Engineering & Technology Research, Vol. 1 No. 1 (2017) p. 10-15

A Review on Hull Design for Amphibian Aircraft

Kamarul, A.M.,*[1], Xu, Y.,[2], Lewis, A.,[3], Tiu, W.[4]

*[1,2,3,4] School of Engineering and Technology, University of Hertfordshire
College Lane Hatfield, Hertfordshire AL10 9AB, United Kingdom
*[1]Universiti Teknikal Malaysia Melaka,
Hang Tuah Jaya, 76100, Durian Tunggal, Melaka, Malaysia

Abstract: One of the main problems with landing on water is the lack of visual cues to help the pilot with the glide slope. This frequently results in situations where the vertical sink velocity is relatively high by the time the aircraft makes contact. Unlike conventional land based aircraft, an amphibian aircraft does not have hydraulic systems to absorb this impact energy. The hull structure therefore has to be designed to withstand this loading impact without any damage. This is especially so since amphibian aircraft are increasingly being manufactured using composite materials where repair costs can be significant. The project aims to developing a new hull structure with an improved impact resistance. LS-DYNA is used to investigate the structural interaction of the hull with water. The result will be used as guidance for design optimisation. A final hull design will be developed and the performance of the optimised design will be tested through simulation. The project would involve physical testing of industrial composites used in aircraft industry and simulate the impact during landing to determine the failure and its structural integrity. This would provide critical information on the optimum operating condition during landing of an amphibian aircraft.

Keywords: Hull Design; Amphibian Aircraft; Landing; Impact Loading; Composite; LS-DYNA; Optimization.

1. Introduction

Looking at the history, developments of amphibian aircraft can be tracked through the vision of the military advancement of countries, which involves directly in World War One and World War Two. The first category of an amphibian aircraft is the floatplane, which was fitted with pontoon-style floats. Since amphibian aircraft were an aircraft designed to take off and land on the surface of the water these pontoon were attached in place of a conventional landing gear with wheels [1].

The other category of amphibian aircraft is the one with modified lower part of the fuselage copying the shape somewhat like a boat hull, which could float on the surface of water during rest or low speed. This is how the term ‘flying boat’ arises [2]. Both classes of amphibian aircraft, which were flourished in the world war years then, were transformed to become the large elegant flying boats used for intercontinental air services. The capabilities of amphibian aircraft which combine the speed and range are an advantage compared to conventional aircraft due to their ability to land and takeoff on open water. They also have the ability to operate without a hard surface runway and additional safety for overwater operations. Categories of amphibian aircraft are shown clearly in Fig.1 and Fig. 2.

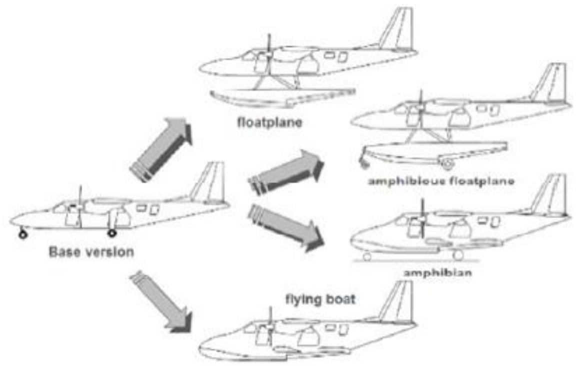

Fig.1 Modifications of twin engine land-based aircraft [3].

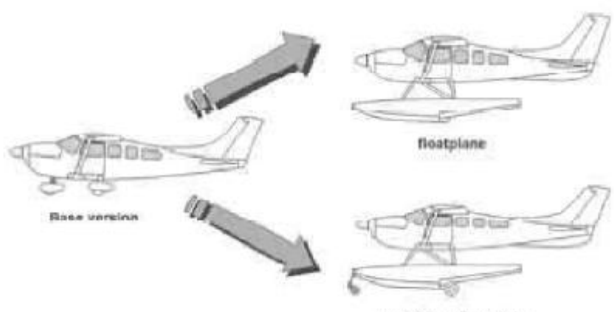

Fig. 2 Modifications of single engine land-based aircraft [3].

Mainly, amphibian aircraft is said to be more complex than a normal land plane since its dual working environment. Considering water landing, the aircraft should be watertight and could withstand the added stress of water impact during landing. The propeller area should

*Corresponding author: kamarulamir@utem.edu.my

ocs.uthm.edu.my/uthmocr/index.php/etputhm

be covered or protected against imminent water spray. Furthermore, it should accommodate safe method for boarding during water and land operation [4]. Preferably, the amphibian aircraft should be crafted to maximize the usage of normal boat docking which would prevent any needs on other specially designed boarding/docking facilities. In addition, it should not reduce the aerodynamic characteristic and performance of its counterpart with comparatively similar sizing.

Since the state of the water surface is always different, it is important for designers to know and understand the effect this conditions. This would provide better appreciation and safety during water contact. Since this research is a progressive dynamic loading which accommodates amphibian aircraft condition during and after water impact, this characteristic will also be studied. Firstly, the water as fluid tries to balance and find a levelling point. In zero or minimal disturbance condition, the water would lie flat and glassy. However, if it is disturbed by the forces of winds, undercurrents, and objects traveling on the surface, it will create waves or movement. In addition, because of its weight, water can exert a powerful force. This will produce significant drag forces as the water flows around or under the object which is moving through or on its surface. As the speed of a moving object on the surface of water doubled, then the forces acting on the object will be exerted approximately at a factor of four. This is caused by the force of water acting along the entire hull or float aircraft with central pressure which constantly changing and is dependent on the pitch attitude, dynamic hull or floats movement and wave action [5].

Second, the balancing through lower hull drag, at a given deadrise angle of a concave (or flared) hull, and desirable spray characteristics (which favour lower dead rise angles) will reduce landing load impact (which decreases with increasing deadrise angle) [6]. This is therefore could be achieved by using composites for float or hull construction which will give an advantage for such hull types compared to aluminium. In addition, corrosion may also be avoided by using fibre material for the basic structure [7, 8], a thin coating and overcoat with waterproof wax [9, 10] and washed / removed (i.e. using an ammonia ammonium sulphate butter at pH 9.6 in aerated deionized water [11]. Despite corrosion issues on composite floats, impact is the other things that need to be considered.

Since water forces would create very high impact loads and lead to progressive cumulative damage which causes surface cracks, abrasions, or signs of delamination [12]. Impact during landing would also affect the spreader bars between the floats, the bracing wires and their fittings. Furthermore, the signs of movement such as loose fasteners, broken welds, or a bracing wire that is noticeably tighter or looser than the others would occur [12].

In the aspect of design configuration, it is crucial to find a drag-minimized envelope on any intended usage of amphibian aircraft during design stage. The moment gradient of the envelope plays an important role for the total drag. It is a necessity since the drag-minimized shape with the centre of buoyancy within a specified range and a favourable hull surface to volume ratio in order to minimize the hull mass [13] and this would significantly reduce the impact force [14].

Furthermore, considerations should be taken on the aircraft landing procedure and speed. Normally, amphibian aircraft were designed essentially for cruising purposes. However, considerations on aerodynamic aspect should also be considered. It should be enough for high lift-to-drag ratio. Meanwhile, during water approach the aircraft touches down with main gear. This promotes downward rotation and reverse thrust is needed for the aircraft to stop. The landing procedures would only end when the aircraft comes to rest. The touchdown speed needs to be greater than the stall speed. In addition, the aircraft also tend to rotate on velocity vector which parallel to the water [15].

However, since the amphibian aircraft porpoising stability is severe, according to Tomaszewski [16], therefore it is necessary to design for much deeper steps for the shape of the floats based on flying-boat hull design. The strengthening of afterbody would improve stability. In the design of a float for good porpoising stability and seaworthiness it is convenient to consider three conditions on the water first is at rest or at low speed (the displacement region), second is during transition from displacement to planing flow (the hump region) and the last is planing on the forebody (the planing region).

This three different water condition depends entirely to the geometry of forebody, afterbody, step and location of floats relative to the amphibian aircraft [17]. Therefore, the absorber design should also consider all the criteria explained in order to achieve optimized design which could resist impact on various operating condition. This is based on the existing designs of floats and hulls for a given static beam loading coefficient, the geometry of the required floats in terms of the beam which floats relatively of the amphibian aircraft.

2. Landing On Water

The primary problem in designing an amphibious aircraft is the large performance penalty incurred due to the adaptation of the airplane to water operations. In fact, in any water operations features, such as floats, a hydrofoil, or a boat-hull and sponsons as depicted in Fig.3, will negatively impact the aerodynamic characteristics of the aircraft. On such, the issues are not only pertinent to aerodynamic problems, but also stability issues that caused by loading due to wave slap. Besides, there will be problems with landing and taking off from anything other than a very calm water state of sea, lake or river.

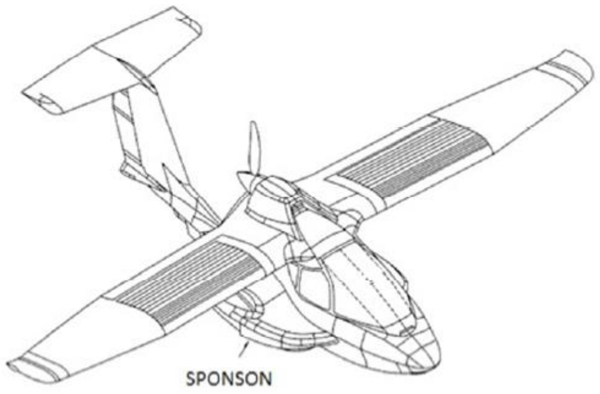

Fig. 3 Sponson on an amphibian aircraft [18]

Even though the reliability issue on rough water services is important, there is limited evidence or study existed for open seawater operation. This includes sea conditions and on surface operating behaviour [19]. Some trials performed with certain condition and criteria's of sea swell but there is limited quantified evidence of water performance data available [19].

Furthermore, these trials were meant only for specific type of aircraft and the focuses were only on take-off and landing performance of the aircraft itself. The result shows in Fig.4 about 90% of all waves are in sea state 4 or lower (i.e. Below 8 ft. in height), while sea state 5 encompasses about 95% of all waves likely to be encountered. Therefore, the aim for amphibian aircraft to have full operational capability in sea state 4, with limited operation in sea state 5 as it is reflected in the amphibian aircraft design notion.

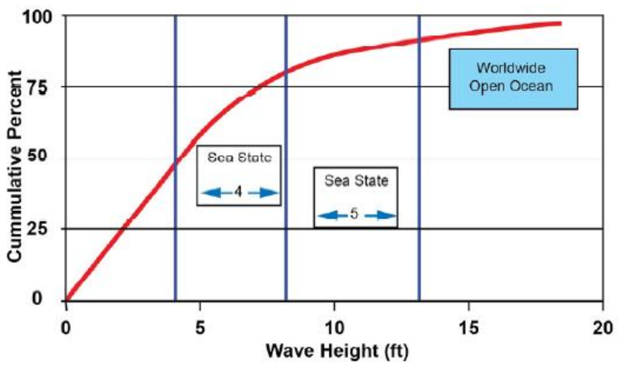

Fig. 4 Amphibian aircraft rough water operation [19].

For example, a research was carried to examine the factors of take-off resistance comparatively during take-off in calm seas and rough seas [20]. In calm seas, an amphibian aircraft could operate at trim conditions (aircraft elevation of nose-up or nose-down) that give a maximum lift-to-drag ratio. On the contrary, lift-to-drag ratio is reduced while having significant waves. This is due to the uncontrollable heaving and pitching of the aircraft in water. The water would increase the resistance of an aircraft and will decrease the take-off performance. This would also be true in landing situation since the aircraft need to cruise until it comes to rest [15].

The major constraint for sea condition take-off and landing are the drag will increase due to the larger wetted length to beam ratio and also spray may become more prevalent which can lead to wetted control surfaces that would be dry under nominal conditions. Water condition does play a major role in determining the landing impact characteristic of amphibian aircraft. Therefore, since 1940, minimum standards of water landing areas were published by US Department of Commerce.

Furthermore, water could cause an impact load on the hull structure due to the force exerted on the hull. These forces are related to the rate of growth of the waterplane area. On this, the development of impact theory has been a main focus in amphibian aircraft engineering since the late 1920's and later promotes slamming theory on planing hulls. Even in the early days, studies were made in areas such as conservation of momentum imparted from the amphibian aircraft to associated water mass of the hull [21]. There were also studies regarding transverse pressure distributions and wave rise during impact [22, 23]. Such studies provide vital information and set baseline for other impact on water theories. Fig. 5 shows the variation of peak pressure coefficient according to those studies.

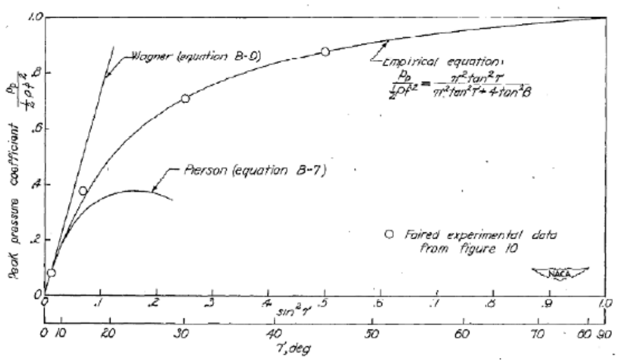

Fig. 5 Variation of peak pressure coefficient [23]

Early impact theories assumed that the momentum of the amphibian aircraft imparted to the virtual mass would remain constant. However, this is only true in the case of vertical drop where the velocity parallel to the keel is zero. For typical oblique amphibian aircraft landings depicted in Fig. 6, momentum of the amphibian aircraft is not only imparted to the virtual mass of the water connected or associated with the impact area of the hull but also to the downwash as the water slides off the step or the rear of the plane.

The cross section at the step determines the momentum imparted to the downwash, whereas the forward cross sections have more effect on the virtual mass. Thus, applying equations that solely consider the vertical velocity during impact and not the resultant velocity of both vertical and horizontal velocities like in oblique landing, neglect the momentum imparted to the downwash [27].

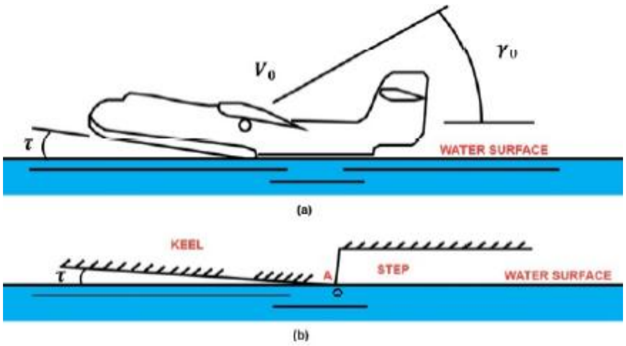

Fig. 6 Typical oblique amphibian aircraft landing [24].

3. Hull Design

The hull structure of amphibian aircraft has to be designed to withstand the loading without any damage while landing. This is especially true since amphibians aircraft are increasingly being manufactured using composite materials in which the repair and maintenance cost are significantly high. Therefore, theory of the early impacts that assume the momentum of seaplane imparted to the virtual mass remain constant will be used. This theory is only true in the case of vertical drop where the velocity parallel to the keel is zero. While for typical of oblique seaplane landings, the momentum of the amphibian aircraft is not only imparted to the virtual mass of the water connected or associated with the impact area of the hull, but also to the downwash as the water passes off the step or the rear of the plane. Several effects of impact load will be determined as such:

a. Severe structural damage can be done to the plating and framing of the fuselage if the loads are not estimated appropriately. According to Faltinsen [25], since hydroelasticity is ignored in most amphibian aircraft's impact theories (which is assumed as a rigid body), then the average pressure is important to the structural response where the cross sections have more effect on the virtual mass.
b. The effect of free water surface wave rise during penetration of impact is necessary to be measured in which the chines may immerse before maximum acceleration occurs. In this case, the acceleration would be less than if the chines had not been immersed. Therefore, an estimate for the rule of chine immersion for length-to-beam ratio hulls, the maximum acceleration, and maximum penetration or draft occurs without chine immersion with normal loading need to be known [26].

4. Recent Interest In Amphibian Aircraft

The fact that 75% of the earth's surface is covered in water provides the opportunity for amphibian aircraft to gain access even to the most remote parts of the world. In most of these remote places, there are no developed runways, but only vast expanses of sea, lakes, and waterways. This offers extremely long natural runway with variations related to the wind blow. In addition, the increase of tourism and the way people tend to travel into natural sanctuary explains the attention on amphibian aircrafts. Gobbi *et al.* [28] mentioned in their report that the number of tourist involves in nature is increasing day by day. Tourists are now focusing on the natural attraction of an area. Amphibian aircrafts were required in terms of society's needs on alternative transportation due to its characteristics as follows:

a. Highly versatile mode of transportation.
b. Point to point connections.
c. Sightseeing tours/tourism. Amphibian aircrafts still hold a considerable novelty value amongst most of the population and therefore will attract tourists and other adventurous types of tourist who want to experience something different and willing to pay more to experience it.
d. No need for runway infrastructures, "unprepared" landing strip, smaller landing fees than landplanes.
e. More access of the earth's surface area than a conventional land plane which is 40% (flying boats) and 70% (amphibian plane). This suggests on usage such as a using the aircraft as fishing boat (recreational) while on water.

This is the reason why amphibian aircrafts were placed on an important and permanent position in the aeronautical perspective.

5. Review Summary

This study would provide an interesting result since the water impact is challenging due to water characteristic itself and also the uncertainties of composite laminate behaviour under progressive failure condition. All of this information would be gathered to provide sufficient information on optimum operating condition of an amphibian aircraft during landing on water. The methodology of using experimental result as a verification tool for the simulation would enhance the understanding towards composite progressive failure. It would also validate the simulation result. Further understanding of composite failure would be crucial. In addition, laminae characteristic and its modelling in LS-DYNA should be one of the priorities for this project. Furthermore, landing angle and initial velocity of amphibian aircraft on particular model type should be studied extensively. In order to fulfil this research, data such as drop test values, material properties and aircraft model should be obtained from the industry. This would provide necessary information on conducting experiment and final simulation. Several aspect of mesh refinement should be done to evaluate and optimized resources in the material.

Acknowledgement

The author would like to acknowledge Universiti Teknikal Malaysia Melaka, Malaysia, Ministry of Education, Malaysia and University Of Hertfordshire, United Kingdom as the sponsors for this study. The author would also acknowledge Equator Aircraft Norway for their full support.

References

[1] Global, S., Seaplanes. Retrieved February 10 2013 from http://www.globalsecurity.org/military/

[2] Loftin, L.K. (1985). Quest For Performance: The Evolution Of Modern Aircraft. Scientific and Technical Information Branch, National Aeronautics and Space Administration, USA.

[3] Majka, A. (2012). The Problem Of Choice Of Light Passenger Seaplane Used For Short-Haul Flights. *Journal of KONES Powertrain and Transport*. 19 (4).

[4] Lohse, J.R., Hutton, J.G. (2000). *Amphibious Aircraft*.

[5] Dauntless, Water Characteristics. Retrieved March 10 2013 from http://www.dauntless-soft.com/ PRODUCTS/Freebies/Library/books/FLT/Chapter15/WaterCharacteristics.htm.

[6] Willford, N. (2006). Seaplane: Design Consideration. *EAA AirVenture Oshkosh 2006 Forums*.

[7] Yuhazri, M.Y., Phongsakorn, P.T., Sihombing, H., A comparison process between vacuum infusion & hand lay-up method toward composite, Int. J. of Basic & Applied Sc. 10 (2010) 63-66.

[8] Said, M.R., Yuhazri, M.Y., Lau, T.W.S., The finite element analysis on hexagonal ring under simple lateral loading, Global Engineers and Technologists Review. 2 (2012)1-7.

[9] FAA (2008). Aircraft Cleaning and Corrosion Control. In: *Aviation Maintenance Technician Handbook – General*.

[10] Yuhazri, M.Y., Jeefferie, A.R., Haeryip Sihambing, Nooririnah, O. Warikh, A.R., Coating effect condition on the corrosion properties of mild steel substrate. Int. J. of Applied Science and Technology, 1 (2011) 45-49.

[11] MacLeod, l.D. (1983). Stabilization of corroded aluminium: the bertram seaplane float. Retrieved May 12 2013 from http://www.museum.wa.gov.au/ maritime-chaeology-web/mcleod.doc.

[12] Service, F.S., (2004). Seaplane, Skiplane and Float/Ski Equipped Helicopter Operation Handbook.

[13] Lutz, T., Wagner, S., (1997). Drag Reduction And Shape Optimization Of Airship Bodies.

[14] Livephysics, Solve Problem Related To Impact Force From Falling Object. Retrieved February 4 2013 from http://www.livephysics.com/tools/mechanics-tools/solve-problem-relatedimpact-force-falling-object/.

[15] Hull, D.G., (2007). Fundamentals Of Airplane Flight Mechanics. Springer Berlin Heidelberg.

[16] Tomaszewski, K.M. (1950) Hydrodynamic Design of Seaplane Floats. (2154).

[17] Smith, A.G., Allen, J.E., (1954). Water and Air performance of Seaplane Hulls as Affected by Fairing and Fineness Ratio. (No. 2896).

[18] Karkow, J., Hawkins, K., Gionta, M., Strand, S., (2012). *Wing tip And Sponson Interaction On An Amphibious Aircraft*.

[19] Jessaji Odedra & Kennell, C., (2004). Use of Seaplanes and Integration within a Sea Base.

[20] Mottard, E.J., (1959). A Brief Investigation of the Effect of Waves on the Take-off Resistance of a Seaplane.

[21] von Karman, T., (1929). The Impact On Seaplane Floats During Landing. (321).

[22] Wagner, H., (1932). Phenomena Associated With Impacts And Sliding On Liquid Surfaces.

[23] Smiley, R.F. (1950). A Study of Water Pressure Distributions During Landings With Special Reference to a Prismatic Model Having a Heavy Beam Loading and a 30 deg Angle of Dead Rise.

[24] Crewe, P.R. (1954) A Proposed Theory to Cover Water Impacts of Seaplanes in which the Craft Has Constant Attitude and a Tangential-to-Keel Velocity Relative to the Water.

[25] Faltinsen, O.M. (2005) Hydrodynamics Of High-Speed Marine Vehicles. Cambridge University Press.

[26] Crewe, P.R. & Gerry, D. (1977) Proposal C-Seaplane Design Problems. (Contract No. N68171-77-C- 8345).

[27] Mayo, W.L. (1945) Analysis And Modification Of Theory For Impact Of Seaplanes On Water. National Advisory Committee for Aeronautics.

[28] Gobbi, G., Smrcek, L., Galbraith, R., Mohr, B., (2011). Report On Current Strength And Weaknesses Of Existing Seaplane/Amphibian Transport System As Well As Future Opportunities.