" (1861) whose armour was designed as an integral part of the structure, so it was impossible to distinguish the unarmoured ends of the ship from the armoured sections.

6. Rudder, steering gear and hostable deck

"*Terribile*" had a single stern rudder placed in the midplane, with a wetted surface of $6.5m^2$, about 1/50 of the lateral area of the bare hull. According to the standards [6], rudder surface of sailing ships ranged from 1/75 up to 1/60 of the lateral area. This seems to confirm that it was decided to provide increased steering and manoeuvring functions compared to sailing ships of same size, considering both ship speed and mission.

The rudder structure was also singular (Figure 4): the lower stock realized a single casting with edge bar and the three arms; the rudder plate was than rivetted upon this casting. Differently from the conventional solution of pintles forged with the lower stock, they were linked to the stern post by a crutch with three nails, guaranteeing easier maintenance, since pintles could be removed and replaced by new ones without acting on the casting. The lower stock was connected to the upper stock at battery deck level, where a watertight gland is placed. The rudder stock continued up to the upper deck, where it was connected to the tiller through a boss made of two pieces. According to the standards of that period [6], the length of the rudder tiller had to be 7 times the rudder stock diameter at least, while the boss that supported it should have a diameter at least equal to 1,3 times the rudder stock diameter.

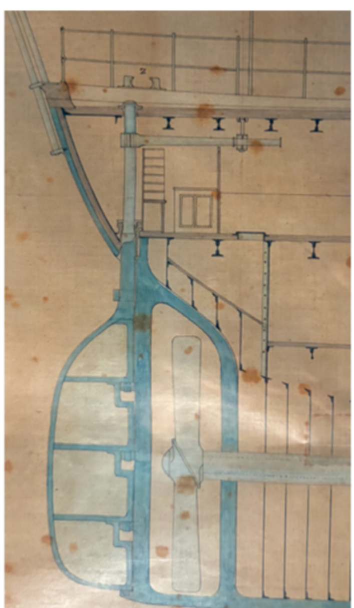


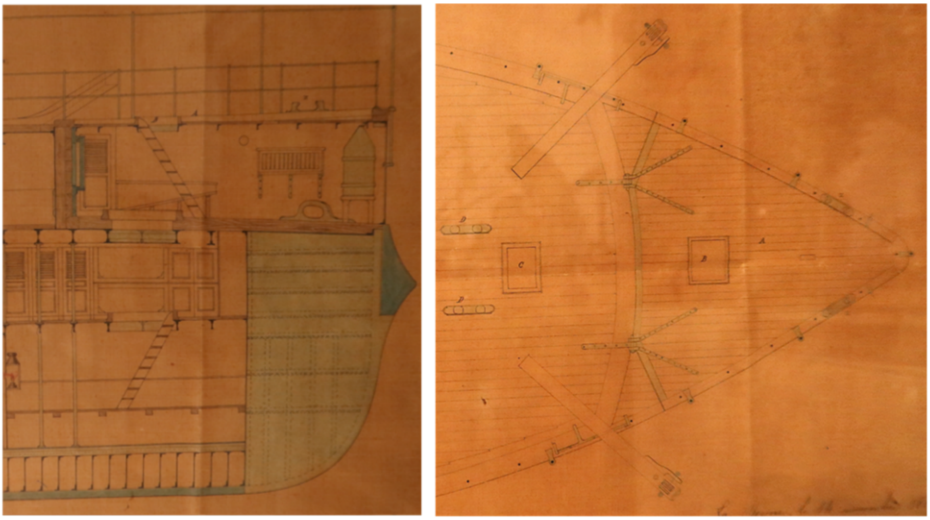
Figure 4. Details of the rudder structure.

According to the available drawings, the "*Terribile*" rudder stock diameter was 200mm and the length of the tiller was 2,8m, i.e. two times the required value, still small if compared with the 5m of the "*La Gloire*"'s tiller. The reason behind these choices was to reduce the torque required to turn the rudder against the pressure of the water flowing past it, making easier the helmsman maneuver. The diameter of the rudder stock, calculated assuming as material mild steel, considering maximum ship speed and a rudder angle of 30 degrees as design conditions, would be 160mm. The difference of about 25% more appears to be reasonable considering the operational profile of the ship and the uncertainties of that time regarding load evaluation and new material properties.

The steering gear was composed of two steering wheels with a diameter of 1,6m operating the ropes connected to the rudder just below the main deck, placed in an armored enclosure on the main deck (Figure 5). The enclosure made of iron plated teak gave officers some protection from small arms fire while they oversaw the naval battle. Small openings in the enclosure allowed them to view the deck and sails and a large hatch at their feet made it possible to communicate with the helmsman located on the deck below. This detail can be considered as a first step toward the centralized bridge control, and it was subsequently applied to others warship of the time. It must be noted that the steering gear solution adopted by "*Terribile*" was exactly the same as the frigate "*La Gloire*" and it is also reported as benchmark in [9].

Figure 5. Details of the armored enclosure.

The fore part of the "*Terribile*" main deck (about 50m^2) was hostable to allow the fore gun shooting through two gun ports located on the front of the armored transverse bulkhead (Figure 6a). For this reason, the deck structure was lighter in comparison to the rest of the deck, having a double frame space between beams and a reduced thickness of the wooden planking. Moreover, the fore shell plating was without the armour. The rotation was operated through two hinges located on the deck (Figure 6b), by means of two ropes reeved into two blocks at the end of the port and starboard catheads. Figure 6a shows also the ram, the appurtenance fixed in the bow and designed to damage enemy ships when struck by it. These strategic battle options (fore gun and ram) gave the opportunity to start a new era, overcoming the old ship of the line doctrine, thanks to the freedom to maneuver in any direction due to steam power.



a) b)

Figure 6. Details of the bow structure and of the hostable deck.

7. Conclusions

The present study investigates some design details of the Italian ironclad "*Terribile*", showing that there is no better period in history for studying the interrelationship between tactics and technology than the shift from sail to steam in the 19th century. But, the rapid pace of technological developments, particularly in terms of gun capabilities and thickness of armour to combat them, quickly rendered warships obsolescent.

At the same time, engines for all types of warships steadily improved as stronger metals made possible higher steam pressures and weight reduction, providing a significant increase of ship's speed, influencing both battle doctrine and ship's body lines.

Although during the transition time many changes took place in nearly every aspect of warship, the design analysis of "Terribile" hull, musts, rudder and shaft arrangements shows a significant good agreement with rule requirements and standards of the time and well represents the state of the art of the shipbuilding in the middle of XIX century.

Finally, the full description of structural arrangement, hostable fore deck and steering gear depict very original characteristic ship details usually not mentioned in technical literature.

List of symbols

Symbol	Unit	Definition
A_W	(m^2)	Waterplane area
B_M	(m)	Midship breadth
B_{max}	(m)	Maximum breadth
BM_T	(m)	Transverse metacentric radius
B_{WL}	(m)	Breadth at the waterline
d	(mm)	Mast diameter
D	(m)	Moulded depth
GM_T	(m)	Transverse metacentric height
H	(m)	Mast height
I_x	(m^4)	Moment of inertia of the waterplane area around x-axis
KG	(m)	Vertical position of the centre of gravity above the keel line
KB	(m)	Vertical position of the centre of buoyancy above the keel line
KM	(m)	Vertical position of the metacentre above the keel line
L_{BP}	(m)	Length between perpendiculars
L_{OA}	(m)	Length overall
L_{WL}	(m)	Length at the waterline
T_{aft}	(m)	Draught at aft perpendicular
T_{fore}	(m)	Draught at forward perpendicular
T_m	(m)	Draught at midship
Δ	(t)	Mass displacement

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