

Fire-safe Airship System Design

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ABSTRACT

This paper presents the new Hydrogen Fire-safe Airship system that overcomes the limitations present in previous airships designs of that kind, when considering their functioning at advanced operative position. Hydrogen is considered to be more effective than helium because of its low-cost production by hydrolysis, which process is nicely driven only by the photovoltaic energy.

This paper presents a novel architectural concept of the buoyant balloon designed to increase the fire related safety, when applying hydrogen as the buoyant gas. The proposed buoyant volume is designed as a multi-balloon structure with a naturally ventilated shape, to ensure that hydrogen cannot reach the dangerous concentration level in the central airship balloon.

This concept is expected to be the start of a novel hydrogen airship type, to be much safer than preceding ones. It permits to reduce the traditional economic costs, when compared with helium inflated airships, due to the helium scarcity in the world gas resources and its related production costs.

This paper presents the volumetric analysis necessary for a preliminary design activity of this novel control system of the ballonets in this airship concept and to define the design of the airship's architecture.

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INTRODUCTION

This paper constitutes the preliminary presentation of fundamental element of the Multibody Advanced Airship for Transport (MAAT) project [1], started in September 2011, and recorded by European Commission on November 28, 2011. It is the project of a novel stratospheric airship based on two separated vehicles: the first is a feeder (with the capability of about 50 passengers or equivalent in terms of freight) and very large cruiser with the capability of 300 passengers. The preliminary project design is under development and most data are qualitative in the actual state of research.

The system is based on a novel operability concept. The cruiser is designed to remain airborne for long times connecting most populated centres and the feeder has to move mainly vertically connecting the cruiser with the ground, connecting rigidly to the cruiser becoming a part of

the cruiser itself. A similar system is completely new in today aeronautic research panorama.

The project requires reaching another fundamental goal: the possibility of using Hydrogen as a buoyant gas for both systems. It is a second fundamental goal which requires an effective analysis of safety conditions and forces to design a novel airship system, because traditional air balloon systems do not permit to minimize the risks connected to Hydrogen use. In fact, the permeability of the ballonnet materials allows the diffusion of hydrogen into air ballonnet, and it would not possible to verify (both globally and locally) if concentration of hydrogen can reach the auto ignition conditions.

To minimize this risk a novel concept of airship has been developed to minimize the risk of reaching the auto ignition conditions considering a possible operative model of the feeder which must assume motion mostly vertical. This paper will present this novel architecture and verify under very conservative hypothesis the volume of the necessary buoyant

gas to reach an operative altitude which is defined between 15 and 16 km.

It is assumed that during the climb, the system has the same attitude of a stratospheric balloon can be controlled only in vertical movements and do not present any resistance to the wind. It can use its own propulsion system to move on a horizontal plane in the reciprocal rapprochement between the cruiser and the feeder.

This paper present, presents the novel architecture of such a defined feeder system which is in a preliminary design phase, the general design guidelines of the control system and the volume variation of hydrogen ballonets in a very specific system configuration.

CRUISER/FEEDER CONCEPT

MAAT project [2, 3] investigates the cruiser/feeder concept in air transport. It aims to verify the possibility of such a system to be economically justified and set into operation. Functional requirements and necessary conceptual solutions are analyzed.

SPECIALIZED AIRSHIPS CONCEPT

The energetic auto sufficiency of the system requires a large photovoltaic hull. It is necessary to provide the necessary electrical power for the predicted energetic needs [8,9,10]. This design scenario is characterized by two different operation modes:

1. Sailing movement: in which the Cruiser propulsion system is enhanced by winds, like a sailing boat which moves on predefined trajectories being pushed by the wind. This movement enables the Cruiser to change position (for example, moving into quieter area) to simplify the rendezvous with the Feeder.

2. Propelled movement: the Cruiser can move into the area of the calm atmospheric conditions utilizing only the propelled propulsion, which guarantees lower energetic consumption.

The sailing movement can be interesting from the energetic point of view, because it can ensure the (1) best performances and (2) operative speeds, ensuring also a lower energetic consumption.

Cruiser and feeder have been conceived as very specialized airships, especially to simplify the controls of such a very complex system (Fig. 1). The feeder is designed to move almost vertically such as a high altitude balloon. It is designed to move vertically by effect of the buoyancy and eventually the reduction of mass in terms of effective ballast. The ballast can be constituted by compressed air or water which could be released safely.

When the feeder reaches the operative altitude (15÷16 km) it can move on a horizontal plane by its own propulsive system.

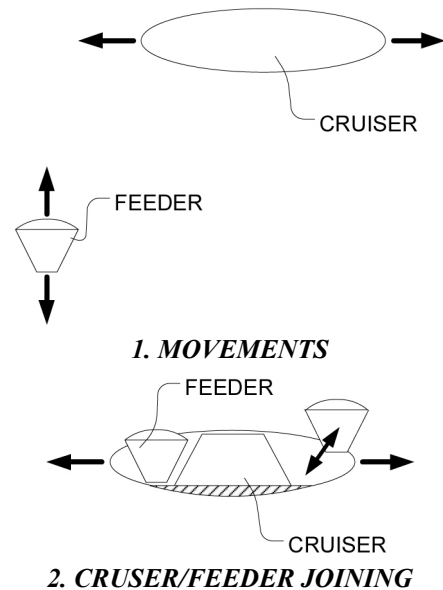


Fig. 1. Schema of cruiser and feeder operability

The cruiser is realized by a central element with one or more feeders attached permanently during flight. One or more Feeders can be released approaching well defined position to bring passengers and freight to the ground and to lift up to the cruiser passengers and freight.

ENERGETIC AND OPERATIVE REASONS OF THE PROPOSED MODEL

MAAT has been defined as a system fully dependent on solar photovoltaic energy. It is advantaged by the substantial increase of the photovoltaic productivity at high altitude, which is almost double than the one verified at sea level [4, 5]. In particular it has also been verified that hydrogen production at 15 km is almost three times in terms of compressed gas at 20 MPa and two times in terms of liquefied gas if compared to the ground level productivity [6].

Energy storage (possibly in multiple forms) must ensure 3 kinds of actions:

1. Basic energy storage system must ensure basic flight performances, especially for the night time conditions maintaining the system in motion (assure energy needed for the averaged propulsion performance);

2. Rapid reactive systems must ensure the ability of the system to guarantee its stability by immediate reaction of the disposable systems, such as batteries;

3. Emergency energy system must ensure the energy needs in the case of emergency situations to guarantee system safety issues, enabling the operations of essential onboard systems (possibly operated by batteries).

The system is being conceived to use hydrogen both as energy storage system (compressed at 20 MPa) and as buoyant gas. It is necessary technical choice because of two fundamental reasons:

1. the high prices of helium;
2. the necessity of continuous replacement of the dispersed gas by ballonets permeability.

This model presents also another fundamental advantage if compared to the traditional use of helium. It allows a continuous substitution of dispersed gas by balloon envelope permeability. The necessary amount of water is demanded to feeder itself.

The vertical movements by buoyancy permits a large reduction of energetic consumption during the travel of the feeder. In fact the energy consumption can be located in higher atmosphere, where the density of the air is much lower and the aerodynamic resistance is reduced.

HYDROGEN ECONOMIC ADVANTAGE

The hydrogen convenience is based on two facts:

1. the constant increase of the market price of Helium encourages the use of Hydrogen as buoyant gas [7];
2. the increased possibility of replacing the dispersed gas into the environment by the permeability of tissues.

These two fact put into consideration to analyze the possibility to use Hydrogen as buoyant gas, as described in the following section.

USE OF HYDROGEN AS BUOYANT GAS

The use the Hydrogen as buoyant gas is explicitly stated to be the qualifying element of the MAAT Project, despite it is a potentially dangerous gas. This risk forces to take into account the risk related to hydrogen by design. The fundamental requirement to ensure the safety conditions for the airship operations is to maintain the relative concentration of Hydrogen outside of the flammability range, everywhere inside the airship volume.

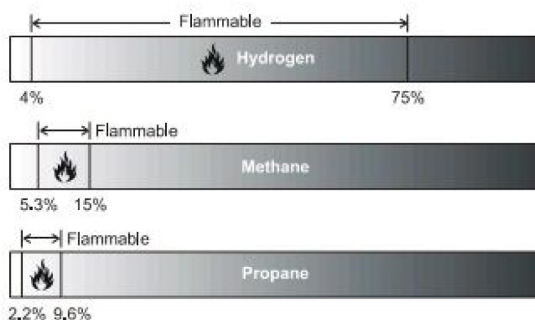


Fig. 2. Hydrogen flammability conditions

The flammability conditions for Hydrogen varies with altitudes and different methods must be analyzed, when selecting terms of the governing equations, to model the atmospheric conditions and the related thermodynamics. The optimum field of application is defined at any altitude, taking into account the emergency conditions related to the possible balloon failures.

Our analysis resulted in the hypothesis to have a buoyancy control method, which takes into account the safety issues, related to the use of hydrogen, and in addition the proposed method can be applied to control the airship vertical movements.

FEEDER - A BALLOON WITH VERTICAL MOVEMENT CONTROL BY BUOYANCY

The concept of the Feeder has been conceived taking into account the above mentioned considerations concerned with the Hydrogen safety issues.

The proposed solution has been named “Multi-balloon Airship Buoyancy” (MBAB). It will guarantee an enhanced level of safety by design, ensuring the buoyancy control of the airships (Feeder and Cruiser) which constitutes the MAAT system. This design strategy allows a novel “open shaped airship” concept, eliminating the need of air ballonets, due to the presence of multiple balloons (inside the airship shape), which ensure high permeability in towards the atmospheric air [12, 13].

The first balloon has a fixed volume and guarantees the necessary buoyancy to maintain the equilibrium at the sea level. One or more balloons placed in the lower part of the shape can vary their volume. Both balloons are designed to use hydrogen instead of helium as buoyant gas.

This design, which guarantees a better control and safety for airships. is worked out through the design of general plants and volume calculations performed up to 20 km, even if the envisaged operative altitude will be lower (15 - 16 km).

The proposed model is different than the one applied in the traditional airship concept design, shown in Fig. 4 and 5.

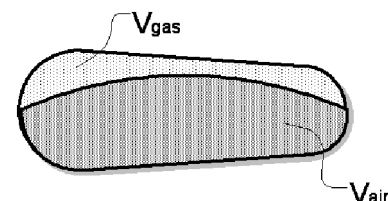


Fig. 3. Traditional airship schema

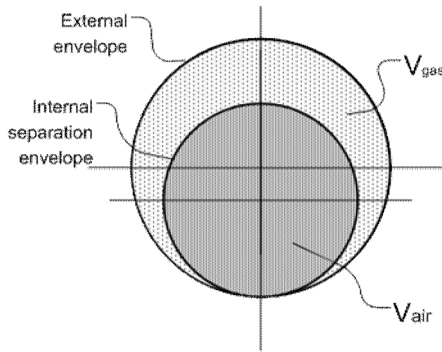


Fig. 4. Traditional airship governing mode.

In this case the behaviour of the system is regulated by governing the volume of the air ballonets (V_{air}).

OPEN BALLOON AIRSHIP CONCEPT AND CONTROL

For MAAT project and especially for the feeder the system buoyancy is not controlled by the air ballonets which are in equilibrium of pressure with exterior atmosphere. This system is dangerous because of the permeability of the envelope limiting the air ballonets. Hydrogen can diffuse through the envelope and can reach anywhere an even local density into the flammability range of hydrogen.

This is the reason why it has been necessary to avoid the traditional architecture considering novel operative models which reduce the risk of reaching hydrogen flammability conditions by design.

Open Balloon Airship concept aims to reduce by design the risk of reaching flammability conditions. It requires a control system that can act on the buoyant gas only moving gas from the top constant volume balloon to the lower variable volume ballonets, maintaining a pressure equilibrium condition with the surrounding atmosphere.

In particular, if the buoyant gas is maintained into equilibrium condition with the external environment, with a little overpressure necessary to maintain the geometric properties of the system, any governed modification of the buoyant gas pressure in the variable volume ballonets produces an effective modification in the Archimedes's force. Any modification of the pressure of the buoyant gas suddenly transforms into a volume modification.

With this mechanism (Fig. 6) 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.

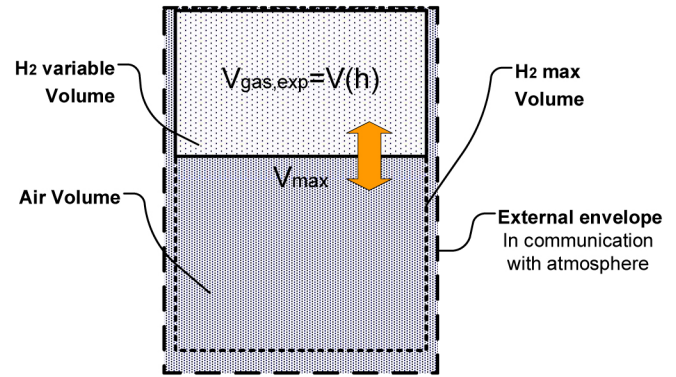


Fig. 5. The novel "Open Balloon Airship" Concept

A schema of this novel buoyancy control mechanism is shown in [Figure 6](#). It addresses at least two problems:

1. related to the conformation of the hydrogen ballonets, especially when they are not filled up to the maximum volume;
2. related to the envelope material from which the Hydrogen balloon is made;

It is not possible to define the geometric disposal of the balloon and to verify the creation of air inclusions. They are very dangerous because the hydrogen released by permeability. These considerations to the necessity to design carefully the ballonets and to avoid absolutely the risk of reaching the auto ignition of the gas. This model requires that the lower ballonets have a very large expansion which can be estimated about six times, moving from sea level to stratospheric altitudes of 20.000 m ([Figure 7](#)).

These considerations are necessary to consider multiple balloon architectures and to evaluate and design of mechanically actuated systems.

It can be observed that the ratio between volume at 20 km and at 0 km is nearly 14. For example, in case of a spherical shape the area of the balloon increases about 5.8 times. There are materials that can guarantee such dilatation, but they are characterized by an inadequate permeability.

This ratio decreases to 8 considering a service ceiling about 15-16 Km. But also in this case it is important to define a mechanical system governing the volume.

A semi-rigid or non-rigid airship requires an internal pressure higher than external atmospheric pressure. This overpressure can be evaluated for a semi rigid airship using the traditional expression by Khoury and Gillett [8] to evaluate the overpressure. In this case further analysis can be performed considering the functional architecture of the buoyancy system.