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Design and Analysis of a Conceptual WIG Craft

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Abstract: *Crafts flying close to the ground benefit from the enhanced efficiency due to decreased induced drag and increased lift from ground effect. The Wig Craft has a speed advantage and efficiency over conventional marine ships and aircrafts. This led us to the idea of using a novel design concept in Wig Craft for various applications. This design concept is an integration of Blended Wing Body configuration and a Box Wing Body Platform. The model was created by exploiting the novel design and the analysis was successfully carried out. Wherein we strived to increase the meshing quality which was then continuously refined in the iterative computational framework provided by the Ansys. The flow properties such as pressure, velocity were measured and visualized. This study of ours will help in future Wig Craft endeavours.*

Keywords: Blended Wing Body, Box Wing Body, Ground Effect, Novel Design, Wig Craft

I. INTRODUCTION

The wing-in-ground-effect (WIG) crafts are defined as those that fly close to the ground surfaces by utilizing the ground effect. This effect is known to improve the efficiency of airplanes during take-off and landing approaches. Most of available WIGE crafts show several common attributes that differentiate them from fixed-wing airplanes such as they have a low wing with large area and small aspect ratio, and a high fin with rudder and stabilizer attached to it at the utmost height. The benefit of using WIG is the extra lift generated. Regular airplane pilots also experience this phenomenon during take-off and landing approaches, as the others who have flight tested it during the landing approaches. The ground effect is due to the presence of surface (ground or water) below the wing and this phenomenon increases as the wing moves nearer to the surface. The effect is the increasing pressure below the wing that changes the overall flow field about it, thus enhance the wing lift-to-drag ratio. Utilizing the ground effect has started around 1960s by the design and development of the WIG craft (or ekranoplan in the Russian terminology). The erstwhile Soviet Scientists especially, Robert Bartini was behind the VVA-14, designed to be able to take off from the water and fly at high speed over long distances and to destroy United States Navy Polaris missile submarines.

1.1 ADVANTAGES OF WIG CRAFT

1. No requirements for an Aerodrome
2. The comfort level of the passengers is close to the Aircraft Standard and doesn't feel any Sea Sickness.
3. Safety of travel as it is operating close to the surface and is easy to land on water, if there is any emergency.
4. Highly efficient and more load capability than an aircraft.

It fills the technological gap between conventional aircraft and ships. A wig craft operates at much higher speeds than ships and more efficiently than aircrafts. Another distinct advantage of a wig craft is its ability to take of anywhere from the sea surface without the need for a runway. It has the potential to equally become both safe as well as fast mode of transport for commercial, military, Logistical applications etc.

1.2 CHALLENGES

WIG vehicles are new and are not yet commercially operated. This means that there is currently no training available for pilots or captains, and both have little experience in operating a WIG vehicle. An option available for the piloting of these vehicles is to deploy aircraft or seaplane pilots. Furthermore, smaller WIG vehicles can be used as training vehicles. Noise can be a limiting operational factor. The noise of WIG vehicles is comparable to that of small turboprop airplanes flying close to the water. It can be reduced, so that it meets acceptable criteria, by using ducted propulsors. Noise close to the terminals can be a factor for acceptance for both travellers and communities close to the terminals.

In the end, the economical profitability will be a key factor. It is known that WIG vehicles can exceed the efficiency of aircraft transport. It is proposed nevertheless that WIG transport is more suitable for short range routes of 150-400 km length. The mean reason for this is that aircraft transport is less efficient due to the frequent landing operations. It can be said that competing with aircraft transport in their speed range is hard due to the on-going competing of low-cost airlines. Another factor of influence worth noting is public reaction and acceptance. The Market pull is only possible when there is a public acceptance. As the public acceptance is not yet available, this indicates that a market push is the only option to enable forward progression with these new vehicles.

The controllability and manoeuvrability of the craft hasn't been always an easier task. Since the early development, the control was an issue. Sophisticated control systems didn't exist at that time which made the pilots hard to control the vehicle. Those were one of the main reasons why this failed during that era. But as the the technology improvised, most of the systems became autonomous and the effort of the pilots reduced over time.

II. INTEGRATION OF BWB AND BXB CONFIGURATION

To solve the current challenges, we decided to use the proposed hybrid platform described in [2]. It combines the advantages of both a Blended Wing Body (BWB) platform i.e. a tailless design that integrates wings and fuselage, and a Box Wing (BXW) platform, i.e. A closed box-like wing formation with no wing tips.

Here we plan to use the hybrid configuration for a light passenger craft. The craft should be able to perform jumps whenever necessary so as to avoid obstacles such as high waves or other incoming ships. The design was established by comparing with the existing wig craft known as Airfish 8. By using the BWB platform, a noticeable maximum 30% aerodynamic efficiency was observed. The blended wing body enhances the ground effect and the BXW platform provides a better control system for the lack of stability present due to the lack of tail and vertical stabilizer.

3.1 BWB PLATFORM

A blended wing body (BWB) is a fixed-wing aircraft having no clear dividing line between the wings and the main body of the craft. The aircraft has distinct wing and body structures, which are smoothly blended together with no clear dividing line. This contrasts with a flying wing, which has no distinct fuselage, and a lifting body, which has no distinct wings. A BWB design may or may not be tailless.

The main advantage of the BWB is to reduce wetted area and the accompanying form drag associated with a conventional wing-body junction. It may also be given a wide Airfoil-shaped body, allowing the entire craft to generate lift and thus reducing the size and drag of the wings.

The BWB form minimises the total wetted area - the surface area of the aircraft skin, thus reducing skin drag to a minimum. It also creates a thickening of the wing root area, allowing a more efficient structure and reduced weight compared to a conventional craft. A conventional tubular fuselage carries 12-13% of the total lift compared to 31-43% carried by the centre body in a BWB, where an intermediate lifting-fuselage configuration better suited to narrow body sized airliners would carry 25-32% for a 6.1% - 8.2% increase in fuel efficiency.

3.1.1 POTENTIAL ADVANTAGES

- Significant payload advantages in strategic airlift, air freight, and aerial refuelling roles
- Increased fuel efficiency – 10.9% better than a conventional wide body, to over 20% than a comparable conventional aircraft.
- Lower noise – NASA audio simulations show a 15dB reduction of Boeing 777-class aircraft, while other studies show 22–42 dB reduction below Stage 4 level, depending on configuration.

3.2 BXB PLATFORM

A box-wing aircraft relies on multiple lifting surfaces (wings, but also horizontal tail) that are connected one to the others, with these connections reducing the drag induced by wingtip vortices. The design was introduced by none another than the one considered the father of aerodynamics, Ludwig Prandtl. Despite years and years of extensive research and development, box-wing aircrafts are nowhere to be found. But the potential benefit has been confirmed. According to some of the latest research efforts by the University of Pisa, the box wing could reduce fuel consumption per passenger by 22 %.

3.3 EFFECT OF ENDPLATE

Due to the ground effect, the lift by rising in pressure on the lower surface is increased and the influence of wing-tip vortices is decreased. These two significant effects improve the lift-drag ratio. On the other hand, the endplate prevents the high-pressure air escaping from the air cushion at the wing tip and causes to increase the lift and lift-drag ratio further [25].

In that evaluation, Irodov's criteria were also evaluated to investigate the static height stability. The results that we got from this reference are that the endplate can improve the aerodynamic characteristics and static height stability of wings in ground effect. Therefore, the addition of an end plate in the Wig-Craft also improves the flight performance of this craft.

3.4 CONCEPTUAL DESIGN

By taking Airfish 8 as a reference and from the novel design mentioned in [2], we have made a design as per our mission requirements, a 6 seater wig craft. It incorporates the blended wing body and box wing configurations. The design has more scope for further improvement. This design concept was adapted from the knowledge of the reference paper [9]. That paper provided us with a lot of information for this design and finally this design was finalised. The Box Wing

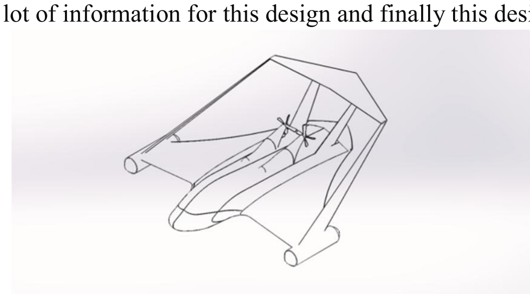

Figure 3.1 A Basic Sketch of Wig Craft

Configuration design assures savings in fuel consumption compared to conventional aircraft. These savings come from a reduction of induced drag resulting in a higher glide ratio.

3.5 SPECIFICATIONS OF AIRFISH 8

The Airfish 8 (AF8) is an 8–10-seater WIG Craft with a 17m x 15m footprint. It is designed to be operated by 2 crew and carrying capacity for 6-8 passengers in standard civilian transport configuration. It is powered by a powerful yet compact V8 car engine that runs on 95 Octane automotive-grade unleaded gasoline. Airfish 8 is designed and built to adhere to the International Maritime Organization (IMO) guidelines. The WIG marine craft is specifically designed to take-off and land on water, avoiding the need for a runway. The vessel has been designed for logistics, transport, tourism and maritime patrol operations.

Length (m)	**17.2**
Wingspan (m)	**15.0**
Wingspan (m)	**15.0**
Height (m)	**3.5**
Empty Weight (kg)	**4350**
Fuel Weight (kg)	**200**
Payload Weight (kg)	**1000**
Maximum take-off weight (kg)	**550**
Seating Capacity	**2 Crew + 6 to 8 Passengers**
Engine	**LS3 V8**

Type	Car Engine
Power (kW)	402
(hp)	500
Take-off speed (km/h)	102
Cruise speed (km/h)	150
Cabin length (m)	4.0
Cabin Width (m)	1.4
Propellers	Two four-blade variable pitch 1.7 m
Operating Height (m)	Upto 7

Table: 3.1 Specifications of Airfish 8

IV. DESIGN PARAMETERS

Certain Design Parameters, as mentioned in, are to be selected in order to set requirements for the overall form, shape and compartmentation of the WIG effect Vehicle for its primary stage of Design. Once the prerequisites are fulfilled the influence of IMO and the Classification Society Criteria can be assessed.

Step 1 - Mission Profile Determination
Number of crew members =2 Crew members + 4 Passengers
Payload Capacity = 650 kg
Engine = 5.8L (351 cu in) Windsor V8

Cruise Speed =150 knots = 77.16 m/s
Range = 320 nm = 592 km

Step 2 – Wig Craft wing dimensions and Estimations
For 2.42 ton wig craft with a total Wing Surface Area(s) of 30.95 m²

Wing loading = $\frac{W}{S}$ = 78.36 kg/m^2

∴Wing Cube Loading = 14.084 kg/m^3

Wing Root Chord Length = 5.82 m

Wing Tip Chord Length = 1.39 m

$$\therefore \text{Taper Ratio} = \frac{\text{Tip Chord Length}}{\text{Root Chord Length}}$$
= 0.238

Mean Aerodynamic Chord (MAC)

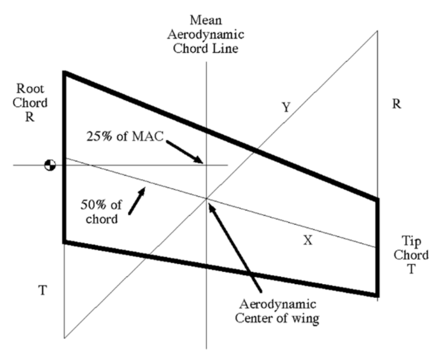

Figure: 4.1 Diagram of Mean Aerodynamic Chord

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∴ Mean Aerodynamic Chord = 3.328 m
Wingspan = 8.32 m

Step 3 - Aircraft Weight Constraint Analysis
With respect to mission profile; overall weight can be calculated.

$W_o = W_{crew} + W_{payload} + W_{fuel} + W_{empty}$

Here from Mission Profile;

$\therefore W_{crew} + W_{payload} = 650$ kg

& $W_{fuel} = 150+50$ (Reserve) = 200 kg

Let's consider Kp = 0.268

$W_o = 2425.37$ kg

$W_{empty} = W_o - 650+200$

$= 2425.37 - 850$

$= 1575.37$ kg

Step 4 - Aero-foil Selection:
The WIG craft will be fitted with NACA 4412 Airfoil with a thickness ratio of 12% for Horizontal tail and NACA 0012 for vertical tail.

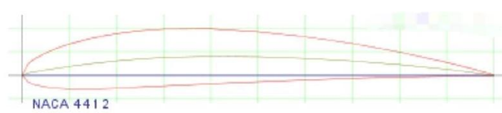

Figure 4.2 NACA 4412 Airfoil

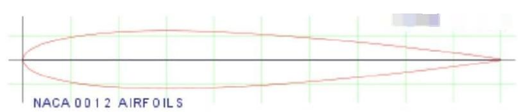

Figure 4.3 NACA 0012 Airfoil

Step 5 – Dimensions of the Craft:
No. of passenger's = 6
Seat width = O.47 m
Seat Pitch / Legroom (PS) = 0.90m
Cabin wall = 0.02 m
Aisle Width = 0.92 m
Overall Length = 9.01 m
Nose Length = 1.248 m
Cabin Length = 3 m
Cabin Width = 1.73 m
Cabin Height = 1.61 m
Cabin Wall = 0.02 m

Design of the Craft

The designed model of the WIG craft in Solidworks is shown below.

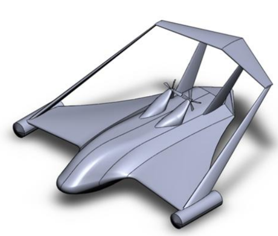

Figure: 5.1 Isometric view of WIG craft

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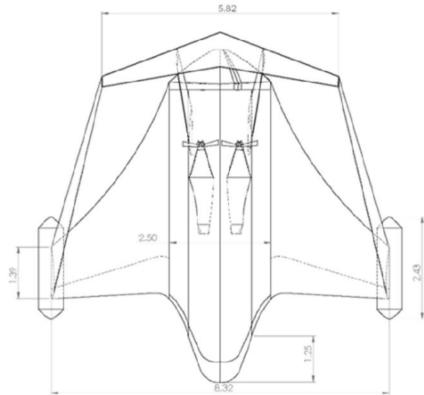


Figure 5.2 (a) Top View

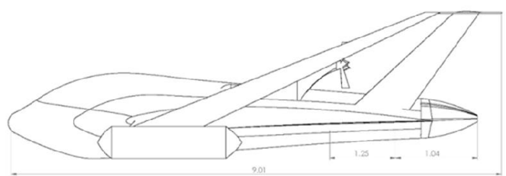


Figure 5.2 (b) Side View

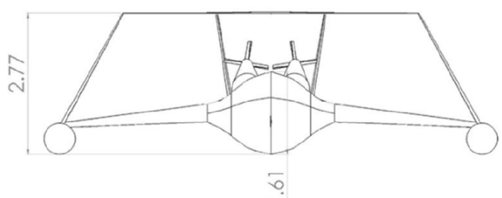
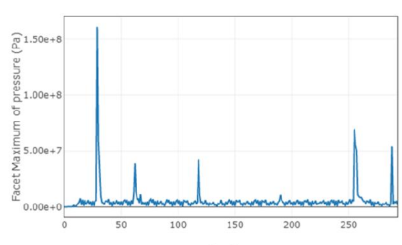


Figure 5.2 (c) Front View

VI. ANALYSIS

The solid model we made using Solidworks was then later analysed using ANSYS. The objective was to analyse the WIG craft under boundary conditions of velocity at 77.16 m/s. Ground effect conditions has not been incorporated with such as the low lying surface that produces the ground effect, which in this scenario is the sea. Moreover we weren't able to replicate the varying sea wave which mainly affects under real flight conditions. Therefore the WIG is analysed under the normal cruise conditions. After importing the file in ANSYS, a cylindrical enclosure was given in Design Modeller. After the geometry was successful, we meshed in high quality and then the solutions were obtained.



Graph: 6.1 Pressure v/s Iterations Plot

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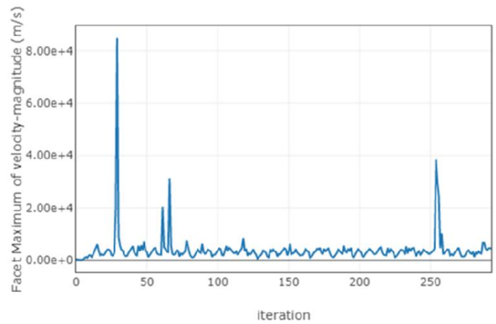
The above graph represents the Facet Maximum of pressure against the no. of iterations.



Graph: 6.2 Velocity v/s Iterations Plot

The above graph represents the Facet Maximum of pressure against the no. of iterations.

6.1 VISUALISATION

The flow properties such as velocity, pressure and temperature over the wigcraft are visualised below

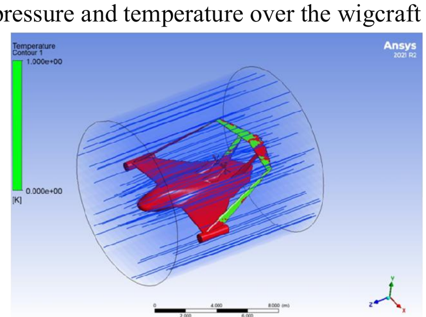


Figure: 6.1 Pressure Contour

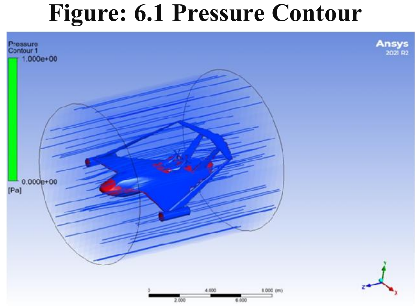


Figure: 6.2 Velocity Contour

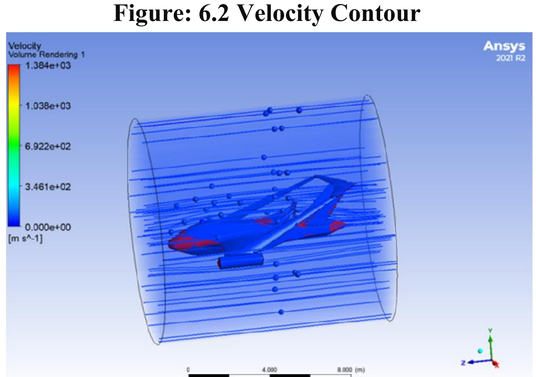


Figure: 6.3 Temperature Contour

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VII. CONCLUSION

Therefore, this paper provided with a WIG (Wing-In-Ground effect) Craft which is a 6 seater and having a Blended Body Design with Box Wing Body configuration for enhanced efficiency as discussed above. Considering the fact that this is a combination of both an Aircraft as well as a Ship like machine, a lot of design parameters were needed to be considered. Finally, a full body analysis of the Wig Craft was performed in order to obtain its Pressure, Velocity, Drag and Density contours, in order to study its feasibility for future projects. Given the fact that, the power train used in our WIG Craft is a car engine. Here, the analysis was done in a cylindrical enclosure in which, we tried to improve the mesh quality at the finest using the Tri-Mesh setup. The iterations were done at a boundary condition of 77.16 m/s at normal atmospheric pressure.

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