Research on Aerodynamic and Structure Optimization of Airship

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Abstract

Stratospheric airship is a type of spacecraft near the space, compared to other aircraft, the flight speed is low, landing and landing site is simple, heavy load, can be a long time fixed-point and other characteristics. The design process of the stratospheric airship is to meet the weight distribution, the balance of buoyancy and gravity balance, balance of thrust resistance and energy balance. The multi-disciplinary design optimization method can meet the requirements of aerodynamics and structural mechanics, and effectively improve the overall design level of the stratospheric airship. AS a stratospheric airship an important component, while affecting the aerodynamic, structural properties, so the design is particularly important. The hull is the main part of the lift, which has important influence on the aerodynamic performance of the airship. The optimal design of the hull must take into account the strength and rigidity of the structure while pursuing the aerodynamic performance. Therefore, this thesis mainly focuses on the optimization design of the hull body profile parameters of the stratospheric airship.

Keywords

MDO, Airship, Optimization.

1. Introduction

The stratosphere is the most calm part of the atmosphere, free from weather and almost never wet. The area is neither a category of aviation nor a space category. As the stratosphere has stable meteorological conditions and good electromagnetic properties, national researchers have been trying to use the stratospheric airship platform for long-term observation and communication. Into the 21st century with the rapid development of related technologies in the world set off a research and development of the stratosphere airship platform boom.

As the airship and aircraft compared to the low speed, takeoff and landing site is simple, do not need long-distance runway, compared with the helicopter, heavy load, fixed point when the fuel consumption rate is minimal. So the airship can be used as a high-speed and high-energy aircraft to add, can be used for long-distance transport, polar expedition, oil and coal exploration, disaster relief, live broadcast, aerial photography, advertising operations and other civilian areas; can also be used for intelligence collection, Early warning detection, communication security and early warning and missile defense and other military fields.

In the military, the stratospheric airship with synchronous satellites, low Earth orbit satellites, high-altitude long-range unmanned aerial vehicles are not excellent features. It can be fixed in the ground synchronization position, but also according to the immediate need to automatically move from one area to another area, as shown in Figure 1. Today's satellites and unmanned aerial vehicles can not carry more than 2 tons of heavy load, UAV can not stay in a single location. However, the stratospheric airship has the flexibility to work 24 hours a day, working for up to several years. The stratospheric airship carries the radar at a glance, beyond the limits of the topography of the mountain, tall buildings and other parts of the Earth's surface.

On the basis of the overall layout, the design process of the stratospheric airship is the need to meet the problem of weight distribution, buoyancy gravity balance, thrust resistance balance and energy balance. The design process covers a number of disciplines, including structural mechanics, aerodynamics, control theory. The coupling between disciplines makes the interrelationships of disciplines, but the interdependence and constraints between disciplines in this case make the design process of airships very difficult.

The design process of the stratospheric airship is a typical systematic complex project. According to the system engineering point of view, the conceptual design phase is responsible for determining the shape, load, size, quality and other overall performance of the high-altitude long-jet stratospheric airship. All good or bad characteristics of the stratospheric airship are determined at the beginning of the design Down. There are many criteria for measuring the success of a stratospheric airship design, which is usually not unique.

As the requirements of the airship is multifaceted, the benefits of multi-objective overall optimization are the ability to coordinate the analysis of multiple aspects of the requirements, so as to explore the program potential and improve the design quality.

In the process of the design of the stratospheric airship, some of the disciplines need to be considered and highly integrated, and the overall design process of the airship is organized by the Multidisciplinary Design Optimization (MDO). Through the comprehensive analysis of the system, the program selection and evaluation Interdisciplinary cooperation to achieve automated design, can be very large to improve the technical quality, increase the degree of optimization of technology.

2. Pneumatic and structure analysis

2.1 Airship model

2.1.1 Sub-section Headings

In general there are rigid airship structure, semi-hard and soft three. Blimp airship, also known as pressure, this capsule shape depends on the internal and external pressure to get into the helium produced. This type of airship in the course of the flight should be attached to the airbag that is the airbag, if the external heat caused by the internal helium heat increases the internal and external pressure increases, the use of the valve to the internal gas from the airbag release appropriate, both to ensure both inside and outside The pressure is appropriate, but also to ensure that the main capsule of the helium will not be affected, while the skin will not be too much because of the expansion of the gas lead to deformation or even damage. If the other circumstances, if the main capsule of the gas due to temperature or other reasons to reduce the pressure, resulting in insufficient lift, but also the external gas into the sub airbag to maintain the required air lift in the air to ensure that the original shape of the airship. For the airbag, the main role for the control of the airship rise and fall there is to maintain the airship in the designated distance from the navigation, to facilitate the downside of the airship forward pitch angle, for the stratospheric navigation process of the match. In this paper, select the soft airship as an optimization target.

The composition of the stratospheric airship consists essentially of a streamlined capsule for the supply of lift, a loaded pod structure, and a tail fin with a flying yaw heading. This paper modeled the use of double ellipsoid single airbag hull.

As shown in Fig. 1, the two long and half axes of the hull are, defined as:

$$\frac{x^2}{a_1^2}+\frac{y^2}{b^2}=1, \frac{x^2}{a_2^2}+\frac{y^2}{b^2}=1 \tag{1}$$

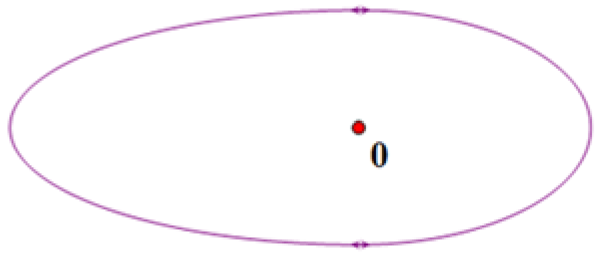

Fig. 1 Simplified hull model

According to the demand set the parameters as follows, Table 1:

Table 1. Parameter base value

Parameters	Base Data	Parameters	Base Data
Short Axis b(m)	6	Altitude (km)	20
Long Axis (m)	24	Gas Density (Kg/ m3)	0.088
Long Axis (m)	31	Gas Pressure (Pa)	5460
Working Pressurep(Pa)	1300	Temperature (K)	216.65
Poisson's Ratio	0.3	Young's Modulus (GPa)	4.5
Density (Kg/ m^3)	1107	Ultimate Stress	160
Allowable Stress	80		

2.2 Aerodynamics

2.2.1 Control equation

As a static aircraft, in the case of determining the volume of the hull, the airship to rely on the control of their own internal strength of the capsule and the same internal and external pressure to generate buoyancy. The hull is generally the main reason for the buoyancy of the airship because the air around the airship is a low-speed incompressible airflow. Using CFD method to simulate the airship around the environment, so this paper chooses the three-dimensional incompressible Renault average N-S equation as the control equation. The SIMPLE algorithm is used to solve the governing equations. The computational grid adopts the body structure grid, the far field boundary condition adopts the far field pressure boundary condition, and the surface is the non - slip boundary condition.

Three-dimensional incompressible, dimensionless N-S equation is expressed as:

Continuous equation:

$$D(V) \equiv \frac{\partial u}{\partial t} + \frac{\partial v}{\partial t} + \frac{\partial w}{\partial z} = 0 \qquad (2)$$

Momentum equation:

$$\frac{\partial u}{\partial t} + \frac{\partial^2 u}{\partial x} + \frac{\partial (uv)}{\partial y} + \frac{\partial (uw)}{\partial z} = -\frac{\partial p}{\partial x} + \frac{1}{\mathrm{Re}} \nabla^2 u \qquad (3)$$

Equilibrium of the above equation yields the Renault average N-S equation. We introduce the S-A turbulence model to form a closed system of equations.

2.2.2 S-A turbulence model

Using the equation turbulence model, the Spalart-Allmaras (S-A) turbulence model. Under these conditions, we do not need to estimate the length dimension associated with the shear stress thickness, and the equation for the S-A turbulence model can be obtained as follows:

$$\rho\frac{D\bar{v}}{Dt}=G_v+\frac{1}{\sigma_{\bar{v}}}\left\{\frac{\partial}{\partial x_j}\left[(\mu+\rho\bar{v})\frac{\partial\bar{v}}{\partial x_j}\right]+C_{b2\rho}\left(\frac{\partial\bar{v}}{\partial x_j}\right)^2\right\}-Y_v \quad (4)$$

CFD can simulate the flow of gas under the control of the three equations of fluid motion by numerical methods. When dividing the grid, the structure of the airflow is divided into the grid. When the shape parameters are updated, start CATIA to get the new 3D model, and then import the ICEM CFD preprocessing software for the grid division, reset the boundary conditions and perform the aerodynamic calculation.

2.3 Structure

The main static load of the stratospheric airship is the weight, the pod load and the lift. The lift is applied to the capsule in the form of a trapezoidal differential, and the pressure difference along the hull perpendicular to the height is given according to the following formula:

$$P=P_0+(\rho_{a0}-\rho_{he0})gh \quad (5)$$

$$h=y+b \quad (6)$$

Where h is the distance between the plane at which the load is applied and the lowest point of the maximum cross section of the hull, y and b are the ordinate of the applied point and the maximum radius of the hull, respectively, the pressure at the lowest point of the hull Difference value.

At the same time, the total buoyancy of the airship is calculated according to Archimedes' law:

$$F_{buo}=\rho_{ref}V_{as}g \quad (7)$$

Airship during navigation by air flow resistance is:

$$F_{drog}=0.5C_{DV}\rho_{ref}U_{as}^2V_{as}^{2/3} \quad (8)$$

In addition to its internal working pressure, the pneumatic pressure data is derived from FLUENT and interpolated to the ABAQUS model after coordinate transformation.

3. Aerodynamic and Structure Optimization

ISIGHT is a set of tools that can be used to integrate the software used in the design process and automatically optimize the software system platform. ISIGHT by the United States Engienious Software company developed. ISIGHT is an open integration platform that integrates commercial CAD software and CAE solvers easily using ISIGHT's process integration interface. ISIGHT can be integrated in addition to driving all commercial software other than commercial software, the same can also be connected to self-developed programs, such as FORTRAN, C + +, Visual Basic or script.

An MDO algorithm can decompose the system into subsystems, and this decomposition method can be consistent with the existing engineering design of the organization in line to avoid the subsystem of the coupling analysis; the subsystem can be simultaneously analyzed and optimized to improve efficiency ; Can also find the global optimal solution. Collaborative optimization (CO) is a multi-level MDO algorithm that decomposes the multidisciplinary optimization design into discipline-level optimization and system-level optimization through disciplinary-level optimization and system-level coordination using relaxation factors. The optimization issues that can be defined for this optimization framework are as follows:

Given parameters:flying height of 20km altitude,flight speed at 15m/s,carry 500kg of load including pod.

Optimize target: minimal weight

Design variable:shape parameters

Restrictions:floating weight balance, pushing resistance balance

The range of variables for contour optimization problem is shown in Table 2 below:

Table 2. Shape parameter value range

Numble	b	a_1	a_2
Min	4	20	27
Max	8	27	35

According to the aerodynamic / structural MDO framework of the airship, as shown in Fig. 2, prior to optimization, the DOE sample point file needed to build the proxy model. The process is as follows: DOE module, delete the intermediate file module,airship parameter update module,shape model generation module neumatic mesh generation module,pneumatic analysis module,structure wireframe generation module,structural finite element module,structure optimization module,response module.

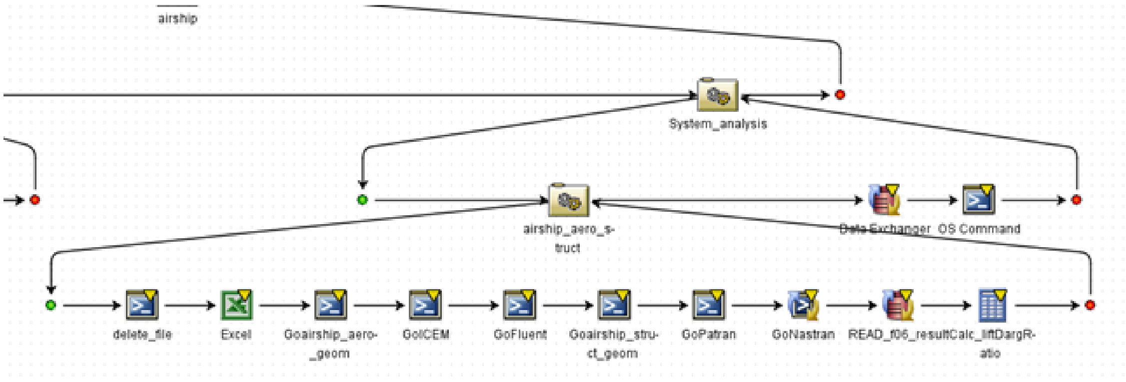

Fig. 2 Optimized framework

Where the DOE module is the core and controls the execution of the entire process. The DOE module generates all of the test sample design parameters, and then executes the following modules cyclically. Each time you run, delete the last run left by the middle file, and then follow the changed parameters to build the changed aerodynamic, structural analysis module, ready to start aerodynamic analysis and optimization of the structure above, and finally iterate to get the variables and be able to the overall quality of the structure.

After obtaining the DOE sample point file, it is then possible to construct the entire aerodynamic / structure optimized computing environment.

4. Conclusion

Based on the second-order optimization method based on agent model, the adaptive sampling method is used to improve the program by the quadratic programming solution in each iteration process, and then find the optimal solution.

The resulting airship optimization target results are shown in Table 3 below. It can be seen from the table that, compared with the initial parameters, after the system-level optimization, the parameter data of long axis is reduced, the parameter data of long axis is increases, the data on the short axis b do not vary much, finally get the minimum weight is 214kg.

Table 3. Optimization Results

Variable	Results	Variable	Results
Long Axis (m)	21.1274	Short Axis b(m)	6.79
Long Axis (m)	33.1355	Weight M(kg)	214.7830

According to the load conditions and the aerodynamic analysis data generated by the pressure difference of the hull, the optimal solution with the optimal target is obtained according to the second iteration of the agent model combined with the circumferential stress and the norm stress given in the structure. The optimization results show that, under this method, the coupling contradiction of the aerodynamic/ structural structure can be integrated to help the engineering staff to obtain the ideal optimization target.

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References

[1] Smith M S, etc. Applications of Scientific Ballooning Tech2nology to High Altitude Airships[R]. Aerospace America,2006,(2).
[2] C. Li, W.Q. Yin, X.B. Feng, et al. Brushless DC motor stepless speed regulation system based on fuzzy adaptive PI controller, Journal of Mechanical & Electrical Engineering, vol. 29 (2012), 49-52.
[3] YAO Wei, LI Yong, WANG wenjun, et al. Stratospheric airship optimization method and design parameters sensitivity analysis [J]. Journal of Astronautics,2007,28(6):1524-1528..
[4] Colozza A. Initial feasibility assessment of a high altitude long endurance airship [J]. Ohio: Analex Corporation, 2004,21(1)：56-58.
[5] Mueller J.B, ZHAO YiYuan, Garrard W L. Development of aerodynamic model and control 1aw design for a high altitude airship[C]//3rd"Unmanned Unlimited "Technical Conference. Chicago: AIAA, 2004: 1-17.
[6] AN Weigang,LI Weiji,WANG Haifeng. Multi—objective optimization design of envelope shape of a certain airship with deviations considered [J]. Journal of Northwestern Polytechnical University, 2007, 25(6): 789-793.
[7] M. Baker, J.Giesing. A Practical Approach to MDO and its Application to an HSCT Aircraft [J]. AIAA, 1995, 04(1):95-3885.
[8] Kroo.L, Altus.S, Braun R.D., Gage E, and Sobieski.I. Multidisciplinary Optimization Methods for Aircraft Preliminary Design[J]. AIAA, 94-4325.
[9] Patrick.N.Koch,J.P.Evans,David Powell. Interdigitation for Effective Design Space Exploration Using iSIGHT [J]. Journal of Structure and Multidisciplinary Optimization. 2002,3:111- 126.
[10] WANG Haifen, SONG Bifen, LIU Bin, et al. Exploring configuration design of high altitude airship [J]. Journal of Northwestern Polytechnical University, 2007, 25(1):56-60.