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CONCEPTUAL STUDY OF AN INNOVATIVE HIGH ALTITUDE SOLAR POWERED FLIGHT VEHICLE

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Abstract

Solar powered UAV，High Altitude Airship（HAA） and High Altitude Air Balloon are the main types of lower speed near space (20 to 100 km) flight vehicles. They have super long endurance, more than 30 days, above most airplanes, and can hardly be detected and attacked either. The vehicles therefore can be favorable when combined with different kinds of information acquirement equipments.

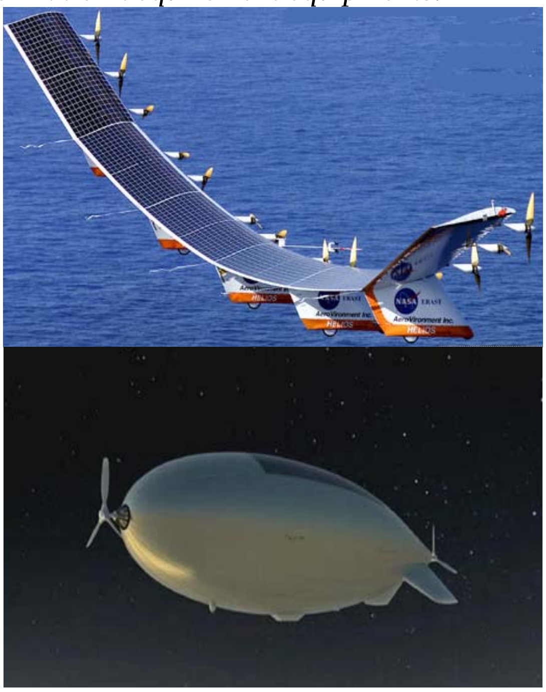


Fig.1 "Helios" and "Yuan Meng"

Europe and America are leading the way of the development of solar planes, while most of the solar planes they made and the concepts processed have large AR and wing span. The run way, the time, the weather available for the wide shelves is infrequent as the new one usually refreshes the size record. Weight design of solar powered UAV has so many problems to deal with that the payload is always strictly limited. It also can't be ignored that the complex flow field in the troposphere is a threat for the slender shelves.

HAA, adopting the aerostatics theory，has more superiority in the issues like payload and take-off & landing conditions. The body of HAA, whose volume could be huge, ranges from ten thousands to hundreds of thousands of cubic meters. The balance between its power requirement of flight control system, weight and the energy management can be an endless iteration.

Based on the technical features of the solar powered UAV and HAA, an innovative concept of high altitude solar powered flight vehicle, named Ladder, is proposed in this paper. Part of the problems will be solved with this combination concept, and its technical details are discussed in the paper.

The paper is divided into three sections:

1) A brief introduction of the Ladder concept

This paper compares the technical characteristics of current low speed near space flight vehicles. Furthermore, the Ladder is briefly introduced as well as its configurations in different flight phase.

2) Research of the conceptual design

This paper indicates the main contents and design method of Ladder. The key techniques of the design for the solar wing and ship body are illustrated and analyzed. Based on the configurations in different flight phase, the energy management is briefly introduced.

3）Technical detail analysis of Ladder

The technical details of the conceptual design schemes are analyzed, and the feasibility of *each technique is studied. Further thought of the research method is established.*

1 Introduction

Obviously, the features of HAA and high altitude solar powered UAV can make complementary advantages by some way. The concept of Ladder is proposed here as a trial to combine each other. The issues like take-off & landing condition, payload and flight safety for solar powered UAV and flight control, power requirement and huge volume for HAA could be obviously improved.

Ladder is made up of two parts, the solar wing and the airship body, as presented in figure 2. The solar wings can sweep forward and backward from the level position (configuration 2) and can be locked in the position of 80 degree, 0 degree and -45 degree correspond to the configuration 1, 2 and 3. The GC moves as the solar wings are sweeping.

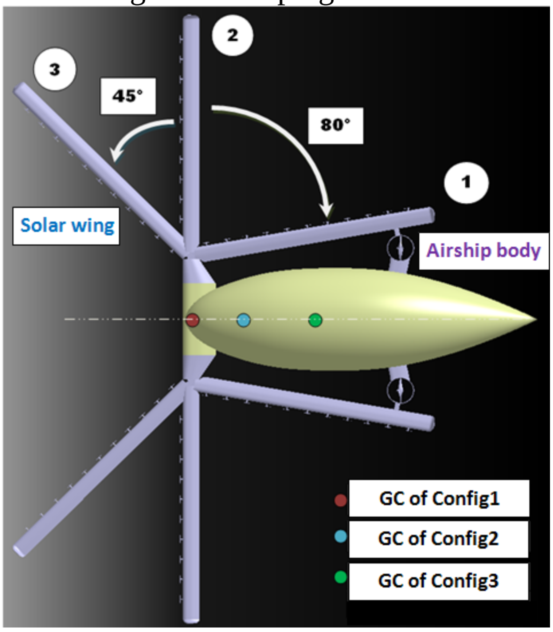


Fig.2 Basic Concept of Ladder

In configuration 1, the GC of Ladder is the centre of form of the airship body, and Ladder can takeoff and climb in an airship way. The solar wings are fixed and no lift generated from the wings is needed in the first takeoff and climb phase. In this way, comparing with solar powered UAV, Ladder can take off without runway, landing gears, power cost to provide lift, and the wings can be kept in a significant safer position, as presented in figure 3.

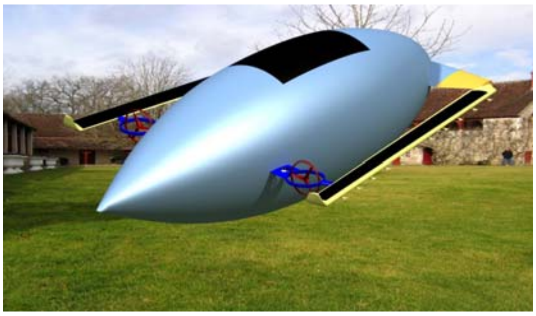


Fig.3 Take-off and Landing Configuration

After the first takeoff and climb phase with configuration 1, the solar wings will be unlocked and sweep forward by the thrust from the distributed engines on the wings to position 2, the cruising configuration, as shown in figure 4.

Fig.4 Cruising Configuration

Ladder will climb when the solar wings start to provide lift, until the cruising altitude. The attitude and the flight path can be controlled by the lift of the wings and the thrust of rotors fixed on the tail of the airship body. As solar power is stronger in higher altitude, Ladder should cruise in configuration 2 in the day and absorb/accumulate energy for the flight as well. Not like the airship, Ladder can easily change the attitude to a more efficient solar power gathering one, as shown in figure 5, so that the solar battery can provide and store more electrical power for the whole vehicle.

Fig.5 Solar Power Absorbing/Accumulating Flight

Ladder can hover in the air in both configuration 1and 3 at the same altitude. Some differences between the two kinds of hovering should be described. Firstly, hovering in configuration 1 can keep the solar batteries upward, as a traditional airship way. Secondly, hovering in configuration 3 style, as shown in figure 6, looking like a "daruma", can make the vehicle more stable, which is so important for the equipments carried by Ladder.

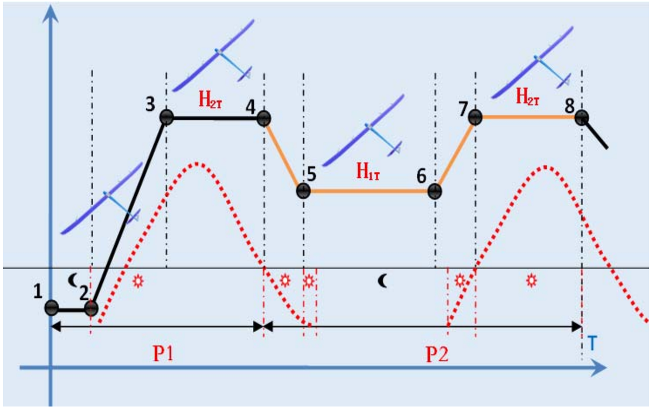
Fig.6 Hovering in the Air

The transformation from one configuration to another seems to be sci-fi in feel. However, this is the tunnel to combine the two parts together indeed, to achieve the profits in take-off & landing, energy cost, flight safety and flight control efficiency, etc.

2 Concept Design

2.1 Long Endurance Flight Strategy of Ladder

The classical flight profile of a high altitude long endurance solar powered UAV is shown in figure 7. The phase 4-8 presents the whole 24 hours flight, and the coming flight days repeat this phase until the day of landing. The key point of the flight strategy is that the plane descent from the daytime cruising altitude H_{2T} to the night cruising altitude H_{1T} during the sunset to reduce the power requirement in a 24 hours flight.

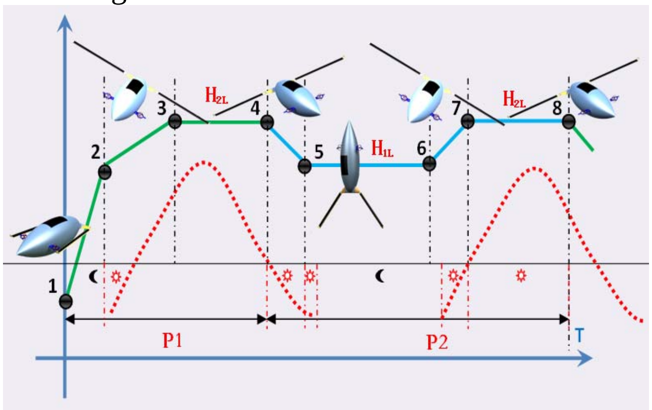


1-2 take-off; 2-3 first climb; 3-4 first cruise; 4-5 descent; 5-6 cruise in the night; 6-7 climb; 7-8 cruise in the daytime

Fig.7 Flight Profile of Long Endurance Solar Powered UAV

The reason for that can be explained with our research results: 1) The power needed for the plane to keep a level flight reduces a lot when the altitude decreases. The gross energy can cut down about 40 percent, H_{2T}=20000m and H_{1T}=12000m; 2) In the descent phase the plane can keep a long flight, about 3 hours, with a little energy cost.

The flight profile of Ladder is similar, shown in figure 8. The phase 4-8 presents the whole 24 hours flight likewise.



1-2 take-off & rise; 2-3 first climb; 3-4 first cruise; 4-5 descent; 5-6 hovering in the night; 6-7 climb; 7-8 cruise in the daytime

Fig.8 Flight Profile of Ladder

The flight strategy can be described as: 1) Ladder can rise itself to H_{1L}, the hovering altitude, in phase 1-2 by the buoyancy of the airship body to cut down the power and battery requirement needed in the take-off and climbing; 2) The 2^{nd} point is similar to the second one of a solar powered UAV; 3) Ladder can hover in the night at H_{1L}, also can decrease the energy cost in a 24 hours flight.

2.2 The Linkage between H_{1L}, H_{2L} and the Configuration Parameters

As the concept of Ladder introduced above, two main rules have to be fulfilled in its primary design:

1) At the hovering altitude H_{1L}, the buoyancy of the airship must support the whole Ladder, both the solar wings and the airship body;

2) At the maximum cruising altitude H_{2L}, the buoyancy and aerodynamic lift of the airship body and the lift from solar wings must support the whole Ladder together.

Based on the rules, two equations can be listed below.

For H equals to H_{1L},

$$F_{BABH_{1L}} = G_{wingH_{1L}} + G_{ABH_{1L}} \quad (1)$$

For H equals to H_{2L},

$$F_{BABH_{2L}} + L_{wingH_{2L}} + L_{ABH_{2L}} = G_{wingH_{2L}} + G_{ABH_{2L}} \quad (2)$$

Where $F_{BABH_{1L}}$ is the buoyancy of the airship body at H_{1L}, $G_{WINGH_{1L}}$ is the gravity of the solar wings at H_{1L}, $G_{ABH_{1L}}$ is the gravity of the airship body at H_{1L}, $F_{BABH_{2L}}$ is the buoyancy of the airship body at H_{2L}, $L_{WINGH_{2L}}$ is the lift of the solar wings at H_{2L} $L_{ABH_{2L}}$ is the lift of the airship body at H_{2L}, $G_{WINGH_{2L}}$ is the gravity of the solar wings at H_{2L}, and $G_{ABH_{2L}}$ is the gravity of the airship body at H_{2L}.

In the primary design, the aerodynamic lift of airship body can be ignored, and the change of *g* and the volume of airship body via altitude aslo. While, we can get,

$$F_{BABH_{1L}} = G_{wingH_{1L}} + G_{ABH_{1L}} \quad (3)$$

$$\rho_{H_{1L}} V_{AB} = m_{wing} + m_{AB} \quad (4)$$

And,

$$F_{BABH_{2L}} + L_{wingH_{2L}} = G_{wingH_{2L}} + G_{ABH_{2L}} \quad (5)$$

$$\rho_{H_{2L}} V_{AB} + L_{wingH_{2L}} / g = m_{wing} + m_{AB} \quad (6)$$

From equations (4) and (6), the result can be written as below,

$$L_{wingH_{2L}} / g = (\rho_{H1L} - \rho_{H2L}) V_{AB} \quad (7)$$

The equation (7) is the linkage between H1L, H2L and the configuration parameters.

2.3 Concept Design of Ladder

The models for the design of the high altitude long endurance solar powered UAV and HAA are available and utilized in the concept design of Ladder. In addition, the limits of the configuration design, the arrangement and the energy management have to be considered. The flow chart is shown in figure 9.

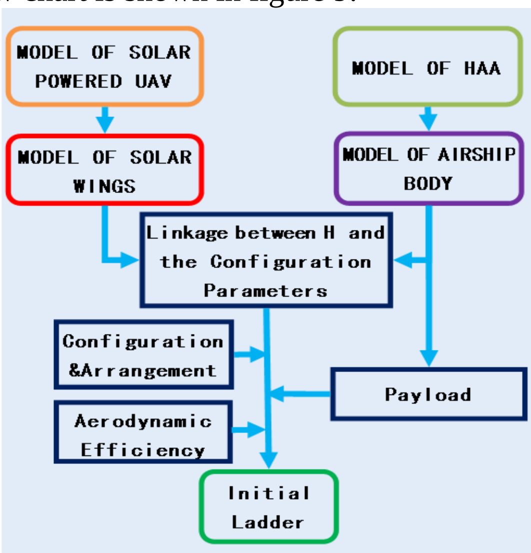


Fig.9 Flow Chart of Concept Design

As we can see from figure 9, the model of solar wings is based on the model of solar powered UAV with some modification including the details about the payload, the landing system, the battery, the wing structure and the control surfaces, etc. For Ladder, the wing load (*W/S*) and the aspect ratio (*AR*) are chosen based on the design experience of solar powered UAV design.

The model of airship body is based on the model of HAA with some new parts as a result of the modification of the wing model. The L D ratio (*L/D*) is chosen as a classical HHA.

The linkage between H_{1L}, H_{2L} and the configuration parameters is described in the last section. The calculation results shown in figure 10 choose 20000 m as H_{2L} and different H_{1L} ranges from 11 to 19 kilometers.

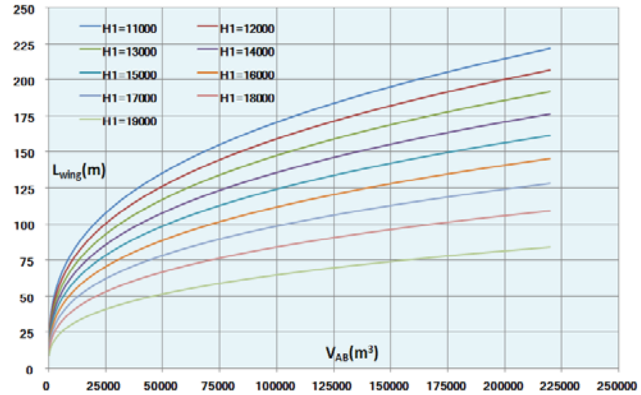


Fig.10 Results of the Linkage between H_{1L}, H_{2L} and the Configuration Parameters

The limits on configuration design mainly consider the requirement of the geometry parameters, GC and trimming. Which is funny, the configuration parameter, K_{conf}, almost only change with H_{1L}, and H_{2L} is fixed, as shown in figure 11. And the K_{conf} will give us the suggestion on feasible range of H_{1L}.

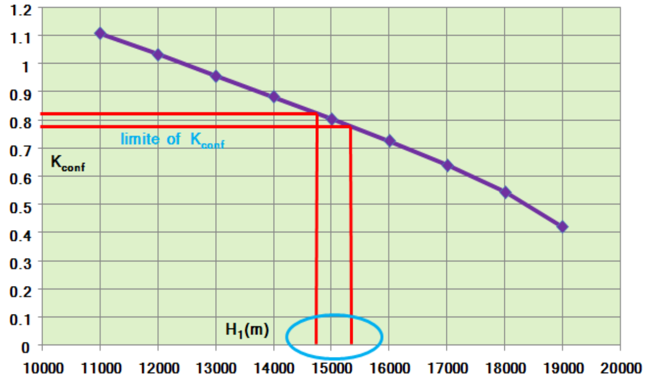


Fig.11 Feasible Range of H_{1L}

While the H_{1L} is fixed (15000m), you can choose different size of Ladder via the requirement of payload ability and the aerodynamic efficiency, as shown in figure 12.

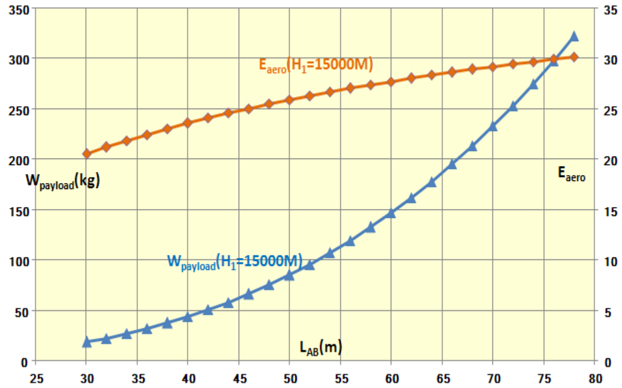


Fig.12 Design Results of Ladder

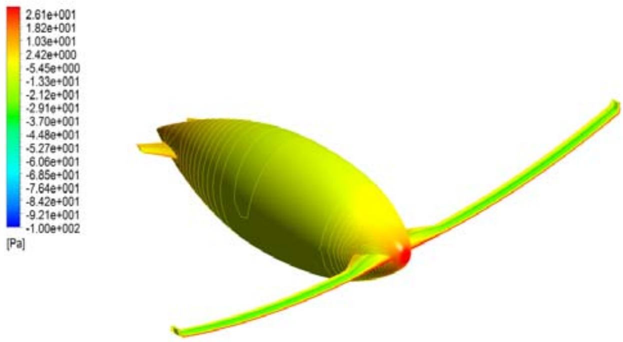


Fig.13 CFD Result of Ladder

3 Technical Details Analysis

3.1 Macroscopic View of the Three Kinds of Vehicle

Macroscopic results of different kinds of vehicles with same payload design are compared in figure 14. The solar wing of the pink Ladder is almost in the same size of the blue solar UAV, while the pink airship body is obviously smaller than the huge black HAA. It seems to be that Ladder is the solar UAV which fixed a not so huge airship that can solve the problems including establishment, energy and occasion needed in take-off & landing phase, and also can keep itself safe in unwilling weathers or system failures.

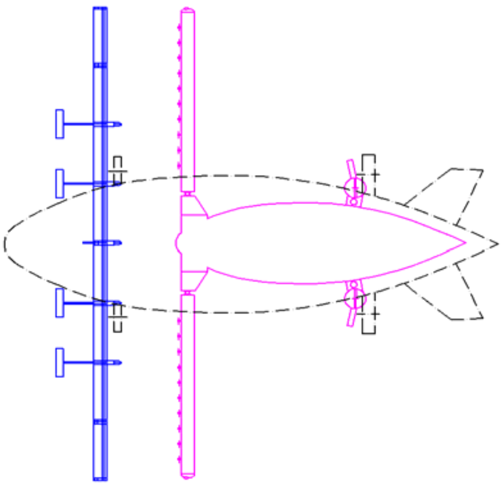


Fig.14 Comparison of the Vehicles

3.2 Flight Control Improvement

The yaw and roll control of the HAA and the pitch control of solar powered UAV are not so satisfying at present. The flight control of Ladder is easier by take advantage of the control of the lift and the thrust control of the propellers on the wings. Since the arms of the forces are longer, the flight is more efficient.

3.3 Aerodynamic Efficiency

Compared with solar powered UAV, Ladder can make an augmentation in aerodynamic efficiency through two ways: 1) the propellers on the solar powered UAV need an average high efficient performance ranging from zero to about 20 kilometers high. However, the propellers on the solar wings of Ladder do not have to work in the lower air so the fix-pitch propellers can be more efficient, about 10% higher, than the fix-pitch propellers for solar powered UAV. 2) One question may come out from your mind in the first sight is Ladder, that how can this plane keep a high L/D ratio by dragging a big ball? For this reason, the first point need to be explained is that as Ladder does not need to fly in the night, a high aero performance is not so important. The second one is that although the “big ball” can cause larger resistant force but its buoyancy force/drag ratio, similar to L/D for fixed wing aircraft, is bigger. So, by the truth, Ladder can make an augmentation in aerodynamic efficiency.

3.4 Balance in Hovering

As shown in figure 15, Ladder acts like a “daruma” when wind blows on it. The fin fixed on the airship body can help Ladder improving stability to keep the propeller, on the airship body, thrusting toward the wind and resisting the side force directly.

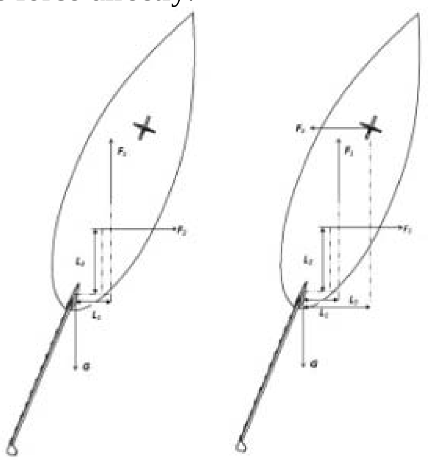


Fig.15 Balance Analysis in Hovering

4 Conclusion

This paper makes an introduction of a concept study for an innovative high altitude solar powered flight vehicle, and the concept is named Ladder. The research of the conceptual design and technical detail analysis of Ladder is introduced to make the technology visualized. And we hope this paper could bring something novel to you.

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