Preliminary scantling design of Aerodynamically Alleviated Marine Vehicles (AAMV)

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For very high speed marine crafts the aerodynamic forces can become of the same order of magnitude as the hydrodynamic ones, especially for small vessels. Although these forces can lead to instability issues in some cases, they can also offer a new range of possibilities to sustain the weight of the craft. The vessel can be equipped with aerodynamic lifting surfaces in order to alleviate the weight of the vehicle, leading to a lower effective displacement, hence lower resistance and required power.

The estimation of the total weight of the vehicle and of its distribution is of paramount importance, since it strongly affects the whole design process. Due to the lack of commercially established AAMV configurations, and due to the substantial differences between AAMV and other fast vehicles, regressions based on historical data derived from present and past vehicles are not available. The proposed approach is therefore based on the High Speed Craft Code and on first principles of structural engineering, considering both global and local behaviour of structural components. The developed procedure works out an estimate of the weight of the structure using as input data only the main characteristics of the AAMV under design and it represents a starting point in the scantling design of an AAMV in the first steps of the design spiral.

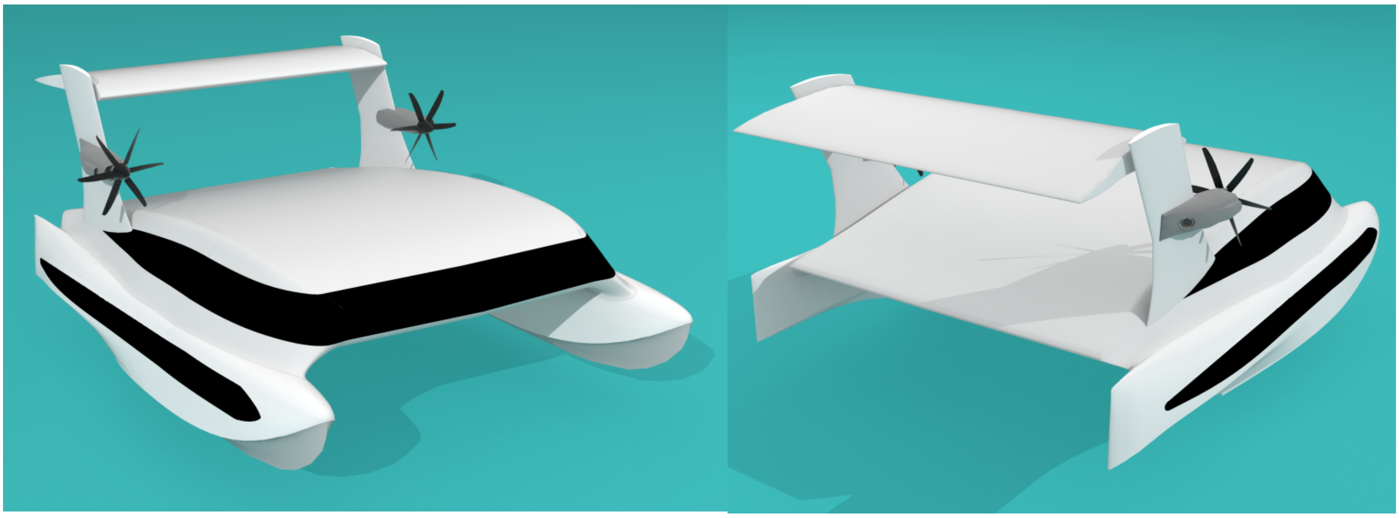

Figure 1: 800 nm range luxury AAMV concept, 8 guests and 4 crew (courtesy of Renaissance Design (UK) ltd)

1 INTRODUCTION

1.1 Context

Several new high speed marine vehicle configurations have been developed due to an increasing demand for such vehicles in civil and military marine transportation (Clark et al. 2004). An AAMV configuration can be classified as a Wing In Ground effect (WIGe) vehicle, but it is characterised by a different design approach, leading to a vehicle substantially different from the WIGe configurations developed so far. For a comprehensive review on WIGe see (Rozhdestvensky 2006).

In general, WIGe vehicles are designed considering mainly the airborne phase and therefore the capability of such vehicles while in waterborne phase are very limited: no waterborne cruise speed considered, very high drag at low to medium waterborne speeds, very limited manoeuvring capabilities.

An AAMV configuration is designed instead to operate successfully in a number of modes: low speed displacement and so-called semi-displacement waterborne modes, high speed waterborne mode, and finally airborne mode for high speed transit, although not beyond the influence of the ground effect zone.

In 2006, a research program aiming at investigating such configuration was initiated at Cranfield University, focusing on the estimation of the loads and the vehicle dynamics during the high speed waterborne phases, when hydrodynamic and aerodynamic forces of the same order of magnitude can occur (Collu, 2008). Among the results, a concept configuration characterised by very high lift-to-drag ratios has been defined (Williams et al. 2010), and a model of dynamics specific for this configuration has been developed, deriving a novel static stability criteria (Collu et al. 2009).

In 2013 a one year feasibility study of an AAMV configuration for the luxury market has been carried out for a private company by a consortium composed of Cranfield University, Universitá di Genova, and Universitá di Napoli Federico II. Firstly, an investigation into the state of the art technology of luxury motor yachts and WIGe vehicles has been performed. In parallel, a market investigation into a number of luxury motor yachts (main dimensions, inertial characteristics, power and propulsion, deck layouts, number and size of cabins, etc.) has been carried out, leading to the development of a database of luxury motor yacht characteristics. The main aim was to collect the necessary data to inform the design of the luxury AAMV configuration.

Secondly, a feasibility assessment of this concept was started. Using the collected data, a design synthesis model for a luxury motor yacht was developed and benchmarked against the motor yacht database (MYDB), in order to have a validated automated process upon which to build the AAMV design model. The developed code was then expanded to take into account the new elements of the AAMV configuration (mainly the wing and the aero-propulsion system). During this exercise, a spiral design procedure specific for the AAMV configuration was eventually defined (Figure 2).

Each single conceptual/preliminary design step shown in Figure 2 was defined and a dedicated routine implemented in Matlab™; an overall Multi-Disciplinary Design (MDD) approach was so developed into a vehicle synthesis model, as inspired by the spiral design approach adopted for the marine vehicles (Gale 2004). As the original spiral design, also this one is iterative since the parameters of each module have an impact on all the other modules.

This automated process approach was applied to perform several conceptual/preliminary designs, one of which is presented in Figure 1.

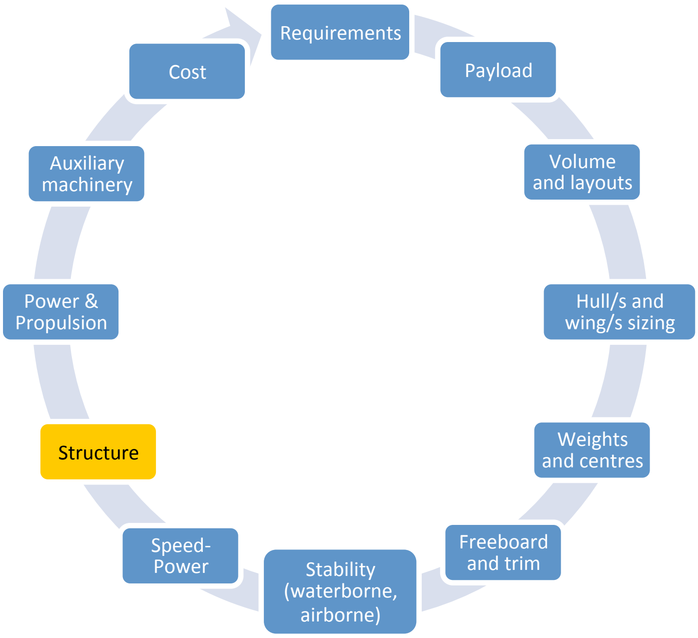

Figure 2. AAMV spiral design [courtesy of Renaissance Design (UK) ltd]

1.2 Problem statement

The main aim of the present work was to develop a suitable method to estimate the structural weight and its centre of gravity position, in order to contribute to the overall conceptual preliminary design illustrated in Figure 2.

The AAMV configuration considered in the present paper is designed to have both a waterborne cruise mode and an airborne cruise mode. Due to the second mode, the need to have a light vehicle is very important, pushing for structural solutions closer to the aviation industry rather than to the traditional high speed marine vehicle industry.

On the other hand, each AAMV mission includes waterborne phases, and in particular high speed waterborne phases during the take-off, the waterborne high speed cruise, and landing phases. The hull of an AAMV has therefore to withstand the hydrostatic and hydrodynamic loads typical of fast marine crafts.

At the moment very few WIGe vehicles have been developed with such characteristics and the lack of data in the literature make very difficult to rely on the statistical methods usually adopted not only for the conceptual/preliminary design of marine vehicles, but also for the design of aircraft (Roskam 1989). Therefore it was necessary to develop a preliminary and reliable method to perform the preliminary scantling of the vehicle.

2 LITERATURE REVIEW

In the following an overview of the sources utilised to develop the scantling approach for the AAMV configuration is presented, based on the approaches developed for HSMV and WIGe vehicles.

2.1 High Speed Marine Vehicles

The structural layout for new HSMV must take into account several aspects and among them:

- global weight of the structure,
- hull type and geometry (e.g. monohull, catamaran, hull shapes, etc.),
- materials,
- minimum required scantlings,
- noise and vibration consideration (especially for luxury vessels).

Transverse or longitudinal framing layout must be assessed in order to get the best performance from a structural point of view, bearing in mind that there are advantages and disadvantages for both systems. Global loads of the hull girder, due to the buoyancy and weight distributions of the vessel, as well as to the action of waves and inertial loads, will result into primary stresses. A transversely framed vessel usually shows thicker plating in order to withstand the buckling coming from global loads.

It is important to notice that the vast majority of HSMV, where weight is crucial, show longitudinally framed structures. A longitudinal layout of the reinforcements may also facilitate the construction process either of metallic and composite structures. On the other hand, in case of catamaran configurations, a mixed approach is imperative as the cross deck structure shall withstand the transverse bending moment and twisting.

For luxury vessels it is usually important to keep the noise and vibration levels under a certain level and it is important to keep this requirement in mind since the first phases of the design. Some structural layout, as for example a longitudinal framing system, allows to better deal with vibration issues also during next phases of design. Some studies have concluded that longitudinally framed decks are advantageous with respect to vibration control (Roy et al. 2008**).**

Though, the longitudinal framing layout can be of limited benefit if the local loads dominate the scantling of the vessel. Despite longitudinal frames layout sometimes allows to cut down in structural weight, noise and vibration requirements may penalise the ability to build a very light structure.

Concerning the acting loads on high speed marine vehicles, standards and guidelines such as High Speed Craft (Light) Craft (HSC or HSLC) codes issued by classification societies give good guidance to the designer concerning for example, global loads, local loads, design criteria and so on.

Material plays an important role in building construction especially for fast marine vehicles of limited dimensions (length up to 24 meters). Composite materials are widely studied and quite comprehensive explanation of their behaviour and their application can be found e.g. in (Greene 1999). One of the advantages is the anisotropic feature which allows the designer to use them in the most efficient way depending on the fibre orientation. Unfortunately, this feature is also the one that make them difficult to be assessed in early phases of design (as the concept design is), when the stress fields are not fully known yet.

2.2 Seaplanes and WIGe vehicles

One of the challenges in WIGe vehicle designs comes from the structural side since the purpose of these vehicles is to operate in very different conditions during typical missions. A WIGe is optimised for the airborne phase, but has to withstand also waterborne phases (taxi waterborne, take-off and landing).

The physics underpinning an AAMV (and WIGe) configuration is substantially different from that of a high speed (planing) craft. The main difference consists in the virtual weight variation, due to the fact that the aerodynamic lift reduces the amount of buoyancy and hydrodynamic lift required to sustain the (alleviated) weight of the vehicle.

This leads to a substantial reduction of pressures (hydrostatic and hydrodynamic) on the hull. In particular, it is possible to observe that increasing the speed, the wet loaded area, the integral of pressures, and the highest values of the hydrodynamic pressures decrease.

To evaluate how much this behaviour affects the loads on the hull structures, it is useful remember that on the bottom of a totally planing craft (without hydrostatic buoyancy as well as aerodynamic lift), the loaded wet surface decreases increasing the speed but, to have the lift-weight equilibrium, the pressures increase: this trend entails the virtual transcend of the pressures (and loads). The practical consequence of this behaviour is that the evaluation of the loads cannot be performed according to the procedures typical of marine vehicles.

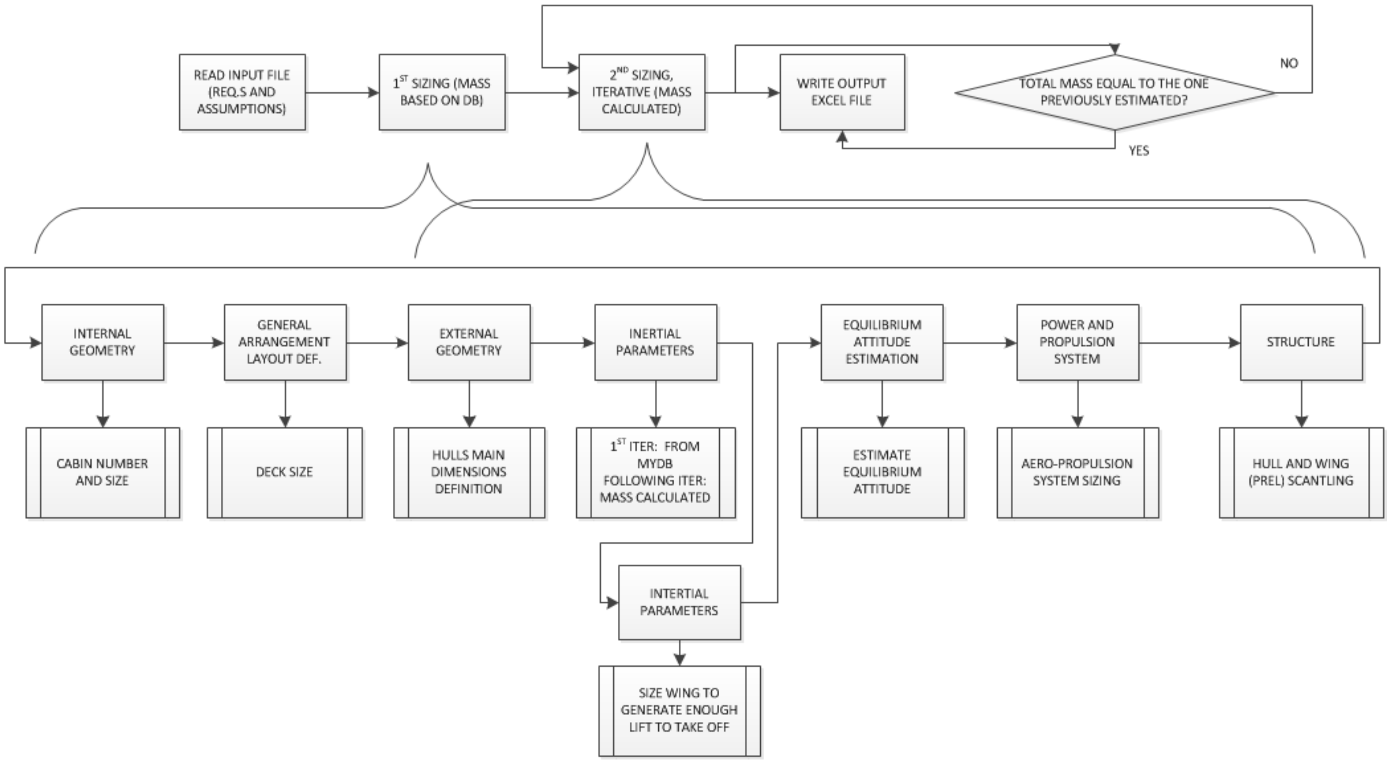

Figure 3. Multi-Disciplinary Design iterative cycle

Referring to the first evaluation of the structural weight of the AAMV, the different dynamic loads reduce the reliability of the statistical operators based on database of ships or boats and highlight the need to achieve a procedure specifically conceived for AAMV.

WIGe vehicles' structural design guidelines and good practices refer to conventional aircraft and, where applicable, to high performance marine craft standards. In some cases, it is suggested that reference is made to the British Hovercraft Safety Requirements for hydrodynamic loads (Fach et al. 2004). As an example, the WIGe tail is designed according to aerospace specifications, but must be manufactured using material resistant to corrosion in a harsh environment, as for marine craft. At the same time the global structural arrangement of the fuselage or hull is a stressed skin supported by ring frames and longitudinal stringers, like those of an airplane. The central section of the hull has heavier frames and stringers to distribute the loading from the payload contained in the hull, plus its own weight into the structure of the wings. But, as in high speed marine vehicles, the lower part of the hull has heavier plating, supporting frames and stringers dimension to resist the hydrodynamic loads while planing at speeds up to take-off.

The global structure should be capable of withstanding the normal set of flying load cases, and the lower surface must be designed for planing pressure and slamming loads in a seaway for speeds below those of take-off. As an example, pressure measurements on the bottom structure of two different two-seater WIGE craft have shown that slamming loads during take-off and landing are the governing load cases (Fach et al. 1999).

The wing structural configuration is similar to aircraft wing structures, with more complex design cases. Significant bending moments applied to the main wing/s by hydrodynamic loads under the hull/s at speeds up to take-off can indeed occur.

An important aspect is that no pressurisation of the fuselage is needed, since the vehicle is not designed to operate at high altitudes, and therefore it is possible to look at more radical shapes than traditional aircraft configuration (blended wing).

The low sides of the wings have also to be designed to withstand slamming loads. Due to the presence of an air cushion, these loads are smaller than the loads of the wet-deck area of an HSC catamaran whereas the upper surfaces are subject to aerodynamic loads only (Fischer, et al., 2004).

As far as materials is concerned:

- Stainless steel can be used for the highly loaded elements of the structure;
- Composite materials are characterised by a high corrosion resistance, water tightness, and require a lower number of stiffeners than aluminium;
- Composite materials can show flaws due to their method of manufacture and they are less suitable than aluminium to withstand impact loads.
- Aluminium materials are still used in aeronautical field and probably this solution is the best choice also for the WIGE vehicle due to its welding features.

3 METHODOLOGY

3.1 *Multi-Disciplinary Design (MDD) methodology*

According to the well known naval architecture design procedure, a holistic approach represented by the design spiral of Figure 2 should be carried out in order to fully integrate all mission requirements and design constraints into the final construction. The design procedure of an AAMV was faced following a similar path. The main idea was to define the vehicle mission requirements, thereafter, design constraints were identified.

In Figure 3 a flow diagram of the implemented MDD approach is presented.

The main input data (number of passengers, range, waterborne cruise and max speed, airborne cruise speed, take-off speed, "luxury level", max take-off sea state, type of service, sea area, airborne cruise flying height, fuel reserve, crew members, propulsion system type, mission profile) are used to perform a first design of the vehicle. In the first cycle, the number of cabins and their size is derived in the internal spaces (based on the luxury level chosen and the number of passengers), and then the cabins are allocated either in the hull or in the wing defining the general arrangements layout. The total area and volume of each deck is so derived. These two first steps are performed only once, as they do not need to be estimated again in the cycle.

Based on the total area required for each deck, having selected the hull type (catamaran is the suitable choice) and given a length-to-beam ratio of the hull/s, the hull/s are sized (main dimensions).

Then the main inertial parameters of the AAMV are estimated. For the first iteration these parameters are initialised based on the data of the motor yacht database (MYDB) developed on purpose, while these are calculated from the second iteration on considering the inertial characteristics of each sub-system of the AAMV (i.e summing the weight of each system). Knowing the main inertial parameters and having the take-off velocity as input, it is possible to design the wing, as the take-off phase is the governing phase for this system.

Having an external geometry defined (wing/s and hull/s), it is possible to estimate the equilibrium attitude of the AAMV configuration for a range of speeds, and from this to estimate also the power-speed curve. It has to be noticed that the equilibrium attitude approach adopted has been developed specifically for AAMV configurations, and it takes into account at the same time the hydrostatic, hydrodynamic and aerodynamic forces to calculate the attitude. It is based on the long-form Savitsky method (Doctors 1985), modified to take into account the influence of the aerodynamic lift, drag and moment generated by the aerodynamic surfaces. Since they are operating in ground effect, the effect of the distance from the ground (as well as the angle of attack) is considered in evaluating the aerodynamic forces (Collu 2008).

Then, based on the power and propulsion system type (e.g. Turboprop), it is possible to choose from a database of existing power and propulsion system the most suitable one.

At this point it is possible to perform the scantling design of the structure of the hull/s and wing/s, as illustrated in details in the next sections.

The previously mentioned steps are repeated iteratively, until the convergence criteria based on the total estimated mass is satisfied.

3.2 Hull structural scantling

Various approaches were applied to obtain the hull/s scantlings of the vehicle.

3.2.1 HSC approach

The definition of High Speed Marine Vehicles is found in the HSC Code adopted by IMO (BV et al. 2002) as: *"High-speed craft" is a craft capable of maximum speed, in metres per second (m/s), equal to or exceeding:* $3.7\cdot\nabla^{0.1667}$*, where* ∇ *is the volume of displacement corresponding to the design waterline (*m^3*), excluding craft the hull of which is supported completely clear above the water surface in non-displacement mode by aerodynamic forces generated by ground effect.*

Such a definition is not entirely applicable to a WIGe vehicle neither to an AAMV. However, it constitutes a reference for the naval architecture performances of these vehicles.

In order to obtain a preliminary scantling design of the AAMV hull structure, the HSC Code was then applied. Actually, WIGe guidelines were issued by IMO (MSC/Circ.1054) but no prescriptive provisions are reported as far as scantling design is concerned. Rather, the HSC Code provides useful parametric formulations, suitable to obtain a preliminary scantling design of the hull structures and allowing estimating the hull weight and its distribution.

Scantling checks are based on first principles, and formulations can be easily adapted/modified as deemed necessary. Basically, hull plating and stiffeners were verified adopting prescriptive formulations reported in HSC Code.

Hull motions and loads are defined as per HSC Code. Static, dynamic and impulsive loads are considered. Even if WIGe specific loads like e.g.

landing impact are not defined, in lieu slamming loads are considered sufficient for the intended aim.

In order to explore the design space of the structural design, the ordinary frame spacing was initially selected according to the RINA Rules for pleasure crafts: $s_r = 1.2 * (0.35 + 0.005 * L)$ where s_r is the ordinary frame spacing and L the hull length.

A Matlab™ routine was developed based on the HSC rules. The main data needed to start the calculations with the HSC approach are:

- Main dimensions of the vehicle (Length, Beam, Draft, Displacement etc…)
- Service type (Passenger/Ferry/Cargo, Supply, Pilot/Patrol, Rescue as per applied rules)
- Environmental conditions (sea state)
- Construction material

The main outputs are:

- Structure system total weight
- Structure system centre of gravity position

A database of stiffeners, usually used for standard constructions, was implemented in the code, the drawback of using this database is that the estimated structure could be heavier compared with the one designed that makes use of bespoke members. To tackle this heavier weight coming from the use of the above database, an optimization based on the stiffeners spacing was implemented in the code. The stiffeners' spacing is changed within an interval of ±20% of the reference spacing given by the RINA Rules and the spacing resulting in the lightest hull structure is then selected.

In order to take into account for the use of composite materials, useful advices were found in some researches for marine vehicles. In particular, information were found in the report published by the LASS project (www.s-lass.com) about the influence of lightweight design using both composite and aluminium materials. Among other studies, a ship similar to the current AAMV configuration (in terms of main dimensions and type of service) is studied. At the end of this study, the lightest composite configuration achieved a 52% lower structural weight for the hull, if compared with the aluminium configuration version. This is the result of not only the reduction of structural material amount, but also of the consequent reduction in required power.

(Goubalt & Mayes 1996) investigate the benefits of composite constructions using as a baseline a 55m long steel patrol craft. This ship is similar to AAMV from an operative point of view (rough operative environments are expected along the ship's life) but it is not similar with regard to its main dimensions. The main conclusion is that using composite materials for this ship concept could allow a saving from 30% to 40% of the weight for primary structures.

The AAMV scantling tool performs the design of the structures assuming that a metallic alloy is used (aluminium or steel), for which the Matlab™ code has been properly developed and validated. Then, depending on the selected composite material, the total structural weight is reduced by a certain percentage depending on composite reinforcement type (glass or carbon fiber).

3.2.2 Flying Boat Fuselage approach

Another approach to estimate the hull structural weight was implemented, based on the approach derived by (Roskam 1989). Empirical regressions allow an easy and quick way to have an estimate of the weight of the different systems of an airplane, depending on the type of aircraft.

In the present work, it has been assumed that the closest category of airplanes to the AAMV configuration analysed is the seaplanes one, and therefore adopting this approach it is assumed that for the AAMV configuration the structural weight of the hulls will be similar to the structural weight of the fuselage of a flying boat.

As previously mentioned, it is reasonable to think that the structure of the hulls of the AAMV configuration will be a little heavier than that of a seaplane, so this approach can give a lower limit for our weight estimation regarding the structural part.

3.3 *Wing structure*

Different approaches were followed also for the scantling design of the wing.

3.3.1 "Roskam" wing weight estimation approach

Similarly to the approach used for the hull/fuselage, (Roskam 1989) presents formulae to estimate the structural weight of the wing. It is worth remembering that the wing configuration considered for the luxury AAMV is quite uncommon (e.g. aspect ratio is close to one, sweep angle is zero), as well as the load distribution being quite different. Nonetheless, the values estimated using the Roskam approach are close to those derived by the direct approach illustrated in the following paragraph.

3.3.2 Direct wing weight estimation

With this approach the design of the structure is performed with a direct method, i.e. each structural member (plating, stiffeners, primary members) is verified depending on the loads acting on the wing.

The spars are designed taking into account the global transverse bending moment, while the other elements have been checked by direct calculations based on beam theory taking into account local loads. It is worth highlighting that no loads coming from water impact on the bottom of the wing were considered.

Averaging the weight obtained by the Roskam approach and the direct approach is considered a good compromise.

3.3.3 Wing Weight Estimate as a hull deck

This approach is based on the average hull deck structural weight per unit of area, and so it is available only if the HSC code approach was applied for the hull weight estimation. The deck weight per unit area is multiplied by the wing area to obtain the wing's structural weight estimation. As expected, this approach gives very high values as the deck is verified considering higher acting loads.

3.4 Two step validation: "core" MDD and structural module

Unfortunately, no data of already built vehicles are available for comparison purposes being WIGe design and construction a rather small niche.
Therefore, the design spiral in Figure 2 was initially developed to perform the MDD of a luxury yacht, in order to have a "core" of elements able to be validated against available data. This "core" MDD, later developed into the one represented in Figure 2, was benchmarked against 16 luxury motor yacht data (Sanlorenzo SL82, SL88, SL94, SL104, SL108, 40ALLOY, Azimut 60, 78, 95, 55S, Ferretti 500, 750, 870, 881, Westport PM85, W98) collected from the manufacturers website. In Table 1 are compared the (absolute) average error difference between the values obtained with the "core" MDD program and the values provided by the manufacturers. The parameters considered are: total weight, main dimensions (LOA, B, T), total cabin area, and total installed power.

Weight	Main dim	Area Tot	Power
20%	13%	12%	26%

Table 1. Comparison between the "core" MDD output and the manufacturers' data for the 16 luxury motor yacht considered

The error can be considered acceptable within the framework of a conceptual/preliminary design approach. Furthermore, the data collected are considered to be the most reliable source available, but the main aim of these websites is to advertise their products, and therefore the approximation of the data presented could be substantially high. Based on the experience of the authors who are familiar with the Italian motor yacht manufacturers, these figures can be approximated by up to 30%.
Again, due to the lack of real data for AAMV configurations, the alternative validation approach has been to verify/validate each of the MDD modules separately.

As regard the structural module, the validation has been performed against the software MarSpeed (developed by the BV) for the hull structure. Same configurations were taken into account using MarSpeed and the structural developed scantling routine based on HSC and direct calculations, and a good match was found, e.g. comparing minimum required plate thicknesses, and in turn the section weight per unit length. A brief summary of this comparison is given in Table 2.

		AAMV code	*Marspeed*
		Section at x=20 m	
DECK	*t [mm]*	*3*	*3*
SIDE	*t [mm]*	*9*	*9,5*
	t [mm]	*9*	*9*
	t [mm]	*8,5*	*9*
	t [mm]	*8*	*9*
	t [mm]	*7,5*	*8*
BOTTOM	*t [mm]*	*18,5*	*18,5*

Table 2 example AAMV code - MarSpeed validation

After this first basic validation, the code was further developed working out the scantling calculations for a series of transverse sections along the length of the hull and finally getting the longitudinal weight distribution as per the example in Figure 4.

It is worth noting that mainly local loads are considered in first approximation for such vehicle (being length about 24 meters), since longitudinal bending has less impact on the design, though transverse bending was taken into account in wing scantling design.

As usual, the longitudinal weight distribution assumes a prismatic shape of the hull in longitudinal direction, setting 20 equally spaced stations subdivision by default. However, the code user may set a finer subdivision of the hull length, even aft and fore only, where aft and bow shapes need a more accurate description of the weight distribution.

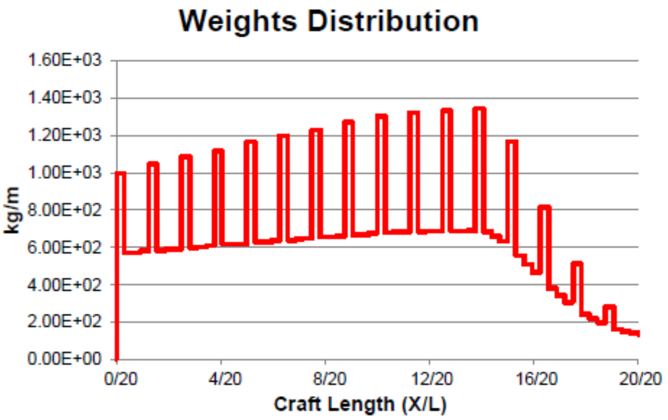

Figure 4. Example of longitudinal weight distribution

Concerning the validation of the wing scantling, a flexible way to validate the implemented code based on direct calculations was not found mainly because of the unusual configuration of this structure. It is worth to remember that the wing shows an aspect ratio close to one and a zero sweep angle.

The real structure will not probably behave as a cantilever beam as assumed in the check calculations and the limit state condition would probably be the buckling. However, in this phase of design the cantilever scheme was accepted as one of the worst case conditions giving a relatively simple way to work out a weight estimate as results are in agreement with those of regressions and other methods, despite differences were not negligible.

4 CASE STUDY

4.1 Introduction

During the project a number of sensitivity analyses have been carried out in order to highlight the design driving parameters. Among these, a sensitivity analysis varying the hull material has been performed, taking as baseline configuration the one derived using as input the values in Table 3, and resulting in the baseline configuration illustrated in Table 4 after running the vehicle synthesis model.

4.2 Main results

In Figure 6 through Figure 8 the impact of changing the hull material on three main parameters are illustrated (total mass, wing span and total installed power).

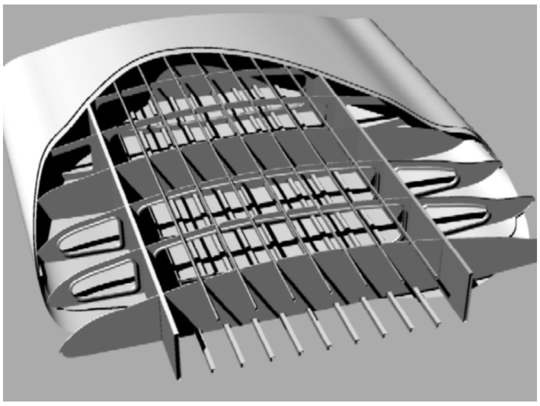

Figure 5. Wing scheme adopted for the direct scantling approach

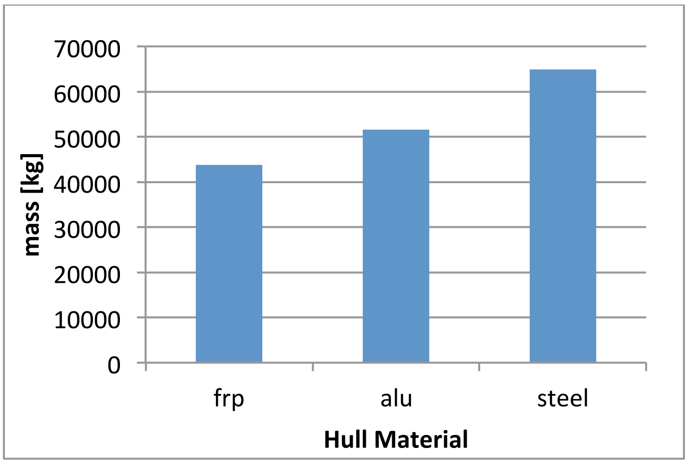

Figure 6. Total mass VS hull material, Fibre Reinforced Plastic (frp), aluminium (alu), and steel

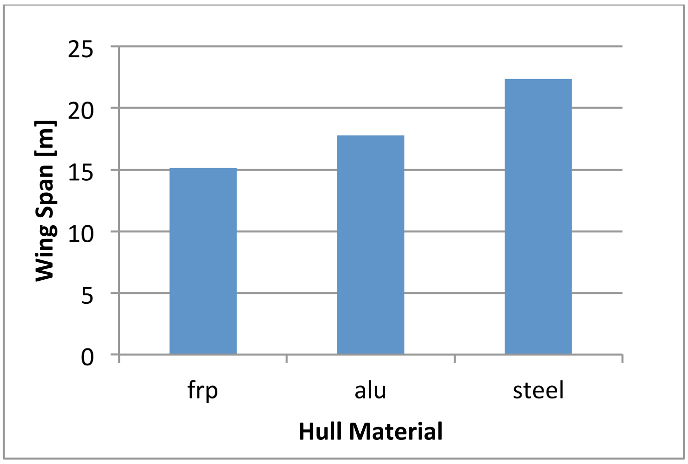

Figure 7. Wing span VS hull material

Input parameter	Value	u.m.
No of guests	8	\
Range @ cruise speed	800	nm
Cruise speed – waterborne	28.5	kt
Max speed – waterborne	32	kt
Take-off speed	60	kt
Cruise speed - airborne	100	kt
Luxury level (1-3, low to high)	3	\
Max take-off sea state	3	\
Type of service	Passenger-Ferry	
Sea area	Open Sea	\
Fuel reserve	10%	\

Propulsion system type	Turboprop
Hull main material	Alu
Wing main material	FRP

Table 3. Case study main input parameters

Inertial characteristics			
mass	51681	kg	Total mass
structure	35%	\	Structure mass %
L_{cg}	8.09	m	from transom
V_{cg}	1.72	m	from keel
Geometry: general			
L_{OA}	26.98	m	\
Width	24.08	m	\
Draft	0.82	m	At rest
Geometry: Hulls			
Number	2	\	\
Length	27	m	Hull LOA
Beam (single)	3.14	m	Hull beam (single)
Beam (tot)	24.08	m	Hull beam (total)
Height	3.00	m	\
Molded depth	1.89	m	\
Deadrise	14	deg	\
Geometry: Wings			
Number	1	\	\
Length	24.3	m	Mean aerodynamic chord (MAC)
Wing span	17.81	m	\
Profile	DHMTU	\	\
ETA	2	deg	Angle between keel and MAC
Power and Propulsion system			
Total power	3650	kW	Total installed power
Number of engines	1	\	\
Power per engine	3650	kW	Single engine power

Table 4. Case study, baseline configuration

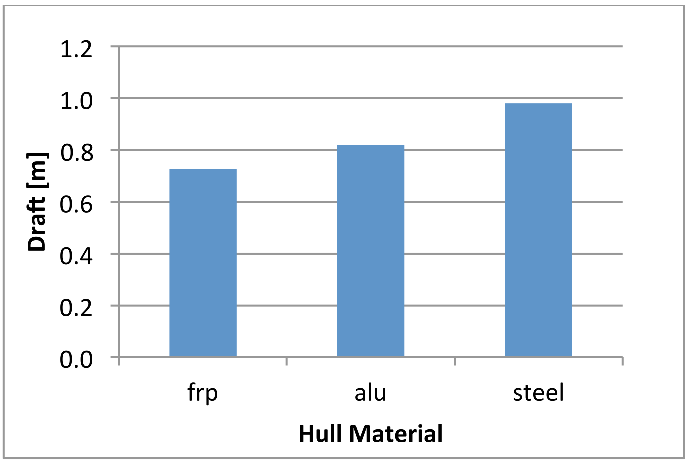

Figure 8. Draft VS hull material

4.3 Discussion

The baseline configuration initially has both the hull and the wing made of FRP. It is important to make some preliminary considerations about this material.

Usually FRP manufacturing processes are more expensive than those for aluminium and steel. FRP is suitable for mass production, because the cost of the required moulds can be spread over a number of vehicles. The FRP manufacturing process leads to a product with higher margins of uncertainty (its mechanical features depend greatly on the direction in which it is stressed), and because of that during the scantling process some safety margins have to be considered, leading to a heavier vehicle. Within the structural scantling code, it was not possible to take into account these aspects, and because of that the resulting weight calculation is less accurate with respect to the weight calculation for aluminium and steel.

The total mass of the vehicle (Figure 6) is strongly influenced by the choice of the hull material. The total mass using aluminium hulls is about 50t, i.e. 6t more than having hulls in FRP, while the total mass having steel hulls is approximately 65t, much higher than both FRP and aluminium. It has to be said that steel has been considered only for comparison and completeness, but in general this material is considered not suitable for an AAMV application.

As expected (Figure 7), a heavier configuration requires a larger wing area in order to generate the lift necessary with the same take-off speed. Since the length of the vehicle (and therefore the chord of the wing) does not change, the wing span passes from 15.1m using FRP, to 17.8m using aluminium, to 22.4m for the steel configuration. If a maximum AAMV width is imposed, then it can have a substantial impact on the choice of the material for the hulls.

Similarly to the wing span, also the draft of the vehicle (at rest) follows an expected trend. The draft for the steel configuration and the aluminium configuration is respectively 35% and 13% higher than the draft for the FRP configuration (0.73 m).

The hull material strongly affects the whole AAMV design. The best trade-off material seems to be aluminium, also considering its better performance against corrosion and its ability to withstand impact loads, which are supposed to be quite frequent especially during take-off and landing.

The results presented are well expected, and qualitatively it would have been possible to predict them without developing a dedicated spiral design approach. Nonetheless, the important contribution of the present method is that it allows conducting sensitivity analyses and estimating quantitatively the impact of each parameter on the overall design, step that would have not been possible without the development and implementation of the present approach.

5 CONCLUSIONS AND FUTURE WORK

A multidisciplinary design approach specific for AAMV configurations has been developed, based on a spiral design derived from the marine industry and modified to take into account the novel aspects of this concept. The approach has been developed and implemented in modular fashion, in order to allow the further development and refinement of each single module. In the present work the module to perform a preliminary scantling of the hull/s and wing/s is presented in more detail.

Starting from the scantling approaches developed for high speed marine vehicles, seaplanes and WIGee vehicles, several approaches have been developed and compared. This approach has been developed for the early phases of the design of an AAMV configuration, and therefore an approximated, but quick and robust approach was needed. The aim was not to accurately predict the wanted parameters, but to estimate them and to have a quantitative measure of the impact of different choices on the overall design, such as the sensitivity analysis presented in the case study.

For the case study, the best trade-off material seems to be aluminium, also considering its better performance against corrosion and its ability to withstand impact loads, which are supposed to be quite frequent especially during take-off and landing. Composites guarantee the lightest configuration, a desired characteristic due to the airborne phase of the chosen mission, but they are particularly susceptible to impact loads and need more detailed structural design to exploit their performances.

Further studies are needed in order to assess if through alternative solutions it would still be possible to use composites hull. If steel is chosen for the hull, it has a substantial impact on the total weight of the vehicle, to the point that, unless strictly required, it should not be considered as material of choice.

In conclusion, a vehicle synthesis model has been preliminary studied for the design of AAMVs, certainly worth to be further developed but still able to provide necessary advices to designers in order to understand the impact of basic design choices.

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