Advance Seaplane Concept Design and Operation based on 2050 Visionary Concepts for Future Aeronautical Transport

Alan Canamar
University of Glasgow
University Avenue, Glasgow G12 8QQ, United Kingdom
alancanamar@hotmail.com

Ladislav Smrcek
University of Glasgow
University Avenue, Glasgow G12 8QQ, United Kingdom
Ladislav.smrcek@gla.ac.uk

Aircraft design has been affected by the actual economical difficulties showing no radical progress in this field of study. The purpose of this paper is to explore more radical, environmentally efficient, and innovative technologies. An example of a 2050 Visionary Aeronautical Design Concept is the creation of an advance "out of the box" amphibian aircraft. The project analyzed technical solutions, and a conceptual design concept for the creation of this amphibian aircraft. The preliminary design development leads to the creation of an Advance Amphibian Blended Body Wing Aircraft (AABWBA). The use of an advance boat hull concept, in this case a trimaran, exceeded its water capabilities. AABWBA excels in air performance due to the high results generated by the Blended Wing Body (BWB) Aircraft. Adapting modern turbofan engines instead of turboprop engines gave the AABWBA better water takeoff capability, as well as air performance. A final solution was a retracting float system mounted inside the hull, reducing the aerodynamic drag noticeably. Modern ideas for 2050 vision are the creation of futuristic seaports in order to increase seaplane traffic, public and commercial awareness, and expand market schemes.

Keywords: Seaplanes, Trimaran, Amphibious Aircraft, Future Aeronautical Transport, Blended Wing Body Aircraft

1 Introduction

During the years of 1950 – 1980, the world was experiencing an exponential growth in technological advances due to the superpower rivalry between the United States and the Soviet Union. The aeronautical industry as well got caught in this expansion of technological exploration. The empirical guidelines during those days were: higher, further, and faster. In the late 1990's, this exponential growth reached it maximum peak. The world was experiencing economical problems, and certainly the aeronautical industry felt its effects. This "out of the box" thinking that emerged during the postwar era is restricted now to the same problems, money and social acceptance. Now, according to the European Vision 2020 guidelines [1], these have become: more affordable, safer, cleaner and quieter. The old empirical guidelines are now forgotten, restricting the researcher's mind to explore radical aeronautical designs.

In order to expand the designer's mind, a modern vision with more radical, environmentally efficient, and innovative technologies was created. The new vision is called Future Air Transport Concept Technologies for 2050 in which the new guidelines will be: safer, quieter, cleaner and efficient. An efficient concept will adopt the early guidelines (higher, further, and faster), with no restrictions in material, capital or infrastructure for planning, designing, testing, and constructing. The research addressed aspects such as new ideas in airborne vehicles, including design, new airport concepts as well as Air Traffic Management (ATM), alternative methods of air transport system operation and their integration with other transport modes. Let us recall this is just a radical way of thinking in order to expand the researcher's mind with no restrictions what so ever.

The purpose of this paper was to create an example of this 2050 visionary aircraft concept, in this case an advance amphibian aircraft. The advance amphibian aircraft was created from a **B**lended **W**ing **B**ody (**BWB**) aircraft and converted into an amphibian by adapting a modern water operation design (trimaran) creating an **A**dvance **A**mphibian **B**lended **W**ing **B**ody **A**ircraft (**AABWBA**). Improvements in water capabilities of the **AABWBA** are shown, as well as air performance. The conceptual design idea converted the **BWB** into the **AABWBA**, assuming the **BWB** has been design or constructed previously. The conversion will reduce the time and costs in construction, manufacturing, regulations, and certification.

2 Review of Literature

2.1 Trimaran

The design method of an amphibious aircraft implemented used a wide variety of methods in order to compare and maximize the desire results. Multihulls have become an alternative boat design for their speed, stability, large capacity and resistance to high waves. Moreover, the drag in case of multihulls is also dependent upon the wave interference between the hulls. Approximately, a 20% increase in drag is observed compared to hulls at infinite spacing [2]. A trimaran is a multihulled boat consisting of a main hull and a two smaller outrigger hulls, attached to the main hull with lateral struts, as shown in Fig. 1 [3].

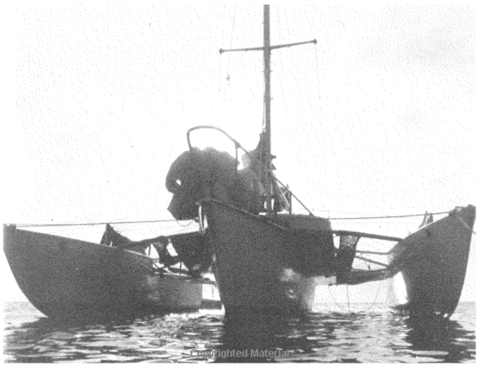

Fig. 1: Trimaran Example [3]

The trimaran possesses some advantages over other types of boat hull designs [4]:

- Low wave resistance at high speed due to its slender ship hulls.
- Superior stability attributable to suitable layout of the side floats. A trimaran can keep a high speed under high sea conditions.
- The wave interference between the main hull and the outriggers can produce a beneficial wave interference optimizing the speed and engine power required correlation
- In case of an emergency the all float structure remains floating even when the hull or the outriggers are severely damaged.

Trimarans are superior in terms of stability because the arrangement of the hulls is such that individual centers of buoyancies have a righting moment about the centre of gravity that helps in stabilizing the vessel. This gives the boat or in this case the seaplane, more roll stability, better water maneuverability, and better water performance at docking and even at high waves. Another important aspect to analyze is wave performance. Seaplanes must have the ability to perform in any weather and water conditions. When a wave passes through a conventional float, it reaches the bow producing a lift force which pushes the stern down; as the wave passes through the body of the float, the center of buoyancy changes along with the wave. When the wave reaches the stern, the lift force pushes the bow; at high speeds, during rough water conditions, a dangerous pitch effect could cause the bow to be submerged and capsize violently. For the outriggers, when the peak of the wave moves towards stern, the lack of buoyancy on this section to the shape, negates the lift force which produces the pitching effect, therefore the outriggers are capable to operate in a wider range of rough water conditions than the conventional floats. Past studies conducted on trimaran shows that wave resistance of trimarans is significantly lower compared to an equivalent catamaran [5]. For this instance, in theory, trimaran has superior seagoing performance.

2.2 Retractable Float System

A concern of using trimaran will be the exposed floats at flight. One solution is to retract the floats or either retracts them inside the fuselage or hull, which in theory will reduce aerodynamic drag.

Tigerfish Aviation developed the use of retractable pontoons called Retractable Amphibious Pontoon Technology (RAPT) [6]. Adapting the same concept idea, the floats will form a single component embodied to the hull and fuselage when retracted. This will reduce the drag form interference factor added by the floats and boat hull [7], hence decreasing the aerodynamic drag. However, retracting the floats into this position will not reduce entirely the aerodynamic drag caused by the floats. A final solution is to place the floats inside the boat hull, as shown in Fig. 2. The floats will be retracted inside the boat hull, the same way the landing gear is retracted inside the fuselage. The only drawback will be the added structural support required, compromising an increase in weight of the strutting.

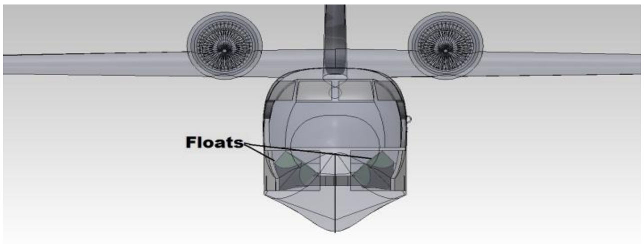

Fig. 2: Example CAD Model with Floats retracted inside Hull

Boat hull seaplanes experience issues with transverse stability. This is due sometimes to the fact that the metacenter is below the center of gravity [8], creating a lower metacentric height. The metacentric height is the measurement distance between the centre of gravity (G) of a vessel and its metacenter (M). A larger metacentric height implies greater stability against overturning [9]. Wing tip floats can counteract heel turn, keeping the vessel stable.

For this design, another advantage of the retracting float system was to keep the seaplane stable. The retracting system can be automated in order to control the seaplane on unexpected heel turns. If the seaplane tilts to a side, the automated retracting system will be configure to maintain a position in the water in which one float will move upwards towards the waterline while the other float will move downwards, maintaining both floats at the waterline. Fig. 3 shows the mechanism of the retracting system in the water.

Last, another advantage of the floats will be as an extra storage compartment. Since the floats do not account for the total displacement of the seaplane, extra fuel or payload could be stored inside the floats, increasing the performance of the seaplane.

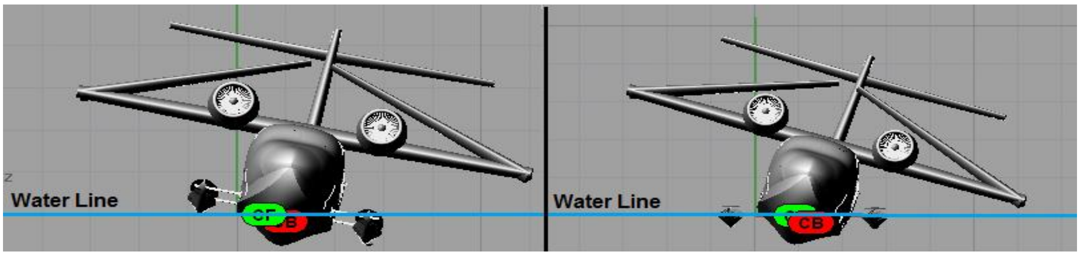

Fig. 3: Heel Overturn Retracting Float System

3 Results

In order to meet the desire results, a mission profile was first set in order to size an amphibian aircraft. The amphibian aircraft must have mid-range size, subsonic aircraft, with a capable payload of around 1,500 kg, a range of around 3000 km, and engines with Short Takeoff or Landing (STOL) capability. In result, the creation of the BWB is elaborated separately. A CAD (Computer Aided Design) Model and performance parameters are shown in Table 1 and Fig. 4.

Table 1: Blended Wing Body Parameters

Gross Weight [kg]	7,600
Empty Weight [kg]	4,600
Max Fuel [kg]	1,950
Fuselage Length [m]	13.7
Fuselage Diameter [m]	2.4
Wing Area [m^2]	39.09
Wing Span [m]	23.47
C_{Lmax}	1.3
Flat Plate Drag Area [m^2]	0.445
Max Speed [km/hr]	900
Thrust Available [N]	40,500

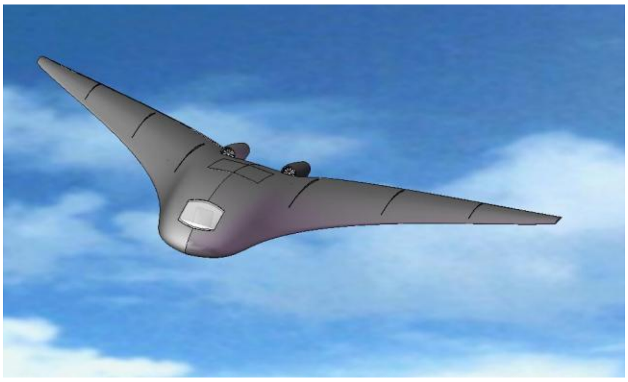

Fig. 4: Blended Wing Body Aircraft

3.1 Weight Breakdown

Using the initial Gross Weight (*GW*) of the aircraft, the weight of the boat hull and floats will be calculated using Langley's experimental testing. Calculation of Float Weight (W_f) was elaborated using a comparative curve of area and streamline form [10], in which the following equation was derived:

$$W_f = GW0.0365 + 43.5 \quad (1)$$

Langley calculates the weight of the boat hull (W_{bh}) based on statistics using materials from 1935; he calculated the weight of the boat hull is around 12% the total gross weight of the aircraft. This expression is shown as follows:

$$W_{bh} = GW * 12\% \quad (2)$$

With the introduction of new materials such as composites, the weight parameters of the floating device could be reduced. Most composite materials have a density of around 1.60 g/m^3, as compared to most aluminum alloys 2.8 g/m^3. Then, it can be assumed that the weight of the material can be reduced by 50%. The added weight of the boat hull and floats will increase the empty weight of the aircraft, reducing payload weight. The new empty weight of the seaplane *(EW_s)* is calculated as follows:

$$EW_s = EW_l + nW_f + W_{bh} \tag{3}$$

Where EW_l is the Empty Weight of the landplane and n is the number of floats or outriggers. The weight breakdown of the BWB and AABWBA are shown in Table 2.

Table 2: BWB and AABWBA Weight Breakdown

Weights [kg]	BWB	AABWBA
MTOW	7600	7600
Boat Hull	0	380
Floats	0	220
Empty Weight	4600	5200
Max Payload	1940	1940
Max Fuel	1480	1480
Fuel w/Max Payload	1060	460
Payload w/Max Fuel	1520	920

3.2 Trimaran Dimensions

The primary functions of any hull is to give the amphibious aircraft buoyancy, and to provide longitudinal and transverse stability on the water and when underway to takeoff speeds. It must also be designed in such a way so as to hold landing impact pressures to reasonable levels. All of these factors can drastically change the form of the hull.

In order to find the necessary calculations for the geometry of a boat hull, the fundamentals of Archimedes Principle must be understood. The volume (*V*) required for the seaplane to stay afloat on water will be calculated based on the displacement weight (Δ_0), as shown in eq. (4).

$$V = \frac{\Delta_0}{w} \tag{4}$$

Where (*w*) is the density of the fluid. Calculation of the total volume of the trimaran should take into account an extra 100% of the total displacement, which represents the "reserve of buoyancy" [11]. Based on the literature review, generally the beam is established as the design reference parameter of seaplane floats and hull [12]. The beam is the widest section of the float as shown in Fig. 5.

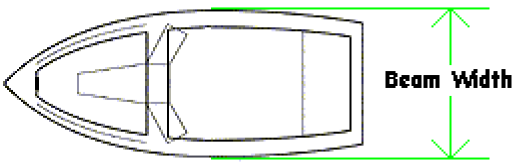

Fig. 5: Beam Width of a Conventional Boat [13]

From fluid dynamics, Tomaszewski came with an empirical formula on how to calculate the beam (*b*) of a hull based on a beam load coefficient (C_{Δ_0}) [12]:

$$b = \sqrt[3]{\frac{\Delta_0}{C_{\Delta_0} w}} \tag{5}$$

The length of the boat hull is calculated using eq. (6).

$$L = \frac{SLR\Delta_0}{b^2} \tag{6}$$

The length of the boat hull is then compared to the minimum fuselage length set by the designer. To calculate the height, simply multiply the beam times 0.65. The key characteristic connection between floats and boat hulls is the slenderness ratio of a trimaran (*SLR*) shown in eq. (7).

$$SLR = \frac{L}{b} \tag{7}$$

The slenderness ratio takes values depending upon the functional utility of the vessel in question. The standard values of slenderness ratio are shown in Fig. 6.

SLR	8-10: 1	For slow cruising vessels
	12-14: 1	For performance cruisers
	20: 1	For extreme racers

Fig. 6: Slenderness Ratio Values [13]

An important component of designing a hull or float is the forebody length. The size of the forebody represents compromising between flight requirements and seaworthiness at low speeds on water. If the length and the beam are too great, the structural weight and the aerodynamic drag limit the performance of the whole seaplane. On the other hand, if the length and the beam are too short, the spray characteristics become a limitation in gross weight and increase the hazards of operation in rough water [14]. The forebody length (l_f) in for a given beam load coefficient is [12]:

$$l_f = b\sqrt{\frac{C_{\Delta_0}}{k}} \tag{8}$$

From hydrodynamic point of view, the afterbody (l_a) assists getting over the hump and to provide buoyancy at rest. Relation between the forebody and afterbody length is shown in eq. (9 **)** [15]:

$$l_a = (110\%\ to\ 115\%) l_f \tag{9}$$

The total length (*L*) of the hull or float is as follows:

$$L = l_f + l_a \tag{10}$$

Rearranging eqs. (5) - (10 ***)***, and choosing 111% of forebody to afterbody length, the following formula for beam load coefficient was obtained:

$$C_{\Delta_0} = k\left(\frac{SLR}{2.11}\right)^2 \tag{11}$$

The only two unknown variables are spray coefficient (*k*) and slenderness ratio (*SLR*). Spray coefficient can be selected depending on the mission characteristics shown in Table 3.

Table 3: Spray Coefficient Factors

k = 0.0525	Very Light Spray
k = 0.0675	Satisfactory Spray
k = 0.0825	Heavy but acceptable Spray
k = 0.0975	Excessive Spray

Selecting the appropriate spray coefficient (*k*) and slenderness ratio (*SLR*), the beam of the hull (*b*) can be calculated from eq. (5). With the slenderness ratio (*SLR*) selected and the beam hull calculated, the total length of the boat hull (*L*) is calculated using eq. (7 **)**. The rest of the hull characteristics (Bow Height, Forebody deadrise angle, Step Height, etc.) are obtained with the beam hull value. In order to maximize the efficiency of the trimaran concept, the outriggers (floats) should be half the length of the main hull [13]. The same approach as the main hull will apply to calculate the characteristics of the outrigger.

The trimaran was sized using an iteration method by selecting the optimized *SLR* and *k* values desired to meet the necessary trimaran dimensions. The boat hull should not exceed in length and beam the dimensions of the BWB. Using eq. (5) – (11), the dimensions of the trimaran were obtained, shown in Table 4. With the parameters of the BWB and the trimaran, the AABWBA was constructed, shown in Fig. 7.

Table 4: Trimaran Dimensions

	Main Hull	**Outrigger**
Slenderness Ratio	5.24	14
Spray Coefficient	0.0975	0.08
Beam [m]	2.61	0.48
Length [m]	13.69	6.74
Forebody [m]	6.61	3.19
Afterbody [m]	7.07	3.55
Bow Height [m]	1.70	0.04
Y displacement [m]	-	2.35
X displacement [m]	-	-0.86

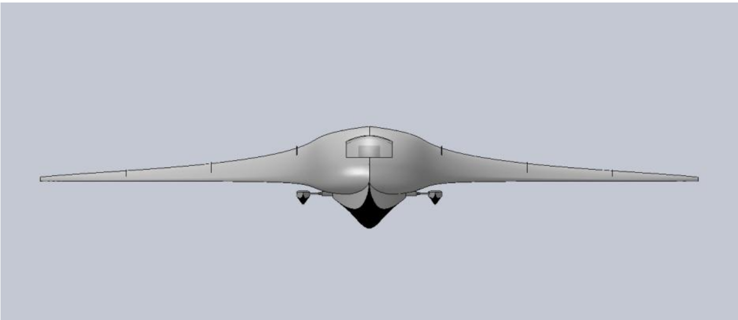

Fig. 7: CAD Model of AABWBA

3.3 Hydrostatic Stability

The AABWBA must excel in water performance. First the seaplane must have an excellent hydrostatic stability. As explained before, the metacentric height *(GM)* measures the static stability of a floating body. To calculate the metacentric height *(GM)*, the following expression is used [16]:

$$GM = BM - BG \quad (12)$$

Where *BM* is the distance between Center Buoyancy (*CB*) and the metacenter (*M*), and *BG* is the distance between the *CB* and the Center of Gravity (*CG*). The derived formula for the reduction in metacentric height (*BM*) on water is [9],[12]:

$$BM = \frac{I}{V} \quad (13)$$

where *(I)* is the Moment of Inertia of the vessel. Location of the *CG* and *CB* was elaborated with the aid of the SOLIDWORKS mass properties analysis. The metacentric height is an approximation of the vessel stability for small angle (0-15 degrees) of heel. Beyond that, the stability of the vessel is dominated by what is known as the righting moment (*RM*), eq. (14):

$$RM = \Delta_0 GM sin\theta \quad (14)$$

Using eqs. (12) – (14), the following image (Fig. 8) was elaborated showing the locations of the waterline, *CB*, *CG*, and *GM*. Since the *GM* is positive, the AABWBA shows it has a positive transverse stability.

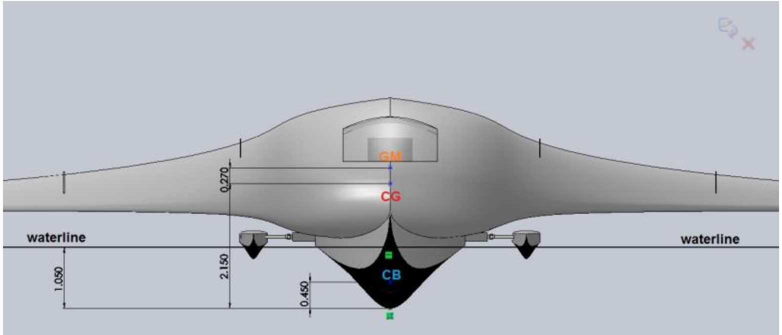

Fig. 8: Metacentric Height

3.4 Water Performance

The AABWBA must be able to takeoff from water, in which the thrust available must exceed the water resistance of the trimaran. Calculating water resistance (R_w) the following equation was used:

$$R_w = 0.5 C_{R_w} w A U^2 \quad (15)$$

where C_{R_w} is the coefficient of water resistance, *A* is the area of load water plane, and *U* is the velocity of the amphibian. The coefficient of water resistance is divided into wave coefficient and coefficient of viscous resistance. Wave coefficient is the resistance of water to the movement of the body across the formation of waves. Viscous resistance is the resistance caused by the friction between the fluid and the object, in this case the floating device, in which factors such as velocity, geometry, and dynamic viscosity are taken into account. Then using eq. (15) and plotting water resistance (R_w) as a function of velocity (*U*) the following graph was obtained.

The graph shows trend lines of drag, water resistance, thrust available of turboprop engine, turbojet, and turbofan engines as a function of velocity. Using the Static thrust available from the BWB of 40,500 N, the curves for turboprop, turbojet and turbofan engines were plotted using the following empirical formulas [17]:

TurboPROP

$$T_A = T_0 e^{(-0.0099U)} \quad (16)$$

TurboJET

$$T_A = T_0 \left[1 + \frac{\gamma - 1}{2} M^2\right]^{\gamma/(\gamma-1)} \left(1 - \sqrt{\vartheta} C M\right) \quad (17)$$

TurboFAN

$$T_A = T_0 \left[1 + \frac{\gamma - 1}{2} M^2\right]^{\gamma/(\gamma-1)} \left(1 - \sqrt{\vartheta} C M\right)\left(1 - (0.1 BPR M)\right) \quad (18)$$

where T_0 is the thrust available at zero velocity, *M* is Mach number, γ is the heat capacity of air (1.4), ϑ is the temperature ratio, $C = 0.28$ and *BPR* is the bypass ratio. The graph (Fig. 9) shows water resistance curve as it increases with velocity until it reaches a maximum point or hump. This peak is the point where the amphibian starts to separate from the water. Therefore the aircraft must be able to produce enough thrust in order to be able to takeoff from water, clearly shown that only a turbojet or a turbofan engines will reach takeoff. For simplicity, the AABWBA used two jet engines.

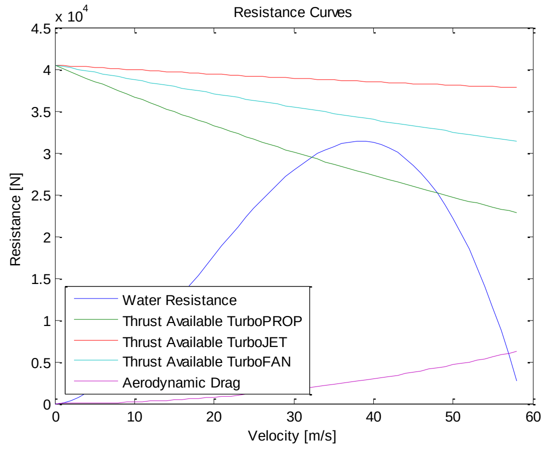

Fig. 9: Resistance Curves

3.5 Air Performance

With the geometry of the trimaran calculated, calculations of the drag increase will be approached by calculating the parasite drag. A useful measure of the parasite drag is the equivalent flat plate-drag area (*f*). Therefore, the total parasite drag (D_P) is [7], [18]:

$$D_P = \frac{1}{2}\rho U^2 f \quad (19)$$

(*f*) is a drag component buildup, and (ρ) is density of air. Each exterior component of the airplane is considered separately, and the total (*f*) of each component is finally sum together. The equivalent flat plate drag area can be computed from the following expression:

$$f_i = C_{f_i} F_i Q_i S_{wet_i} \quad (20)$$

Where (C_f) is coefficient of friction, (*F*) is form factor, (*Q*) is interference factor and (S_{wet}) is the wetted wing area. Using eqs.(19) - (20), the trimaran geometry from Table 4 and the aircraft inputs from Table 1, Table 5 was obtained.

Table 5: Flat Plate Drag Area Breakdown Component

Flat Plate Drag Area Breakdown [m^2]	Landplane	Seaplane [Extended]	Seaplane [Retracted]
Aircraft	0.445	0.445	0.445
Boat Hull	0.000	0.120	0.120
Floats	0.000	0.062	0.000
Strutting	0.000	0.009	0.002
Total	0.445	0.635	0.567
C_d	0.0114	0.0163	0.0145
C_d Increment	0	0.0049	0.0031
Drag Increase		**29.97%**	**21.57%**

Table 5 shows the total drag that the landplane, the seaplane with extended floats, and retracted floats at cruising speed of 900 km/hr and an altitude of 12,200 m. It is explained when an odd shape component is being calculated, an increase in drag form interference factor must be added to the actual value [7]. It is also explained: “The form factor is a measure of how “streamlined” the component is; it is a function of the component thickness-to-length ratio” [18]. In this case, the form interference factor (*F*) from eq. (20) of a flying boat hull must increase by a 50%, and for floats from 75%-300%, depending on the shape. It was then assumed that the interference factor for the boat hull had an increase of 10%, rather than 50% increased, due to the perfect aerodynamic shape mounted of the hull with respect to the fuselage. Retracting the floats shows a decrease of around 10% of the aerodynamic drag, which in theory will increase the performance of the aircraft.

With the drag increase calculated for the AABWBA, a comparison of the flight performance for both the BWB and the AABWBA was elaborated. First, an altitude flight envelope was created, showing the stall speed, maximum speed, and service ceiling of both the landplane and seaplane.

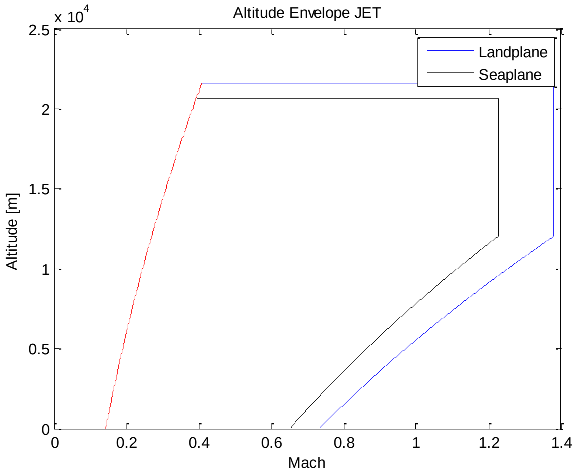

Fig. 10: Altitude Envelope of BWB and AABWBA

A tradeoff between payload and range of the aircraft can be illustrated in a payload-range diagram. There are 3 factors to consider in a payload-range diagram. The top horizontal line shows the maximum payload that the aircraft is structurally permitted to carry. The vertical line represents the total range of the aircraft. Finally, the diagonal line after the range at maximum payload point shows how reducing the payload allows increasing the fuel (and range) when taking off with the maximum take-off weight. This diagonal line represents the tradeoff between maximum fuel and maximum payload. Smaller this diagonal line is, the smaller the tradeoff, therefore obtaining more productivity weight between payload and fuel. In other words, if there is no, or very small diagonal line, maximum payload weight and maximum fuel will almost be of the same value that the aircraft will be able to carry.

Finally, Fig. 12 shows the maneuvering envelope for the AABWBA. The maximum positive load factor is 4.4 and the maximum negative load factor for dives is -1.76. These values are obtained from FAR 23 for a utility aircraft. Fig. 12 also shows the gust envelope. The gust speeds are obtained from Raymer [7] and the maximum gust speed is a function of altitude only. As can be seen from the figure, the gust loads do not exceed the maneuvering loads. This means that the aircraft will not need additional strengthening to withstand gust loads experienced in its flight envelope.

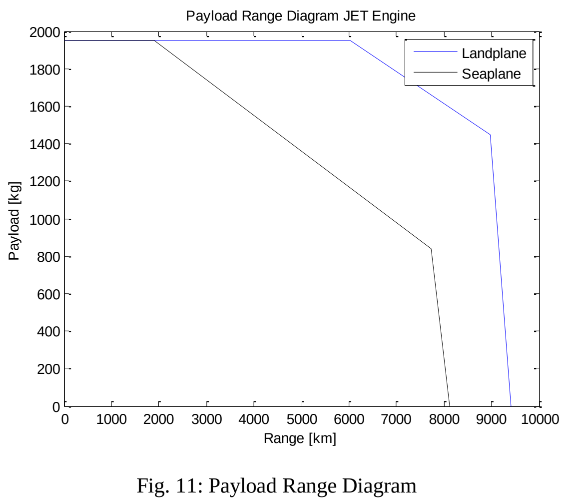

Fig. 11: Payload Range Diagram

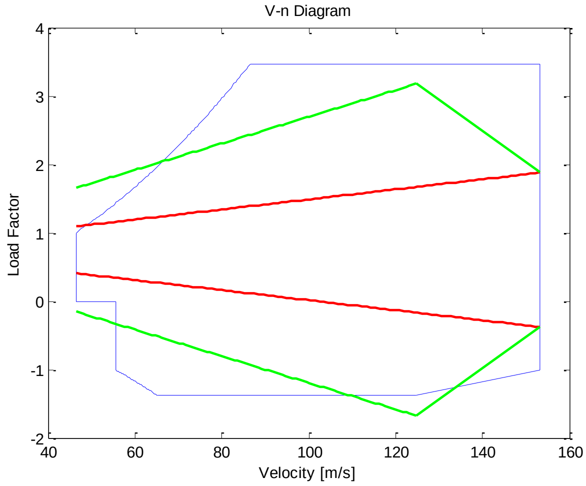

Fig. 12: Maneuvering and Gust Envelopes

4 Conclusions

The preliminary results show some of the advantages of using the trimaran concept into a seaplane design, and the increase in flight performance when the floats are retracted. The design excels in hydrostatic stability. The water performance that a trimaran shows is also significant, in which water resistance is less compared when using other floating aid devices such as wing tip floats or stabilizers.

For the flight performance, mounting the floats inside the hull decreases significantly the drag as compared to an extended position. The aim was to keep most of the AABWBA performance as closed to BWB performance. With the aid of the retracting system, and reducing weight using composite materials, this goal was possible, in which an overall reduction in flight performance of around 10% was observed from the BWB and AABWBA design. Table 6 summarizes the BWB and AABWBA comparison values.

Another analysis made through this research is increment seaplane traffic. Suitable infrastructure (seaports) could be constructed in order to increase seaplane market and operations. The advance amphibian aircraft gets a futuristic design that will attract the attention of investors, and will get a high social acceptance.

As a result, with the aid of Computer Aided Design (CAD) software, SOLIDWORKS, models of this futuristic seaplane traffic model was elaborated shown in Fig. 13 and Fig. 14.

Table 6: Summary of major design values

Parameters	***BWB***	***AABWBA***
Gross Weight [kg]	7,600	7,600
Empty Weight [kg]	4,600	5,200
Max Speed [km/hr]	900	800
Rate of Climb [m/s]	18.15	17.4
Absolute Ceiling [km]	21,578	20,681
Endurance [hr]	10.54	10.23
Maximum Range [km]	8,970	7,731
Thrust [N]	40,500	40,500

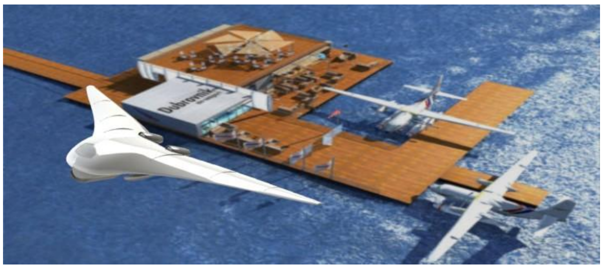

Fig. 13: AABWBA at takeoff from seaport

Fig. 14: AABWBA taxing at seaport

Acknowledgment

I want to give a special thanks to my supervisor, Dr. Ladislav Smrcek, for all his collaboration, support, and help throughout this project. Also a special gratitude to the University of Glasgow for the support on equipment and facilities provided in order to conduct this MSc Research Project.

I would also like to thank Dr. Gerardo Aragon for his support and guidance in the elaboration of the optimization sizing code.

Last, thanks to all of my friends and family that gave me advice, guidance, support, and company during this research project.

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