Development of the IIUM Hybrid Airship

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DEVELOPMENT OF THE IIUM HYBRID AIRSHIP

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ABSTRACT

Hybrid airship is an unconventional type of airship being developed since a few decades ago and is now being tried on a significant scale. In this paper, the preliminary design steps of a winged hull hybrid airship will be outlined and discussed together with a way to achieve controllability of the hybrid airship during both STOL (Short take off and Landing) and cruising mode as well as its aerodynamic characteristics.

INTRODUCTION

Theoretically, a winged hull hybrid airship can accomplish a good combination of the speed characteristics of an airplane and the heavy lifting capacity of an airship [1-4]. The major difference between a hybrid airship and an airship is weight. A hybrid airship generates its passive lift via the traditional 'lighter than air' gas (mainly Helium), which may comprise of 30%-80% of total lift generated, while the rest of the lift is generated from its aircraft like wings (or propulsion system, via vector thrust) and lift generating fuselage. This concept was intended to adapt several aircraft components combined with a soft-skin lifting body. Thus, part of the lift would be generated aerodynamically.

A winged hull airship does not require the complexity of loading and unloading of cargo as compare to a regular airship due to its negative buoyancy. Operationally, the craft may be considered as a STOL vehicle with an effectively low 'wing' loading. Since STOL is of primary concern in this design, hence, the design should be aerodynamically efficient in order for the lifting gas to carry most of the dead weight while the dynamic lift carries the disposable load. However, it may lose the advantage of airship VTOL capability since this type of airship is usually bound to weight penalties due to the concentrated wing loads on the airship hull which requires strengthening of the structure.

Each unconventional airship design invites detailed examination since they are unique according to their unconventionality. However, an airship has unpredictable motions due to the fact that it is filled with a large amount of gas and this can highly affect its flight stability. Consideration and limitation need to be taken into account as early as in the design stage; the aerodynamics of the hybrid airship such as wing and tail placements or orientations needs to be studied to improve its aerodynamic stability.

NOMENCLATURE

L_{hull}	[N]	Lift generated by hull
d/l	[-]	Thickness ratio
W	[N]	Total weight
ΔW	[N]	Effective weight
V_{hull}	[m^3]	Volume of the hull
RE_V	[-]	Volumetric Reynolds number
V	[m/s]	Velocity of oncoming air
C_L	[-]	Lift coefficient
C_D	[-]	Drag coefficient
C_M	[-]	Pitching moment coefficient
C_{LV}	[-]	Volumetric lift coefficient
C_{DV}	[-]	Volumetric drag coefficient
C_{MV}	[-]	Volumetric moment coefficient
L	[N]	Lift
D	[N]	Drag
M	[N/m]	Pitching moment

Special characters

α	[°]	Angle of attack
g	[m^2/s]	Acceleration due to gravity
ρ	[kg/m^3]	Atmospheric gas density
μ	[N·s/m^2]	Dynamic viscosity

Subscripts

$c.g$		Center of gravity

PRELIMINARY DESIGN

The airship model was designed to be partially supported by the buoyancy lift, L_{hull} generated by the hull. The remaining weight, $\Delta W = W - L_{hull}$ is held up by the aerodynamic lift, L_{wing} generated by the wings. The wings will provide negative downward force in flight during manoeuvre and landing [4, 5].

The present model was considered to imitate a conventional aircraft with fixed vertical and horizontal tail fin configuration. Existing heavier than air vehicle design and analysis tools are not directly appropriate for airship design [6]. Nonetheless, the current model has adapted several steps of conceptual approach to conventional aircraft design.

An axisymmetrical streamlined hull with Helium gas capacity of 10 m^3 and thickness ratio, d/l = 0.381 was selected for the airship envelope. A gondola was configured to take advantage of streamline form. The wings were sized to have medium configuration, tapered wing with Clark Y airfoil. Clark Y airfoil type was selected due to its low speed high lift and high maximum angle of attack characteristics. Typically, it is known as thick camber airfoil used in low speed aircraft design. The wing is swept with zero dihedral to improve stability as it has natural dihedral effect [7].

Also, a mid wing layout was chosen as it offers lowest drag due to wing-body interference (towards rear of wind root) compare to high and low configurations. It eases loading/unloading of cargo for generic UAV design. Disadvantages are mainly the structural design, which requires extension of wing-box across the hybrid envelope. If heavy ring frames is use to overcome this, this will definitely cause weight penalty. However there is a possibility of using composite ‘ring frames’ which offer lighter weight and high strength.

Vertical/Horizontal tails use NACA 0012 series airfoil. Vertical/Horizontal tail of an aircraft is known to be important in terms of the whole aircraft dynamic stability. The horizontal tail imposes pitching stability (resting effect) while the vertical tail enforces directional stability. The distance of the Vertical/Horizontal tail from the *c.g* also has the same effect in stabilizing the aircraft. Generally, the further it is from the *c.g* it introduces larger moment in both terms, thus providing greater stability with a smaller surface area. **Figure 1** shows the drawing of the model constructed in CATIA.

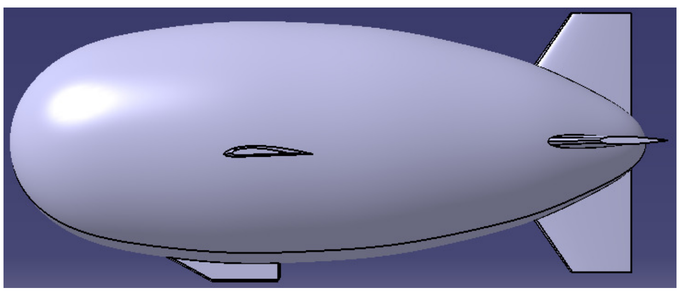

Figure 1 UAV winged hull hybrid airship (side view)

CONTROL SURFACE CONFIGURATION

Simulated flight on the model was successfully carried out in the XPLANE simulator. **Figure 2** shows the simulated STOL/VTOL takeoff and landing.

Figure 2 XPLANE simulations during takeoff and landing

One of the complex solutions implemented in this hybrid airship were its main-wing control surface setup/mixing during various configurations mainly the STOL/VTOL mode (short/vertical take-off and landing) and cruise/plane mode. Both of these configurations are using exponential input setting, shown in **Figure 3**. Flaperon (Control surface that is used both as an aileron and a flap) configuration is used to allow a much more effective control during STOL/VTOL setting and low speed flying. This setup provides large control surface area for effective control authority during both modes.

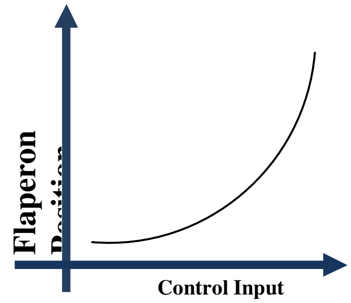

Figure 3 Exponential input setting

The right amount of Exponential Input Setting (EIS) is important to ensure the ease of flying. During small amount of input, the flaperon is deflected by a small amount. This small amount of change is enough to roll the hybrid airship significantly. Without the right EIS the hybrid airship will become too sensitive to control. Similarly larger inputs require faster response (e.g emergency) thus the relationship becomes exponential.

In STOL/VTOL mode, **Figure 4** demonstrates the fully deployed flap configuration which is implemented to reduce drag significantly due to downwash from the propeller. However, this phenomenon also has an added advantage, it provides roll control authority during near ‘0’ forward speed by manipulating the effect of drag due to downwash via the control surface thus effectively roll the hybrid airship to the desired position. **Figure 5** demonstrates the simulated STOL/VTOL control mode. During left turn, left flaperon is in upward position while right flaperon is in downward position with thrust vector at 90°. STOL/VTOL left turn configuration in **Figure 6** causes significant drag due to downwash at left wing. This gives control authority at low speed during STOL/VTOL mode

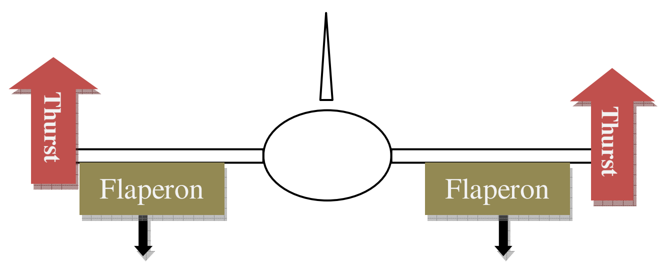

Figure 4 Fully deployed flaps

Whereas during cruise/plane mode in **Figure 7**, the control surface configuration will be that of typical aircraft with flaperons. The transition between both modes required the vector thrust to change angle slowly till the forward speed is fast enough to allow the wing to generate enough lift to carry. Similarly during transition back from cruise mode to STOL/VTOL mode, the vector thrust will be taking over the ‘lift’ generated from the wing by changing its direction to that of vertical.

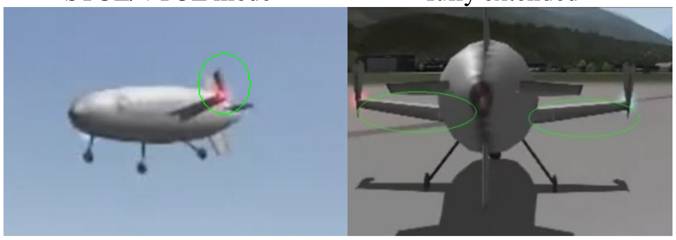

Figure 5 XPLANE STOL/VTOL control mode with 90° thrust position

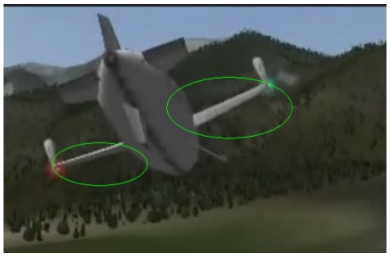

Figure 6 XPLANE STOL/VTOL left turn control mode

Figure 7 XPLANE cruise/plane control mode with 0° thrust position

AERODYNAMIC INVESTIGATIONS

Flow simulation is carried out to study the aerodynamic characteristics of the proposed design. A CFD solver was chosen as a simulation tool for preliminary examinations. Consider a typical aircraft generating most of its lift from the wings. Thus, the lift, drag and moment coefficients of the aircraft are defined as:

$$C_L = \frac{L}{\frac{1}{2}\rho V^2 S}$$

$$C_D = \frac{D}{\frac{1}{2}\rho V^2 S}$$

$$C_M = \frac{M}{\frac{1}{2}\rho V^2 S c}$$

The contribution of the wings to the total aerodynamic performance can be investigated with the above dimensionless parameters. However, the lift of a buoyant body is directly associated to its volume. Thus, the variable S in the above relations is considered to be $(V_{hull})^{2/3}$ instead of the plan area [4-6, 8-9]. The expression may be re-written in dimensionless volumetric coefficients:

$$C_{LV} = \frac{L}{\frac{1}{2}\rho V^2 (V_{hull})^{2/3}}$$

$$C_{DV} = \frac{D}{\frac{1}{2}\rho V^2 (V_{hull})^{2/3}}$$

$$C_{MV} = \frac{M}{\frac{1}{2}\rho V^2 (V_{hull})^{\frac{2}{3}} l}$$

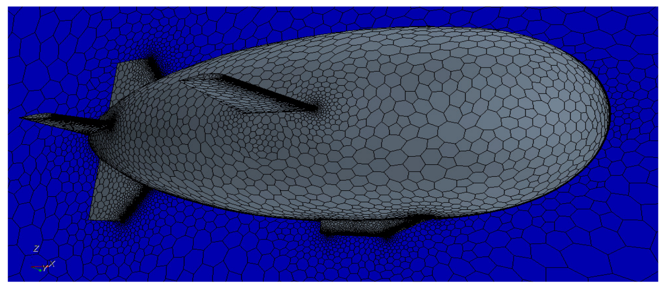

Figure 8 Polyhedral mesh by STAR CD

Some authors consider S as the hull plan area to take in consideration of the large friction drag due to the large surface area of an airship [4-6, 8]. Nonetheless, this paper has adopted S as $(V_{hull})^{2/3}$ to examine the total aerodynamic parameters of the present model. Polyhedral mesh in **Figure 8** was chosen as it provides balanced solution for complex mesh generation problems and relatively easy and efficient to construct [10]. The flow around any component body can later be observed and studied from STAR-CD pre-processing tool shown in **Figure 9**.

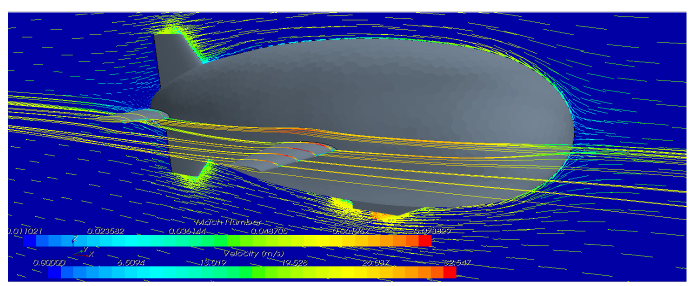

Figure 9 Flow over model at $\alpha = 0°$

CFD simulation was carried out by assuming compressible, viscous, and turbulent flow. The aerodynamic parameters were studied over a range of angle of attack, α (-20° to 20°) and air stream velocity of 20 m/s.

The airship has a circular cylindrical cross section; thus, the flow over the airship maybe regard as a flow over a circular cylinder. The Reynolds number for the air stream calculated using air properties at 1500 ft is 1.8 × 10^6. At this Reynolds number, the model will experience transition to turbulent flow. Moreover, the boundary layer is at first laminar and stable from perturbations at stagnation point. It gradually developed to an instable transition flow at certain region in the downstream directions. Subsequently, this leads to a rapid breakdown to turbulence. Hence, the simulation will be solved using the turbulence model in Star CCM+. **Figure 10** illustrates the Mach number distribution on the model at α = 0. As angle of attack increases, there is a reduction of airspeed over the body to a positive pressure increment. As a result, reducing lift and increasing drag. Also, it is noticeable in **Figure 11 and Figure 12** that pressure changes unevenly over the wing surface.

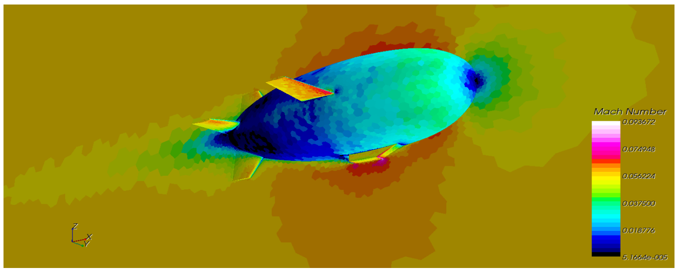

Figure 10 Mach distribution at α = 0°

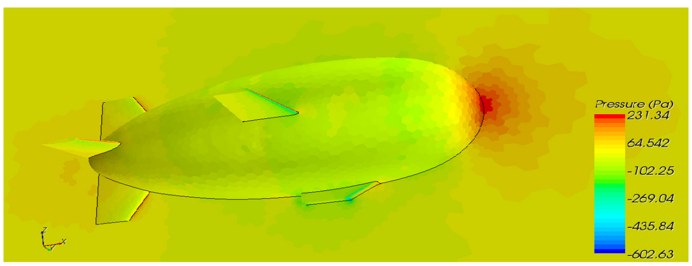

Figure 11 Pressure distribution at α = 0°

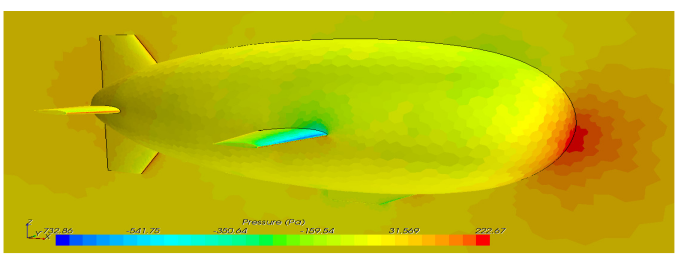

Figure 12 Pressure distribution at α = 20°

Figure 13 shows the computed volumetric coefficients of drag, lift, and moments C_{DV}, C_{LV}, and C_{MV} versus angle of attack respectively. The volumetric drag coefficient has a parabolic behaviour with angle of attack. The curve shows poor axis-symmetry, with minimum drag occurring at α = 0°. The graph also shows that the volumetric drag coefficient is slightly higher at positive angle of attack (-α < +α, where α carries the same value). The lift volumetric coefficient over angle of attack shows slight non-linear shape. In the selected range of α, the lift coefficients is found to be increasing with increasing angle of attack with no sign of stalling. In addition, the reference point for computation of moments is at the centre of gravity. The static stability of the model is illustrated by the negative slope of the volumetric moment coefficient curve.

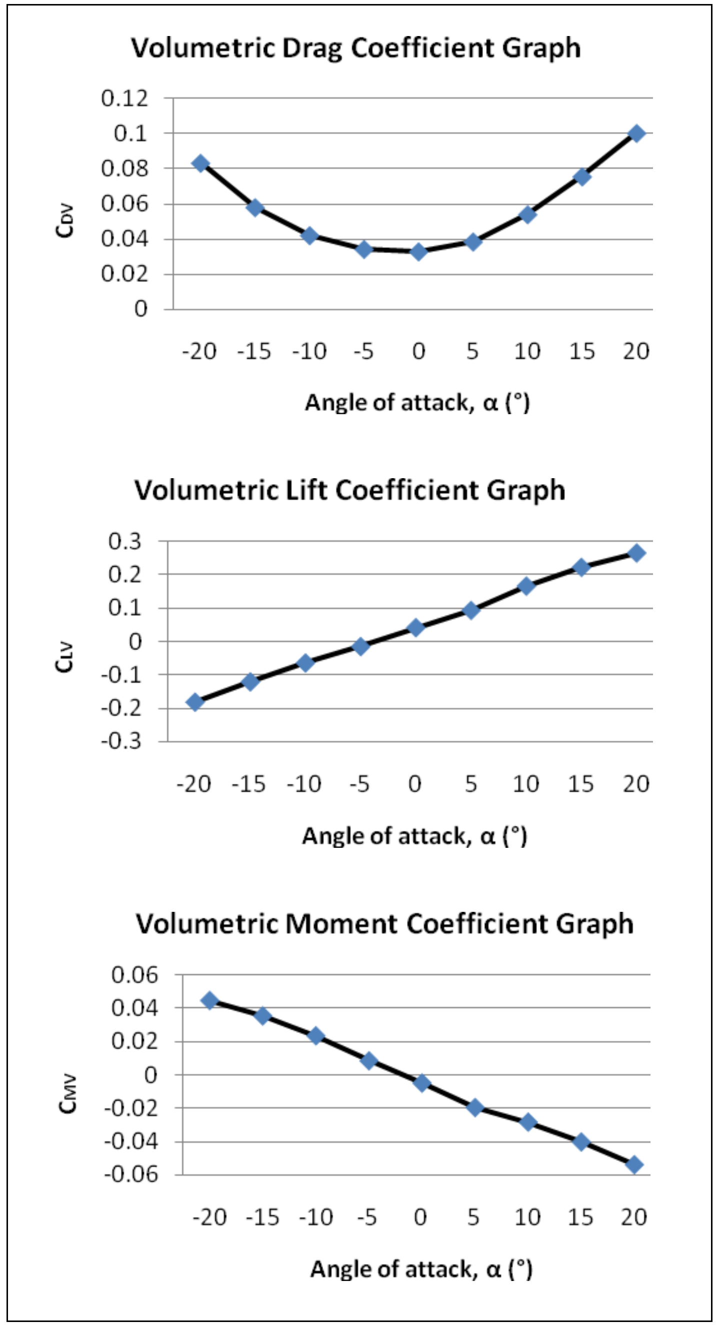

Figure 13 Turbulent model numerical C_{DV}, C_{LV}, C_{MV} results by STAR-CD at RE = 1.8 × 10^6

CONCLUSION

The present paper summarizes the preliminary design of a hybrid airship. A winged hull hybrid structure with streamlined gondola is proposed. The design was successfully test flown in XPLANE software promising positive capability in real flight test. Turbulent model numerical aerodynamic parameters show increasing volumetric lift with increasing angle of attack. Parabolic increase of drag with lift is observed in volumetric drag coefficient graph. The airship is statically stable as seen by the behavior of the Volumetric pitching moment coefficient with angle of attack. However, the simulated results need to be validated experimentally to clearly observe for flow transitions, separations, or irregularities.

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