Design, fabrication and flight testing of remotely controlled airship

by

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Abstract

This paper provides a description of "Micro Airship", which is a non-rigid, helium filled remotely controlled airship designed, fabricated and flight tested at IIT Bombay. Details of the envelope material and stress analysis, fabrication procedure adopted, and the flight tests conducted are provided. Finally, the lessons learnt from this exercise, and the proposed future action is discussed.

Introduction

A Program on Airship Design & Development (PADD) has been launched at IIT Bombay, which aims at developing indigenous expertise in airship technology. The basic purpose of developing the Micro Airship was to provide the PADD team to obtain a first hand exposure to issues related to airship design, fabrication and operation. It also enabled the team to carry out a preliminary assessment of the suitability of the GNVR shape for the Demo airship that it proposes to develop. Further, the Micro Airship could also act as a flying platform for generation of airship design data and experimentation. This activity was seamlessly integrated with an ongoing Aircraft Design Laboratory course for the undergraduate students of Aerospace Engineering Department. By participating in this activity, the students obtained a flavor of being a part of a design team and being involved in the development of an aerial vehicle right from conceptualization to the realization.

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The Micro airship is a remotely controlled, non-rigid, helium filled experimental aerial vehicle, with envelope volume of 6.64 m^3. Its dimensions were constrained by the limitations on the storage space available. The three-view diagram of the Micro Airship is shown in Figure 1.

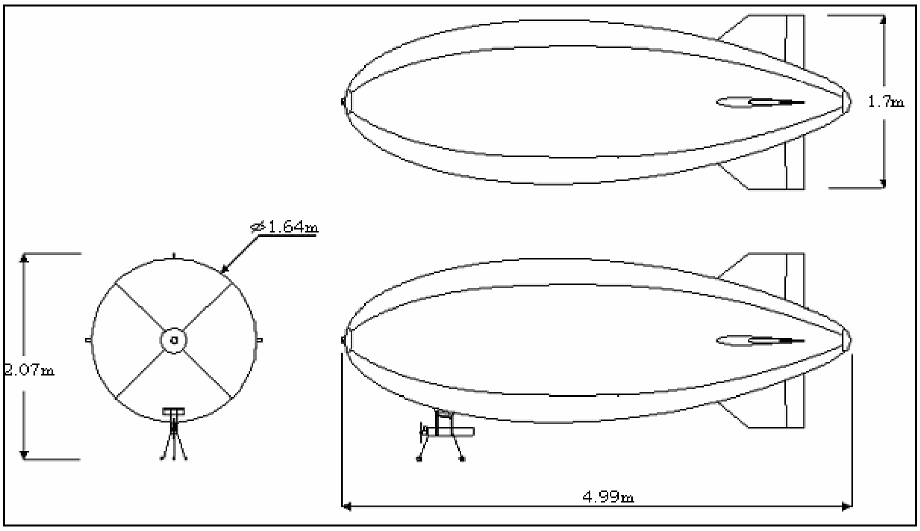

Figure 1. Layout of Micro airship

Selection of envelope material

Several envelope materials for aerostats have been indigenously developed at ADRDE, the material properties of three of them are listed in Table 1.

Property	**Units**	**A**	**B**	**C**
Specific Mass	Gm/m^2	265 ± 15	320 ± 20	350 ± 10
BS along Warp along Weft	 N/5cm N/5cm	 735 686	 150 150	 225 225
Peel Strength	N/2.5cm	29	3	3
H_2 Permeability	$Lit/m^2/$ day	2	2.5	2

Table 1. Material properties of aerostat fabrics developed by ADRDE [1]

It was observed that even if the lightest material (A in Table 1) were used, the envelope itself would weight between 5.06 to 5.35 kg. This would leave a margin of only about 1.4 Kg for all other items, since the net useful lift would approximately be 6.75 kg. Hence, after a market search for suitable lightweight material, a yellow colored PVC film (0.11 mm thick) used for helium-filled balloons was short-listed, and then a sample of this film was characterized as shown in Table 2.

Sr. No.	Property	Value
1	H_2 Permeability (Lt/m^2/day @ 25 cm H_2O column)	3.75
2	BS along warp (N/5 cm)	83.0
3	BS along weft (N/5 cm)	87.0
4	Mass (g/m^2)	141.1

Table 2. PVC film properties tested at ADRDE [2]

Since a typical GNVR shape has already been selected for the proposed Demo airship and aerodynamic and structural data for this shape has already been generated for the aerostats as well; a need was already realized to study the performance of this shape experimentally. Therefore the GNVR shape was selected as hull geometry for Micro airship which in shown in Figure 2 below.

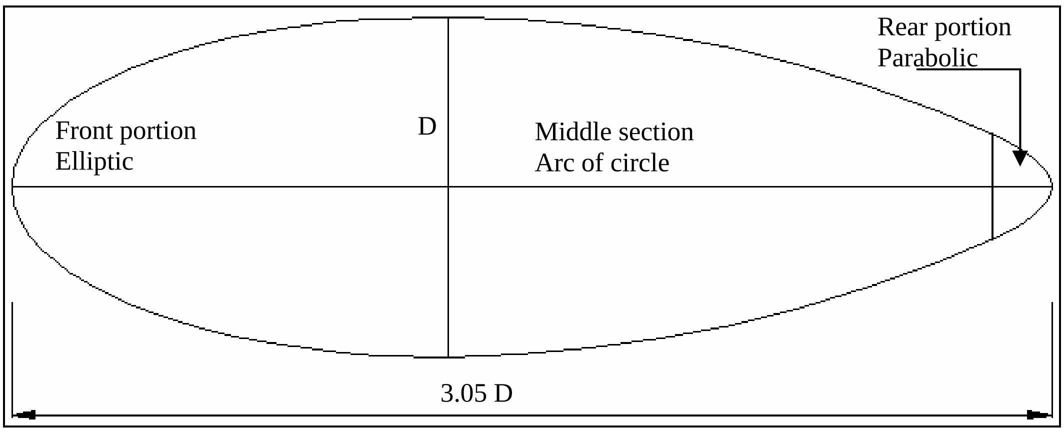

Figure 2. GNV-R Hull geometry for Micro airship

Basically, the GNVR shape consists of a combination of three sections, with a fineness ratio of 3.05. The front section is elliptic, the mid-section is an arc of a circle, and the end section is parabolic. The dimensions of the various sections can be obtained in terms of the maximum envelope diameter, as shown in figure below. The surface area and volume of envelope were calculated by use of numerical integration method.

Envelope design

Coming to design of the envelope against three types of stresses viz. stresses due to Internal Pressure (ΔP_{int_N}), Stresses caused by differential pressure due to head (hydrostatic loading) ΔP_{head} , and Stresses due to aerodynamic loadings (ΔP_a) with a maximum speed of 10 m/s.

Now, Maximum stagnation pressure at sea level = $\frac{1}{2}\rho V^2 = \frac{1}{2} * 1.225 * 10^2$

= 61.25 N/m^2.

It was assumed that differential pressure at the centerline was 1.15 times the maximum anticipated dynamic pressure.

$\therefore$ ΔP_{int_N} =1.15*61.25 ≈ 70.4 N/m^2

The pressure due to aerodynamic loading is given below. It was assumed that the pressure coefficient (C_p) for such shape was in the range of 0.3 to 0.35. Thus,

$$\Delta P_a = \Delta P_{aerodynamic} = \frac{1}{2}\rho V_\infty{}^2 C_p$$

ΔP_a = 0.33*0.5*1.225*100 = 20.2 N/m^2

Pressure due to hydrostatic head is given below.

$$\Delta P_{head} = (\rho_{air} - \rho_{he}) g \frac{D}{2}$$

= (1.225-0.169) 9.81*1.64/2

≈ 8.5 N/m^2

Total ΔP = 70.4 + 20.2 + 8.5 = 99.1 N/m^2 ~ 100 N/m^2

Circumferential unit load

= $\Delta P * R$ = 100*1.64/2 = 82 N/m

≈ 4.1 N/5 cm

Since breaking strength in warp direction is 83 N/5cm, hence at V= 10 m/s, the factor of safety (FOS) was found to be greater than 20. Even in worst situation if this speed is doubled (20 m/s), the FOS turns out to be 5.3, i.e. again on safe side.

Stresses in longitudinal direction

Calculations with maximum differential pressure

ΔP_{int_n} = 70.4 N/m^2 (as calculated earlier) ΔP_{head} = 8.5 N/m^2 (as calculated earlier)

ΔP_a = 20.2 N/m^2 (as calculated earlier)

Total ΔP = 70.4 + 20.2 + 8.5 = 99.1 N/m^2

≈ 100 N/m^2

Unit load due to differential pressure = $\dfrac{\Delta PR}{2} = \dfrac{100 * 1.64}{2}$ ≈ 82 N/m

For unit load due to BM,

Maximum BM = 0.029 $\rho u\, vVL^{0.25}$ lb. ft.

(Since l/d < 4, use 4)

= [0.029*0.002378 (slug/ft^3)] * [15 (ft/s)] * [10 m *3.28(ft/m)] *[6.82 m^3 *(3.28ft/m)^3] * (4.99 m *3.28ft/m)$^{0.25}$

=0.029*0.002378*15*10*3.28*4.99*35.3*2.011

$\approx$12.02 lb.-ft $\approx$ $\frac{12.02}{2.2} * 9.81 * \frac{1}{3.28} Nm$

$\approx$ 16.5 Nm

Unit load due to BM = $\frac{BM}{\pi R^2}$ = $\frac{16.5}{\pi * 0.82^2}$ = 7.81 N/m

$\therefore$maximum unit load (tensile)

= 82+7.85 = 89.85 N/m = 4.5 N/5cm

Check for buckling

Minimum ΔP = $\Delta P_{\mathrm{int}_n}$ - ΔP_{head} = 70.4-8.5 = 61.9 N/m^2 (at the bottom)

$\therefore$unit load due to differential pressure = $\frac{\Delta PR}{2}$ = $\frac{61.9 * 0.82}{2} = 25.38 N/m$

Unit load due to BM is assumed to be same = 61.9 N/m

Thus minimum tension in fabric will be = 89.85 – 61.9 = 27.95 N/m which is positive, hence acceptable.

Based on the above calculations, the yellow PVC film was considered to be suitable for manufacturing of Micro Airship envelope.

Fabric Weight Estimate

Based on the data for the specific weight of 141.1 gms/m^2 of the selected material and the calculated surface area 19.1 m^2

The mass of envelope fabric came out to be = 2.69 kg

Assumed additional mass due to hooks

= 0.41 kg

$\therefore$ Total envelope mass

= 2.69 + 0.41 = 3.1 kg

Drag estimation

Firstly, the assumptions were made viz. flow over the hull is turbulent and the drag has been estimated in terms of drag coefficient, max. velocity, volume and the reference area as below

$$D = \frac{1}{2} * C_{dv} * \rho * V_{cr}^{2} * S$$

The drag coefficient (C_{dv}), the Viscosity and Reynold's number for flow was calculated. Viscosity was calculated using: $\mu = 1.7140 * 10^{-5} * \left(\left(T_s + \Delta T\right)/273\right)^{4.256}$

Where:

T_s = standard atmospheric temperature.

ΔT = the temperature above standard atmospheric temperature

Kinematic viscosity was estimated using $visc = \mu / \rho$

Reynold's Number was estimated using $Re = \dfrac{\rho * v * l}{visc}$

As per Hoerner [3], the drag coefficient over the envelope (C_{dv}_h) is given by

$$C_{dv}\_h = \left(0.172 * \sqrt[3]{lbyd} + 0.252 * (dbyl)^{1.2} + 1.032 * (dbyl)^{2.7}\right) / Re^{1/6}$$

Drag coefficient was estimated using: $C_{dv} = C_{dv}\_h \,/\, Drag\_factor$

Where

Drag_factor (Ratio of envelope drag to total airship drag) = 0.5243

The Stabilizers and material

A statistical analysis for stabilizers of around fifteen airships has been successfully carried out during the conceptual designing of the proposed Demo airship. With the use of same practice, dimension for micro airship stabilizer in "+" configuration was calculated. A schematic view of the stabilizer for Micro Airship is shown in figure 3 below. The relevant dimensions of the same are tabulated in Table 3

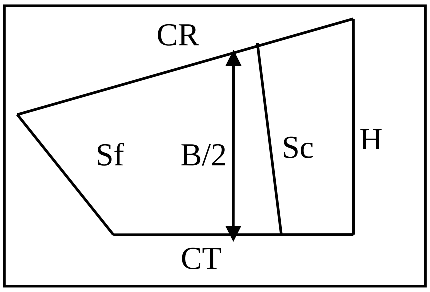

Figure 3. Schematic view of a stabilizer

The extensive and proper application of high-density thermocole and balsa wood strips has been done. Servo controllers with boosters were fitted to each fin in such a way that all control surfaces was made free to rotate around $\pm 30^0$ about hinge.

Parameter	**Fixed Surface**	**Moving Surface**
Surface area	0.24 m^2 (S_f)	0.08 m^2 (S_c)
C_T = tip chord	0.54 m	0.17 m
C_R = root chord	0.91 m	0.19 m
H = height	0.54 m	
B/2 = mean half span	0.43 m	

Table 3. Dimensions of the stabilizers

In order to attach the stabilizer surfaces, a Velcro sheet 660 mm x 20 mm was pasted on the envelope. This was done by sticking the Velcro to a PVC patch, which in turn was joined to the envelope by means of RF heating.

Eight hooks were provided on the envelope surface (in two rows for four each) for attaching high strength wires, which were attached to the stabilizers. For each wire, one adjustable plastic screw was tied so as to maintain the required tension and rigidity of stabilizer with respect to the envelope.

The Gondola

The size of gondola was decided so as to accommodate receiver, battery package, fuel tank, engine and payload. The gondola shape was chosen to be a rectangular framework made of Balsa wood.

To attach the gondola at the specified location on the envelope and also to support it, an aluminum frame was used with a curved top portion such that it exactly matched with the envelope contour. As shown in figure 4 below, a thick layer of sponge was provided on the curved portion such that it avoids the aluminum frame to pierce in to the envelope material.

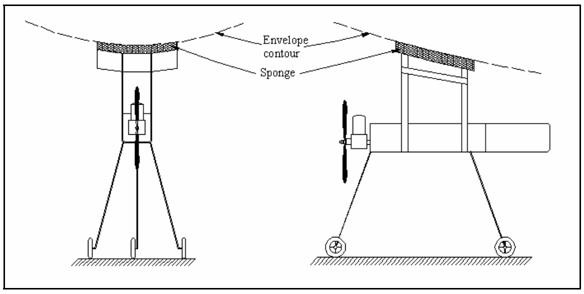

Figure 4. Micro airship gondola

Three landing gears were located at bottom of gondola to support the Micro Airship during landing.

The Power plant

An existing model aircraft engine with an 8” X 6” plastic propeller was selected. Figure 5 shows the typical OS engine.

Figure 5. The OS engine for Micro airship

Specifications of the engine

Type- 0.15 LA-S (OSMG1415), Displacement- 2.49 cc, Bore-15.2mm Stroke- 13.7 mm, RPM- 2500 to 18000, Power O/P - 0.41 BHP @ 17000 rpm Weight- 129.5 gm, Recommended propellers- 8 x 4-6.

Theoretical Estimation of Drag and Thrust available

Thrust available from engine T_a is given by $T_a = \frac{P * \eta_p}{V}$

Where

η_p = Propeller efficiency

= 0.4 (assumed)

V = Velocity of airship

P = Power available from engine

= 0.25 HP (assumed)

Using the above expressions, Thrust required (Drag) and Thrust available (T_a) for the Micro Airship for various forward velocities was estimated, and its graphical representation is shown below in figure 6. The maximum theoretical velocity for level flight is estimated as 32 kmph, which was quite adequate for the Micro Airship.

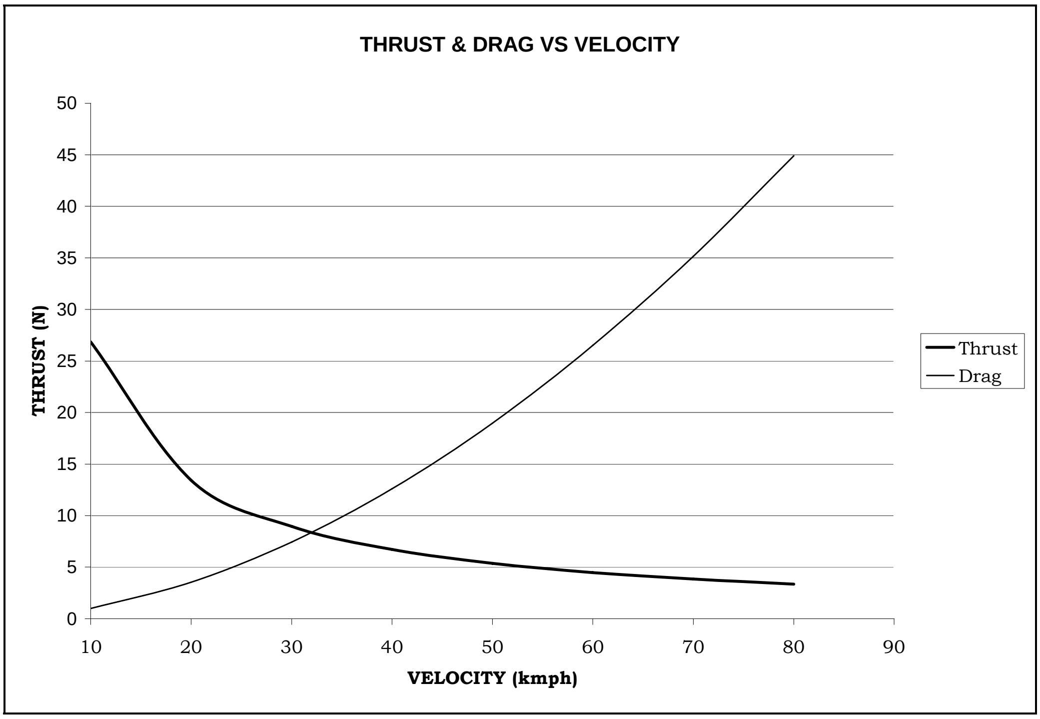

Figure 6. Graphical presentation of available thrust and required thrust

Fuel system

A small tank of 250 ml was located in the gondola, which was considered to be sufficient to last for flight duration of around 15 min. Methanol as fuel with castor oil (for lubrication) was used.

Generation of coordinates of Petals for envelope fabrication

The co-ordinates of the GNVR shape were scaled down to match the Micro Airship length. A fourth order polynomial fit was generated using these co-ordinates, and the cross-sectional shape of the envelope was generated. It was decided to manufacture the envelope in four petals for ease and accuracy in fabrication, as well as to minimize the wastage of the fabric. The co-ordinates of the petals were generated along the length. Figure 7 illustrates the sketch of the gore petal made of single panel.

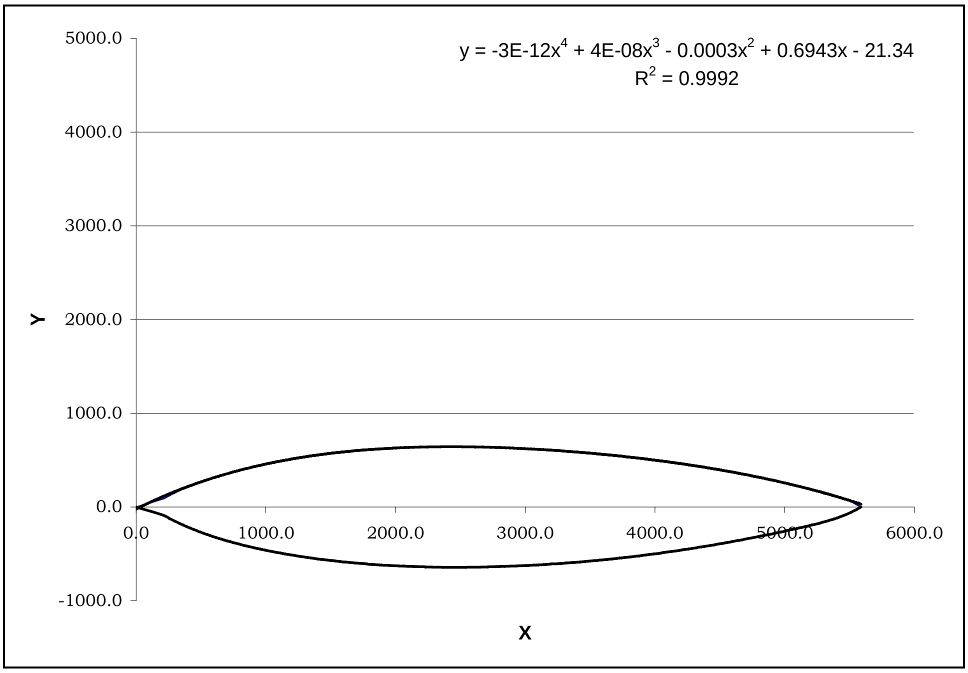

Figure 7. Micro airship envelope gore petal

Estimation of Weight and CG Location

The weight breakdown of the Micro Airship was obtained by actual weighing of each component. Table 6 lists the weight of components and their CG location. The reference for CG location was taken as the nose of Micro Airship for the X-axis, and the centerline of envelope was considered as a reference for the Z-axis.

The Gondola location was adjusted to match the overall distance of CG to the overall distance of CB (In other words, to locate CG below CB). The location of gondola was calculated and transferred on the petal such as to provide suitable hooks for gondola attachments. Table 4 shows the exact break up of the locations of all components of Micro airship.

COMPONENT	Weight (kg)	X_{ref} (m)	X_{cg} (m)	Weight *(X_{ref}+X_{cg}) (kg-m)
ENVELOPE FABRIC (with hooks)	3.10	0.00	2.50	7.73
PATCHES	0.20	0.00	2.50	0.50
NOSE	0.05	0.00	0.00	0.00
STABILIZER	1.10	4.33	-0.49	4.23
RIGGING	0.10	4.33	-0.49	0.38
GONDOLA	1.25	0.94	0.23	1.46
BALLAST	0.45	0.00	0.00	0.00
TOTAL	**6.25**			**14.31**
X_{cg} = 2.29 m				

Table 4. CG locations of components

Thus, the CG of Micro Airship was estimated to be located at 2.29 m from nose.

Description of Flight Tests

The first flight was carried out without stabilizers. The purpose of first flight was to check whether the airship could fly without stabilizers and also to check whether the engine selected was sufficient to meet the requirements practically. The flight test revealed that envelope-gondola combination was unstable. The maximum speed achieved was estimated to be between 3 and 7 m/s.

The second test flight was with stabilizers. Several descending approaches and touch-and-go were successfully accomplished. Some modifications were needed to be done viz. an extra ballast of 500 gm was attached at nose to balance the airship. So it was decided to shift the gondola position towards nose by 2mm mm. to reduce the ballast weight.

The third test flight was conducted as part of a series of demonstration flights that was carried out as part of the annual student technical symposium “Techfest 2002” at IIT Bombay. A hand-held GPS was installed on the airship during this flight; Table 5 shows the GPS readings recorded.

Parameter	**Value**
TOTAL TRIP	1.9km
FLIGHT DURATION	10:12 min
MAX. SPEED	24.5 kmph
AVG. SPEED	11.2 kmph
MAX. ALTITUDE	75 m
CRUISING ALTITUDE	69 m
TRACK	0.3 km

Table 5. GPS recording for the third test flight

Lessons learnt from the Micro Airship

The Micro Airship enabled the design team of PADD to gain first hand experience in design, fabrication and operation of remotely controlled airship. The ease of controllability due to control surfaces and performance of all electronic mechanisms like servos achieved while operating this airship was exceptionally good. Making an aerial vehicle with the use of LTA technology within a short time span from its conceptualization to realization was really an exciting experience.

In technical terms, the Micro Airship demonstrated that the statistical method followed for estimating the stabilizer and control surface size was quite satisfactory, and that GNVR shape is quite suitable for airship applications.

Some pictures of the Micro Airship during flight tests are shown in Figure 8-10.

Figure 8 Micro Airship just before launch

Figure 9 Micro Airship Just after Take off

Figure 10 Micro Airship above the ground

References: -

1. Gupta, Sudhir, and Malik, Sandeep, “Envelope Details for Demo Airship”, ADRDE report, January-2002.
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4. Khoury G. A., and Gillett, J. D., Eds., “Airship Technology”, Cambridge Aerospace Series: 10, ISBN 0 521 430 747, Cambridge University Press, 1999.