Practical Design of an Airship

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Airships have great potential for transportation, detection, tourism, and advertisement. This article presents the results of a practical design of an airship. A wood model of the air bag is tested in the wind tunnel and the coefficient of air resistance is determined. A waterproof cloth and the effect of the load on the adhesive tape used to connect the air bag, the gondola, and the tail part are tested. The resistant forces, the centroid of components, and the required power of the airship are determined. With the technical and weight consideration, the conceptual design of the airship has been developed. Thereafter, the prototype of the airship is fabricated.

Introduction

WOO and Murthy[1] performed the geometric linear and nonlinear static analyses and determined the free vibration characteristics of airships. Grech and Weigel[2] reported the survey of the crashed USS Macon airship. Onda and Morikawa[3] studied the structural design concept of the model, the design data, and the attitude control principle. Louchev[4] developed a steady-state model of the temperature regime of airships and hot air balloon shells. Baum and Louchev[5] analyzed the influence of conductance on the temperature regimes of thermally thin shells and truss constructions. Nagabhushan and Pasha[6] derived the equations of motion to investigate analytically the lateral and directional maneuverability characteristics and the powered yaw control augmentation of an advanced airship.

The purpose of this report is to present the results of a practical design of an airship. It is assumed that the windspeed is 10 m/s. It is desirable that helium provides the lift of the airship, that the airproof cloth has enough strength, that the airship is able to change the altitude and direction arbitrarily, that the airship be easily maintained and transported, that its weight is light, and that the factor of safety is high.

Phases of Design

The front-soft and rear-hard structure is determined during the conceptual design. The wood model of the airbag is used to determine the air resistance and the dynamics of the airship from the wind-tunnel test, and the result is used for the embodiment design. The dimensions and the strength of the airship are determined from the numerical calculation during the detailed design. The aft skeleton and the gondola are produced after the test of the cloth and connecting adhesive tape. The prototype of the airship is then fabricated within six months from the beginning of the work.

Experimental Data

In order to determine the air resistance during the flight of the airship, a wood model of the air bag with the scale of 1:30 is fabricated. The temperature and the density of the air are 14°C and 1.226 kg/m³, respectively. The weight of the mounted bar is 400 g. The measured strain of the mounted bar is 238 × 10⁻⁶. A piece of waterproof cloth with the dimensions of 10 × 10 cm and the thickness of 0.0844 mm is used in the

test, and the temperature of the water against the cloth is 20°C. No bubble exists when the water pressure is 1.125 atm and some small bubbles attach on the side of the cloth when the water pressure is 1.216 atm. If the load acted on this piece of cloth is 40 g, the elongation, stress, and strain are 1 mm, 46,493 N/m², and 0.01, respectively. Therefore, according to Hook's law, the modulus of elasticity is 47.4 kg/cm². The Kyosho Le Mans 360 Gold electric racing motor is used with the 7.2 V and 1200 mA Ni-Cd batteries for the dynamic test. The results of the thrust force are shown in Table 1. If the 8-V and 6-A lead batteries are used, the thrust forces remain about 710 and 700 g during 0–60 and 60–180 s, respectively.

Since a strong adhesive tape was not available during fabrication, a common adhesive tape with 2 × 2 cm was used to connect the air bag, the gondola, and the tail part. The results of the effect of normal load acted on it are shown in Table 2. The tensile strength of the adhesive tape is 0.185 kg/cm². If it is used to sustain the transverse load, the results are shown in Table 3. The transverse strength of the material is 0.3 kg/cm².

The Reynolds number is defined as $Re = (\rho V L/\mu)$, where μ is the viscosity of air and L is the characteristic length that is the maximum diameter of the air bag.[7] Some calculated results are obtained based on the experimental data. For a small deformation, the strain is proportional to the load that can be used to determine the coefficient of air resistance defined as $C_d = (2D/\rho V^2 A)$, where D is the resistance, ρ is the density of air, V is the speed of air, and A is the projection area of the air bag. The coefficient of air resistance vs the Reynolds number is shown in Fig. 1.

Table 1 Thrust force
of the electric motor

t, s	F, g
0	710
20	655
40	660
60	645
80	545
100	655
120	650
140	645
160	605
180	535
200	420
220	45
240	30
260	15
280	6
300	0–4
320	0–4

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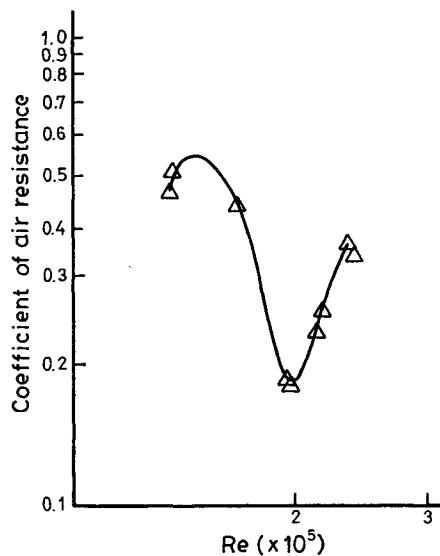†Student, Department of Mechanical Engineering.

Table 2 Effect of the normal load on the adhesive tape

Load, kg	Effect
0.4	No
0.65	No
0.8	No
3.7	Noise of crack
4.0	Separation
7.1	Separation

Table 3 Effect of transverse load on the adhesive tape

Load, kg	Effect
0.4	No
1.0	No
1.2	Separation

Fig. 1 Coefficient of air resistance vs the Reynolds number.

Table 4 Weights and the centroids of all components

Item	Weight, g	Centroid(x, y), m
Helium	3064	(3.2238, 0.0017)
Air bag	3115	(3.1559, 0)
Gondola	4853	(1.8300, −0.957)
Tail wing	1216	(60293, 0)
Aft skeleton	1273	(6.5046, 0)
Rear wheel	50	(6.125, −0.950)
Ring	35	(0, 0)
Adhesive tape	360	(0.5925, 0)

source is required. The maximum power of the remote-control electric motor from the available data is 0.1 hp that is equivalent to a two-stroke engine with the 0.1-in.[3] engine displacement. If the mechanism of the dynamic transmission is similar, the thrust force of the propeller is proportional to the engine power output. Hence, an engine with the 0.5-hp output is used for safety.

From the wind-tunnel test, it is seen that the separation of air from the model occurs. The profile of the air bag is modified to reduce the resistance. Since the full motion wing control is used for the airship, the tail wing rotary shaft and the control mechanism occupy some space. The length of the air bag is determined to be 6.15 m. The lift coefficient of helium is 1.018 kg/m^3 obtained from Woo and Murthy.[1] The volume and the lift are calculated to be 11.004 m^3 and 11.0202 kg, respectively. The buoyancy center located in the x-y coordinate is determined to be (3.119, 0) m. The weight of the air bag is determined to be 3115 g. The pressure of helium is 1.1 atm in order to remain the shape of the air bag.

The purpose of the tail wing is to balance and control the direction of flight. In order to improve the maneuverability and reduce the air resistance of the air bag, the full motion type is designed and the NACA 63009 wing section is used. The tail wing is fabricated to be trapezium. The induced drag is increased, but fabrication is easy and the structure is strong. In order to keep the perpendicular tail wing in the range of the airflow to increase maneuverability, the wing end of the tail wing is slightly bigger than the maximum radius of the air bag. Each piece of the tail wing is the same so that it is easy to be repaired and exchanged. A honeycomb structure that is light, but strong, is used.

The aft skeleton is used to place the transmission equipment of the tail wing. It must be strong to sustain the force of strong wind. An independent air bag, that must also be light and strong, is located at the rear portion to increase the lift. The profile of the rear air bag is made of high-density polyester. The rotary portion is made with the structure of two perpendicular trusses. The rotary shaft passes through it. The servo and the bearing are supported by the structure. The important part is enforced by the plywood. The air bag of the tail end is behind the aft skeleton. The volume and lift are 0.349 m^3 and 0.354 kg, respectively. The weights and the centroids of the parts are shown in Table 4.

The total weight of 10.902 kg is smaller than the lift, 11.556 kg. The centroid is located at (3.2112, −0.4681) m. When it is under a no-load condition, the airship goes up slowly and the inclined angle is 1.54 deg.

If the airship is under a no-load condition and its speed is 10 m/s in the horizontal direction, the calculated results of the lift, weight, resistance, and thrust force of the airship are 11.556, 10.902, 4.924, and 4.924 kg, respectively, and their centroids are located at (3.2238, 0.0017) m, (3.2112, −0.4681) m, (0, 0), and (1.875, −0.978) m, respectively. Therefore, the force acted on the tail wing is 1.452 kg. The coefficient of lift of the NACA 63009 is 0.111/deg, and the inclined angle is determined to be 4.1 deg.

The area of the tail wing NACA 63009 is 0.51 m^2, and the buoyancy center is located at (6.4275, 0) m. If the speed of the airship is 10 m/s horizontally and the maximum operation
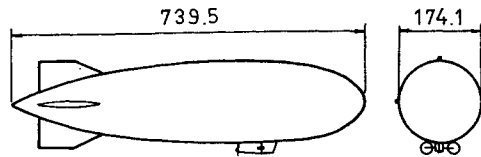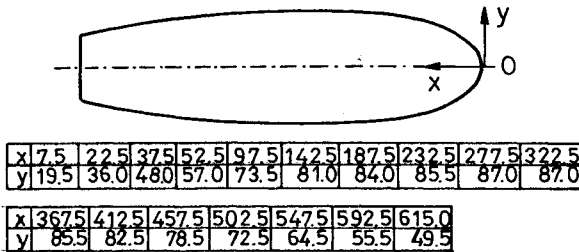
Numerical Calculation

Since the coefficient of air resistance drops and then increases, the flow is changed from the laminar flow to the turbulent flow. On the basis of the dynamic simulation, Re model $= Re$ real, the speed of air blown to the wood model is 30 times that of wind blown to the real air bag. The maximum speed of air in the wind tunnel is 14.03 m/s. The Froude numbers of the wood model and the real air bag are the same for the dynamic simulation. It can be written as

$$\left.\frac{D}{\rho v^2 L^2}\right|_{\text{model}} = \left.\frac{D}{\rho v^2 L^2}\right|_{\text{real}} \tag{1}$$

The air resistance acted on the model is 0.10564 N. If the maximum speed is 10 m/s during the horizontal flight and C_d remains 0.33137 for the reason of safety, the air resistance of the real air bag is 4.924 kg. In other words, the air resistance is increased to 4.924 kg with the maximum flight speed. If the maximum value of C_d of 0.49797 is used for the test, the air resistance becomes 7.399 kg.

Two alike electric racing motors are installed on the air bag. From the dynamic test it is known that the maximum thrust force of each electric motor is 0.71 kg. When the air resistance for the maximum speed is 4.924 kg, the difference of the power required is 3.504 kg. Therefore, a third power

Fig. 2 Airship (in cm).

Fig. 3 Dimensions of the airship (in cm).

x	7.5	22.5	37.5	52.5	97.5	142.5	187.5	232.5	277.5	322.5
y	19.5	36.0	48.0	57.0	73.5	81.0	84.0	85.5	87.0	87.0

x	367.5	412.5	457.5	502.5	547.5	592.5	615.0
y	85.5	82.5	78.5	72.5	64.5	55.5	49.5
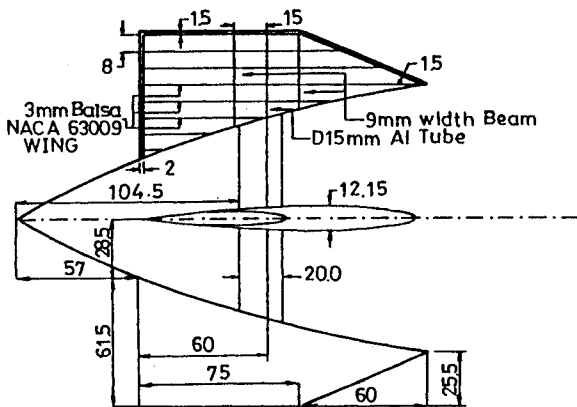
Fig. 4 Tail wing of the airship (in cm).
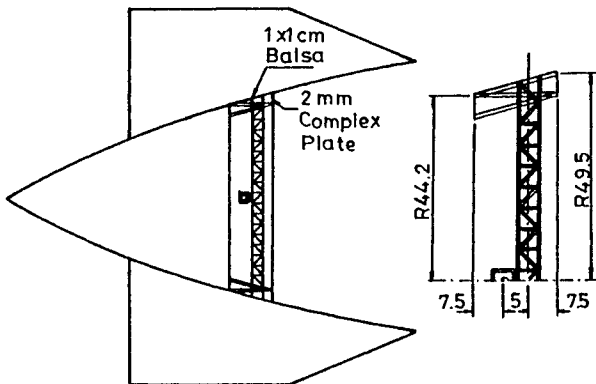
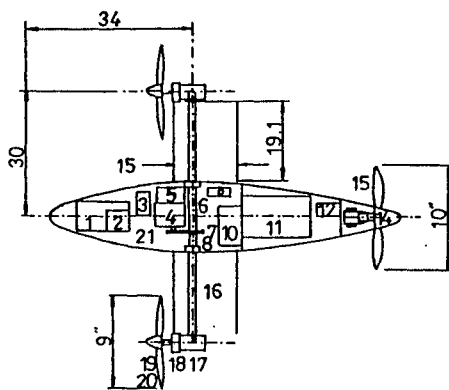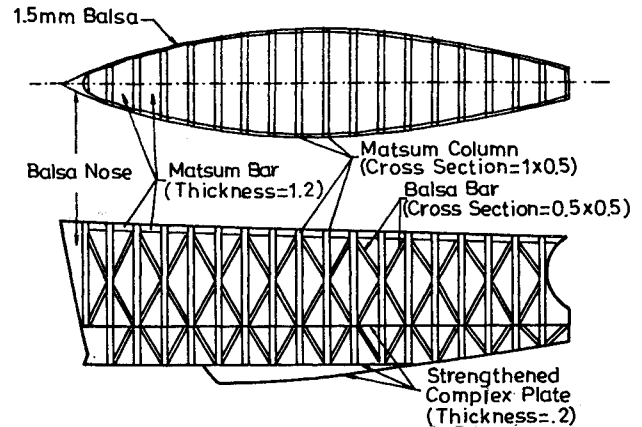Fig. 5 Assembly support structure of the aft skeleton (in cm).

Fig. 6 Gondola (in cm).

Fig. 7 Support structure of the gondola (in cm).

angle of the tail wing is ±10 deg, the moment is 22.7547 kg-m. The horizontal tail wing must assist the stability of the flight in the horizontal direction. If the electrical motor does not change the direction of flight, the moment is 13.4253 kg-m for +10 deg and 32.0841 kg-m for −10 deg, respectively.

If the action of the tail wing is not considered, to rise and lower depends on the electrical motor. If the turning angle is less than 5 deg, the original direction of the thrust force does not change significantly. The moments of the electrical motor are 0.8465 and 0.4886 kg-m for +5 deg and −5 deg, respectively. If it is turned to the thrust line and the total centroid is on the straight line, the moment is zero and the turning angle is −18.07 deg.

Results

The error of the measured data may be up to ±3.5%. The airship designed is shown in Fig. 2. The length and the maximum diameter are 739.5 and 174.1 cm, respectively, as shown in Fig. 3. The tail wing is shown in Fig. 4. The assembly support structure of the aft skeleton is shown in Fig. 5. The gondola is shown in Fig. 6. The support structure of the gondola is shown in Fig. 7. The prototype of the airship has been in the sky twice for demonstration.

Acknowledgments

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