

Quite-Rigid Airship Structure Concept and Design for Enhanced Hovering Capability

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ABSTRACT

This paper explores a novel structural design concept for a demonstrator of a high altitude photovoltaic feeder airship. The presented structural design concept aims to minimize the use of strategic materials in the structure of the airship, but also to maximize the ease of construction of the structure.

The proposed design concept and method an effective analysis of historic airship structures considering their efficiency vs. weight and desired performances. By this analysis a novel structural design has been defined to reach the ambitious goal of a lighter and cheaper structure concept which can ensure comparable performances with traditional rigid airships.

A discoid shaped airship with a central column has been taken into account. Structural calculations and constructive design has been presented in depth.

CITATION: Madonia, M., Trancossi, M. and Coppola, A., "Quite-Rigid Airship Structure Concept and Design for Enhanced Hovering Capability," *SAE Int. J. Aerosp.* 5(1):2012, doi:10.4271/2012-01-1892.

INTRODUCTION

The MAAT (Multibody Advanced Airship for Transport) Project is a large European founded project about a novel concept of airship based on the cruiser/feeder concept. A cruiser which can remain Airborne for a long time and a cruiser which connect the feeder to the ground moving people and goods up and down between the cruiser and the ground [1,2,3,4].

Different considerations have been produced to ensure an innovative design for the feeder system which is the most critical part of the system. In particular the design of a technology demonstrator has been taken into account.

A preceding independent research activity by the E.R.M.E.T.E. (Energetic Research, Management of Energy & Thermofluidynamic Exchanges) named PSICHE (Photovoltaic Stratospheric Isle for Conversion of Hydrogen as Energy vector) have been permitted to define guidelines both for energy based design of an airship [5] and for permits the definition about scaling its dimensions [6].

They have also defined the general guidelines for photovoltaic energy production and conversions at stratospheric altitudes [7,8,9].

By this preliminary activity a novel design method for discoid airship has been developed. By these results and according to the standard design references a novel airship design has been developed.

HISTORICAL REFERENCES

The design activity has been started by taking into account some effective historical references. In particular some inspiration has been taken from an unconventional and famous French project developed during the beginning of the XX century, which has been called Capazza's Airship or Planeur "Bayard Clement" depending on the source [10] designed by the aviation pioneer Louis Capazza.

This project can be assumed as the previous and most interesting ever designed discoid airship, because of the concepts that are included into the project (Fig. 1 and 2).

This airship concept presents at a very preliminary CFD analysis of a simplified model very interesting characteristics. It mixes together the main benefits of a discoid airship with the ones of a traditional one.

Some interesting characteristics of this airship have been implemented into the concept which is presented in this paper. It is because they can be suitable for an airship concept using hydrogen as buoyant gas.

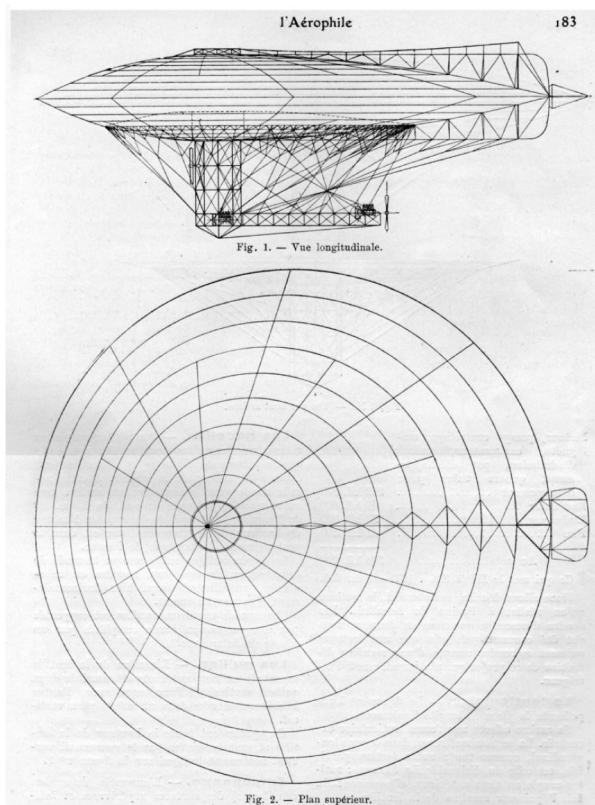


Figure 1. Capazza's airship design

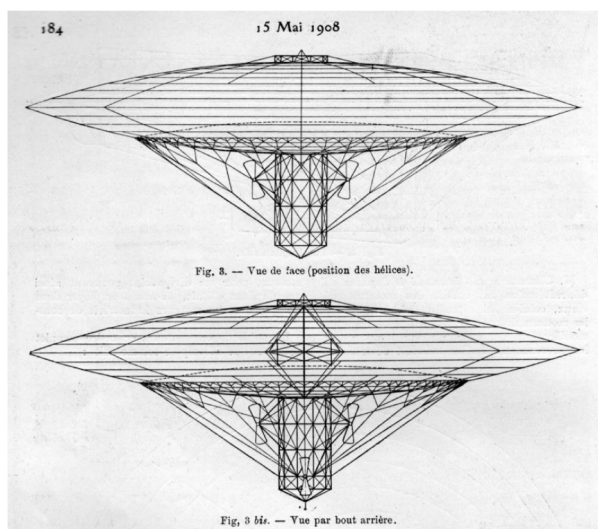


Figure 2. Capazza's airship design views

MISSION PROFILES

This airship is conceived for two main efforts the primary is related to act as a demonstrator of MAAT project feeder concept demonstrator, the second is related to a possible application related to aerial infrared thermography of towns and cities.

The first effort is related to have a system which can move mainly vertically and the second to a system which can move at much reduced speed to permit a continuous monitoring of a predefined territory. For both applications the capability of hovering and of maintaining a correct behavior are more interesting than traditional flight capabilities.

To realize these activities two different mission profiles have been defined.

The first provide the following elements: vertical take off by buoyancy, with engine control against wind; increase of altitude as an aerostatic balloon, some horizontal flight to ensure connection with a moving body.

The second profile can have a directional behavior and must flight on predefined straight routes which can be useful to take shots of the town at predefined distances defined by the optics mounted on the infrared camera.

HYDROGEN USE RELATED RISKS

One of the most important aspects connected to this concept of airship is related to the use of Hydrogen as buoyant gas. It requires some important consideration about the necessity of reducing the dangers connected to Hydrogen use.

In particular it appears a great problem to avoid the possibility of avoiding the formation of mixtures of hydrogen and air which can exceed the lower flammability limit of hydrogen in air.

This element forces to an effective redefinition of the airship concept itself based on the Hydrogen Fire Safe Airship concept [4]. This concept presents a novel variable volume airship concept.

With this mechanism (Fig. 1) the volume of the buoyant gas in the lower inflatable ballonets generate a variation in the buoyant force, which can be related to the associated altitude. In this way the buoyancy of system can be easily controlled. The main consequence of this novel control model is the avoidance of the auto ignition conditions of the Hydrogen, also by introducing air recirculation systems or not hermetic external envelope of the airship.

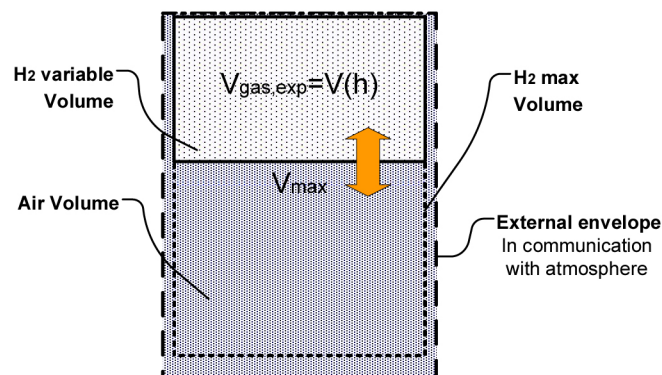


Fig. 1. The novel "Open Balloon Airship" Concept

SYSTEM ARCHITECTURE

For the MAAT system Feeder it has been identified a novel architecture which is conceptually conceived by an innovative airship concept. The architecture is based on the above presented Open Balloon Architecture (OBA), and characterized by an intelligent multi balloon system (Figure 2).

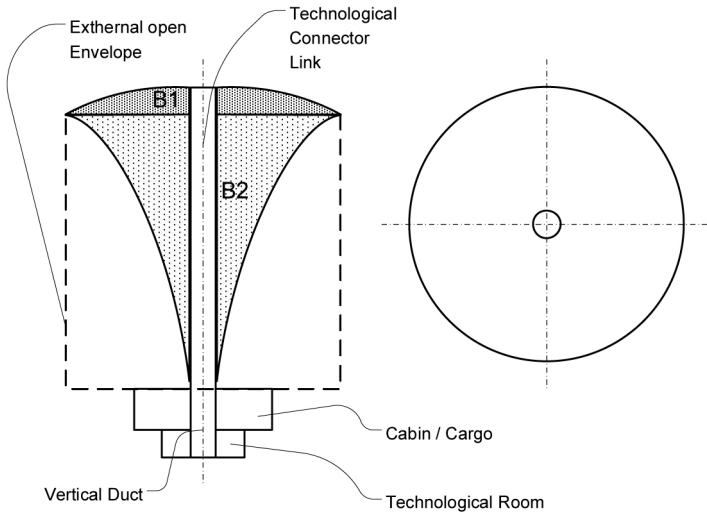


Fig. 2. Airship Schematics of the Open Balloon Architecture

The Bi symbols in Figure 2, represent individual balloons. In particular, B1 represents the primary balloon on the top, which has to guarantee the lift capacity at ground level. B2 is the secondary balloon and represents the balloon, which has to provide the necessary lift, in order to operate at higher altitudes.

BUOYANCY GOVERNMENT SYSTEM

This airship architecture presents an innovative possibility of buoyancy control by volume modification of the hydrogen balloon/balloons. It can be performed into two different ways: by balloon dilatation inside a high porosity fixed volume envelope or by external volume variation.

Both architectures are going to be evaluated considering that the first requires an increase in terms of structural weights.

Airships are being pursued for their ability to lift important with a much reduced energetic consumption. They accomplish this by displacing air with a less dense gas that will rise to seek density equilibrium. A mass balance relationship can represent this principle

$$m \cdot g < g \cdot V_{air} \cdot (\rho_{air} - \rho_{gas}) \quad (1)$$

If the weight of a structure is less than the difference between the weight of air displaced and the gas displacing it,

there will be an upward force generated. The buoyant gas is considered to be unmixed with air.

Maximum Weight or “Lift Capacity”

By equation (1) it is possible to express the maximum weight or “lift capacity” of an airship. It is a function of its lifting gas mass according to the below equation(2).

$$L = g \cdot V_{gas} \cdot (\rho_{air} - \rho_{gas}) \quad (2)$$

A design factor in developing an airship is to ensure that the pressure relationship between the gasses inside and outside the airship hull is not impacted. A certain overpressure Δp_{gas} must be assured to the buoyant gas. It means a constant overpressure must exist inside the hull.

The constant pressure relationship must be maintained.

$$p_{gas}(H) + \Delta p_{gas} = p_{air}(H) \quad (3)$$

in which

$$\Delta p_{gas} = 125 + 0.33 \cdot v_{max}^2 \quad (4)$$

is the necessary optimal overpressure for a semi rigid airship [12].

If the pressure relationship is maintained then lifting gas pressure decreases uniformly with atmospheric pressure as the airship rises and the gas is able to expand its volume. As volume increases, gas density in the hull decreases and the buoyant force is maintained. The buoyant force will lift the airship until the hull volume is at a maximum and the pressure relationship between the hull and the environment can no longer be held constant. At this point the airship has reached its maximum or “pressure” altitude.

The most important parameter, which guarantees an optimal behavior of the airship, is the density ratio (5):

$$\sigma(H) = \frac{\rho_{air}(H)}{\rho_{air}(0)} = \frac{\rho_{gas}(H)}{\rho_{gas}(0)} \quad (5)$$

The density ratio permits to express the maximum lift capacity in a more effective way than equation (2). In particular it can be expressed as a function of zero level density as follows:

$$L = g \cdot V_{gas} \cdot \left(\frac{\rho_{air}}{\rho_{gas}} - 1 \right) = g \cdot V_{gas} \cdot \left(\sigma \cdot \frac{1}{\rho_{gas}} - 1 \right) \quad (6)$$

Lifting gas mass usually remains constant within the envelope as the airship rises, except permeability dispersions. If internal air ballonet deflation is controlled properly, the airship can rise to its maximum pressure height and maintain that altitude. If an airship rises above its pressure height the

pressure difference will be exceeded and lifting gas will be vented resulting in diminished lift capacity. To prevent this from happening, some ballonnet inflation must be maintained. It is a simple solution to avoid the airship from reaching its maximum altitude and the risks of over-altitude gas venting.

Maximum Volume

The maximum lifting gas volume is reached when the gas density decreases without impacting the pressure differential in the hull. Since density is a ratio of the mass of a gas to its volume, the volume of a lifting gas expanded to the equivalent atmospheric density will provide rapid insight into how big an airship must be. The mass of helium used remains constant and the density of helium can be predicted as a function of altitude by taking advantage of the density ratio. The airship size can be predicted by the following equation.

$$V_{gas,max} = \frac{m_{gas}}{\sigma_{max} \cdot \rho_{air,0}} \quad (7)$$

ALTITUDE CONTROL MECHANISMS

The general equation of the system is

$$L = g \cdot V(H) \cdot (\rho_{air}(H) - \rho_{gas}(H)) \quad (8)$$

in which $\sigma(H)$ is expressed by (5). Different mechanism of volume variation can be defined and applied to the conceived airship.

Isothermal Volume Variation

The altitude control by volume variation in isothermal conditions with atmosphere can be expressed by ideal gas equation and it can be expressed as a function of H by the following expression:

$$V(H) = \frac{m_{gas}}{\left(\sigma(H) + \frac{\Delta p_{gas}}{\rho_{gas}(0)} \right) \cdot \rho_{air,0}} \quad (9)$$

If the payload is M_p the general system equation becomes:

$$M_p = V(H) \cdot (\rho_{air}(H) - \rho_{gas}(H)) \quad (10)$$

Temperature Variations

If the temperature of the buoyant gas can vary by any cause the equation of the system becomes:

$$L(H) = g \cdot V(H) \cdot \left(\rho_{air}(H) - \frac{p_{gas}(H) + \Delta p_{gas}}{R_{gas} \cdot (T_{air} \pm \Delta T_{gas})} \right) \quad (11)$$

and the payload is:

$$M_p = V(H) \cdot \left(\rho_{air}(H) - \frac{p_{gas}(H) + \Delta p_{gas}}{R_{gas} \cdot (T_{air} \pm \Delta T_{gas})} \right) \quad (12)$$

Ballast Variations

Mass can have variations to help the airship to reach a predefined altitude or the altitude maintenance. This system requires any kind of ballast which can be safely discharged. This ballast can be of any nature, depending on operative possibilities. The problem of this control mode is related to safe off-board evacuation: liquids such as water and compressed air do not present any danger for the environment and for people beyond.

Mass variation can be represented by a modification of mass. In particular it can be represented as:

$$M(H) = M_p \pm \Delta M(H) = V(H) \cdot (\rho_{air}(H) - \rho_{gas}(H)) \quad (13)$$

Multiple Effects Combination

A multiple effects combination model can be performed by combining the above equations in terms of superposition of effects. This More general equation can be expressed as follows:

$$L(H) = g \cdot V(H) \cdot \left(\rho_{air}(H) - \frac{p_{gas}(H) + \Delta p_{gas}}{R_{gas} \cdot (T_{air} \pm \Delta T_{gas})} \right) \mp g \cdot \sum_k \Delta M_k \quad (14)$$

or

$$M_{tot}(H) = \sum_i M_{volume,i} + \sum_j M_{thermal,j} \pm \sum_k M_{pound,k} \quad (15)$$

which leads to

$$M_{tot}(H) = V(H) \cdot \left(\rho_{air}(H) - \frac{p_{gas}(H) + \Delta p_{gas}}{R_{gas} \cdot (T_{air} \pm \Delta T_{gas})} \right) \mp \sum_k \Delta M_k \quad (16)$$

in which $p_{gas} = p_{air}$.

By this equation the system behavior can be described in different operative modalities.

SYSTEM ARCHITECTURES

Two different system architectures have been taken into account. They are represented in Fig. 3.