Computational Analysis of Load on Envelope of MAGLEV Propelled Transportation Airship using FSI

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Abstract—This focus of this research is to estimate the load acting on the envelope structure by using Fluid Structure Interaction (FSI). Envelope is a principle component of the Airship because it houses the gas which produces the lift and major components. In this paper envelope of airship with the payload of 7500 Kg is designed and analysed at velocities up to 300 Kmph to determine the loads acting on each member. This data is essential for structural design of the MAGLEV Propelled Transportation Airship.

Keywords—Buoyancy, Computational Fluid Dynamics, Envelope, Lighter than Air Transportation, Fluid Structure Interaction.

I. INTRODUCTION

Airships are lighter-than-air vehicles which use buoyancy to produce lift and to stay aloft, like balloons, rather than aerodynamic lifting surfaces like heavier than aircraft. Whereas balloons rely on wind currents for maneuverability, airships can be steered and propelled through the air. Originally airships were called Dirigible Balloons, where dirigible is French word for “Steerable”.

The main types of the airship are non-rigid/blimps, semi-rigid and rigid. Blimps are airships where internal pressure is maintained by forcing air into an internal ballonet, is used both maintain the shape of the airship and its structural integrity. Semi-rigid airships maintain the envelope shape of the airship by the internal pressure, but have some form of internal support such as a fixed keel to which control and engine gondolas and stabilizers and steering surfaces are mounted. Rigid airships have a structural framework which maintains the shape and carries all loads such as from gondolas, engines. The frame work contains numerous balloons, known as “gas cells” or “gas bags” which supply the static lift without having to bear any structural loading\textsuperscript{[1]}.

II. AIRSHIP ENVELOPE SIZING

Airship flight is maintained by virtue of buoyancy rather than lift induced by the forward motion of the lifting surfaces through the air. This makes airships far more energy efficient than heavier-than-air aircraft because they don’t need to expend fuel to stay aloft. Airships are therefore ideally suited to applications requiring loiter and long endurance or range.

A. Aerostatics

The upward buoyancy force generated by an airship is equal to the weight of the displaced air. This force is typically referred to as the “Gross Lift”, and is defined as:

\[ L_G = V_N \rho_A g \] \hspace{1cm} (Equation 1)

Where, \( V_N \) is Net Volume of Air displaced, 
\( \rho_A \) is the Density of Air, 
g is the acceleration due to gravity.

Subtracting the weight of the lifting gas, we obtain the “Net Lift”, \( L_N \). Noting that the volume of displaced air is equal to the volume occupied by the Lifting Gas, the equation for the net lift is:
F_{Lift} = \left( \rho_{air} - \rho_{lifting\ gas} \right) g V \quad \text{(Equation 2)}

Where,

\begin{align*}
F_{Lift} & - \text{Lift Force in N} \\
\rho_{air} & - \text{Density of Air in Kg/m}^3 \\
\rho_{lifting\ gas} & - \text{Density of Lifting Gas in Kg/m}^3 \\
g & - \text{Acceleration due to gravity in m/s}^2 \\
V & - \text{Volume of Air Displaced in m}^3
\end{align*}

Mass of (Payload + Structure) is = 7500 Kg
Net Lift required is = 73757 N
Net Volume of Air Displaced is = 6600 m$^3$

B. Aerodynamics

This lift is produced by the shape of the hull, as we have selected an aerodynamic shape for the hull by the feasibility study; the lift is produced by the motion of hull in air,

\[ L_{Dynamic} = \frac{1}{2} \rho U^2 V^{2/3} \quad \text{(Equation 3)} \]

Where,

\begin{align*}
L_{Dynamic} & - \text{Dynamic Lift in N} \\
\rho & - \text{Density of air at 30 ft in Kg/m}^3 \\
U & - \text{Velocity of Airship in m/s} \\
C_{VL} & - \text{Volumetric Lift Coefficient.} \\
V & - \text{Volume of Airship}
\end{align*}

The Coefficient of lift is determined by taking the feasibility study in to consideration the value of the assigned profile is 0.030.

C. Determination of Drag

Drag is encountered due to the friction between the fabric and the surrounding air, the intensity of the drag is determined by

\[ D_{Dynamic} = \frac{1}{2} \rho U^2 V^{2/3} C_{VD} \quad \text{(Equation 4)} \]

Where,

\begin{align*}
D_{Dynamic} & - \text{Dynamic Drag in N} \\
\rho & - \text{Density of air in Kg/m}^3 \\
U & - \text{Velocity of Airship in m/s} \\
C_{VD} & - \text{Volumetric Drag Coefficient.} \\
V & - \text{Volume of Airship}
\end{align*}

The geometry has a reference area of 17.8 m$^2$ and a thickness ratio of 0.33. For this ratio, the Analytic and experimental values of $C_D$ are 0.0244 and 0.0255, respectively. An average value of 0.025 is chosen for subsequent analysis.

D. Envelope Design

The shape of the envelope has a major influence on its overall performance. Envelope weight is proportional to surface area and lift is proportional to the volume. In an ideal case, the surface area should be as small as possible relative to the volume. Air resistance is also determined primarily by the surface area.

\begin{align*}
\text{Figure 2 GNVR shape with geometry parameterized in terms of maximum diameter}^{[2]} \quad & \\
\text{Figure 3 CAD Model of GNVR Profile}^{[2]} \quad &
\end{align*}
III. CFD Analysis

The Computational Analysis of the Envelope structure is made to validate the theoretical calculations made and to find out the pressure distribution on the envelope shape.

The domain for the flow analysis is shown in the Figure 4. The CFD analysis is made for velocities 0-300 Kmph and the Results are compared with the theoretical values. The velocity and the pressure plots of the envelope shape are shown in Figure 5 and Figure 6.

IV. Results and Discussion

The Static Lift, Dynamic Lift and Drag forces of the envelope shape are computed using the CFD analysis for velocities 0 – 300 Km/h. In Figure 7, Figure 8, and Figure 9 the results from the CFD Analysis and theoretical calculations are plotted. There is a small deviation in the results at higher velocities.

Rigid airships have a structural framework which maintains the shape and carries all loads such as from gondolas, engines.
The structural design of the envelope has been made from the design constraints and the CFD results. The pressure data from the CFD analysis is used. The Structural Design of the Envelope frame is shown in the above figure.

**Figure 10 Structural Design of the Envelope Frame**

A. **Load Calculation on Structure from CFD analysis**

The load taken by each member of the envelope frame is the half of the loading acting on both sides of the member, hence the load acting on each frame is calculated from the results of the CFD.

### TABLE I

<table>
<thead>
<tr>
<th>Member</th>
<th>Load Area in m²</th>
<th>Loading Acting in N/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Cap</td>
<td>88.6</td>
<td>103714</td>
</tr>
<tr>
<td>Frame 1</td>
<td>231.12</td>
<td>101671</td>
</tr>
<tr>
<td>Frame 2</td>
<td>241.19</td>
<td>100957.95</td>
</tr>
<tr>
<td>Frame 3</td>
<td>256.15</td>
<td>100613.6</td>
</tr>
<tr>
<td>Frame 4</td>
<td>264.39</td>
<td>100952.1</td>
</tr>
<tr>
<td>Frame 5</td>
<td>254.28</td>
<td>100764.65</td>
</tr>
<tr>
<td>Frame 6</td>
<td>234.49</td>
<td>101084.95</td>
</tr>
<tr>
<td>Frame 7</td>
<td>203.13</td>
<td>101812</td>
</tr>
<tr>
<td>Frame 8</td>
<td>154.14</td>
<td>102375</td>
</tr>
<tr>
<td>Frame 9</td>
<td>72.04</td>
<td>102975</td>
</tr>
</tbody>
</table>

The load acting on each structural member is tabulated in the Table 1. The FEA analysis of the structure by applying loads has to be carried out.

V. **CONCLUSION**

In this paper a envelope to carry the payload of 7500 Kg is designed and modeled. The Loads acting on the model is calculated both theoretically and computational and the results are compared. Based on the results and the design constraints the structure of the airship is designed and modeled. From the CFD analysis the load acting on each frame is computed and given in the Table I.

### REFERENCES


