# DEVELOPMENT OF A NOVEL AERIAL PLATFORM WHICH MERGES THE CONCEPT OF AIRSHIPS AND TETHERED AEROSTATS

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## Abstract

*This paper proposes a novel LTA platform, the tethered airship that is a merge of airship and tethered aerostat functionalities, combining the navigation abilities of airships and the hovering performance of tethered aerostats that is designed to remain stationary in high wind conditions, to transfer data with high speed data link to the ground base through an electric tether and to fly unlimited time periods. This paper presents the sizing based in a scaled model of the YEZ-2A airship, the designing and fabrication of each component, and the integration that originates the novel tethered airship prototype in which it is validated through flight experiments.*

## 1 Introduction

This paper aims to feel part of the gap between the airship and the tethered aerostat vehicles. This investigation covers the tethered airship modeling, designing, manufacturing and assembling process, validating the prototype through flight experiments. The final goal of this research is to develop autonomous flight capabilities of an airship attached to the ground by a thin cable. The concept is to have an airship that can be eventually connected to the ground through a tether, or in an opposite way, a tethered aerostat equipped with a propulsion system that can eventually perform free flight.

A lot of work has already been done in various projects related to unmanned airships, such as AURORA in Brazil in late 90s [1] [3] [10] [1] [2], Autonomous Airship of LAAS/CNRS [6] [7] [5] LOTTE airship in Germany [14], KARI in Korea [8] [9], DIVA in Portugal [11] and Autonomous Outdoor Airship Project in IIT Bombay [12]. The common drawback is that all these airships were sensitive to the atmosphere conditions, especially to wind gusts[13].

The main benefits of the tethered airship are the expansion of flight envelope of airships, enabling to hover in a high wind speed condition (station keeping), the mobility and agility to tethered aerostat operations when it is moving between hangars or to a different mooring system location (autonomy), perform flight in a constrained area limited by the length of the tether (safety), it allows mid-air charging and high speed data link via electric cable (communication solutions and unlimited endurance).

In the sequence of this paper, the tethered airship concept is introduced and the sizing process for obtaining a model is described in section 2. The design and fabrication of the main components of the vehicle are detailed in section 3. Preliminary flight test results are presented in section 4, and conclusions are made in section 5.

## 2 Tethered Airship Concept and model

A tethered airship is a flight vehicle that has static lift, can perform navigation, and can connect and disconnect to a surface using a single tether with an anchoring device. More specifically, the static lift comes from the Archimedes principle, where the magnitude of the buoyant force is equivalent to the weight of the fluid displaced by the body; controllable flight means the ability of track a desirable trajectory using actuators in a tethered and untethered condition; and the surface is any terrain in solid or liquid state.

There are many combination of shapes and components that can generate a tether airship vehicle. In this paper, the tethered airship is characterized by five main components listed below and they displayed in Fig. 1.

1. Envelope
2. Gondola
3. Fins
4. Tail engine support
5. Tether system

The envelope is designed to retain the lifting gas and to support external loads. The gondola is a rigid support installed on the belly of the airship. It is used to carry the propulsion system, batteries, avionics and the payload. Fins are used for stabilization and maneuverability of the airship dynamic model by changing magnitudes and directions of aerodynamic vectors. The tail engine support is used to care two engines and propellers and it is designed to support load of the thrust force in order to steer the airship in lateral direction. Lastly, the tether system is composed by a series of ropes joined in a confluence point with a single tether that anchors the airship to the ground.

The tethered airship with these main components is able to perform a controllable free flight and to be a station keeping while using the tether system.

In order to design a tethered airship, it was chosen a scaled model of the YEZ-2A airship because its dynamic behavior was investigated by Gomes [4] and its aerodynamics was obtained by wind tunnel data. The original profile and airship sizing is displayed in Fig. 2.

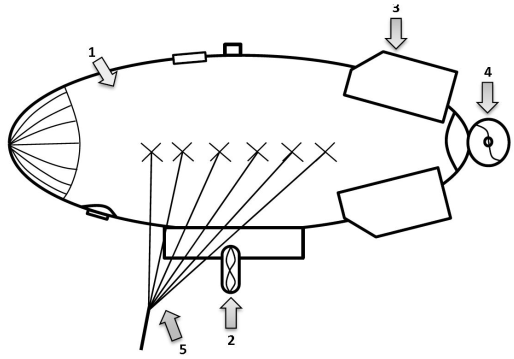


**Fig. 1** Tethered airship concept.

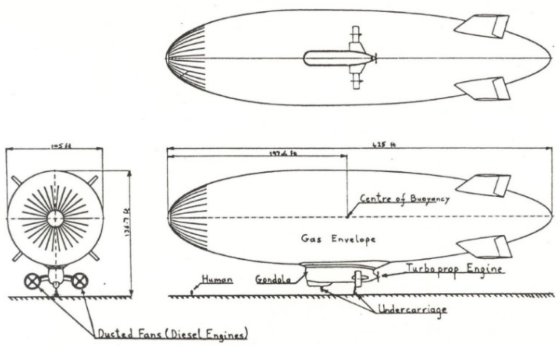


**Fig. 2** YEZ-2A Airship.

The three-dimensional model presented in Fig. 3 was built in CATIA using a scaling factor designed in a multi-criteria optimization based in operational requirements, as of minimum payload weight of 15 kgf, maximum external dimensions in view of transportation purposes and hangar sizing, handling procedures and winch maximum operational loads at 100 meters of height.

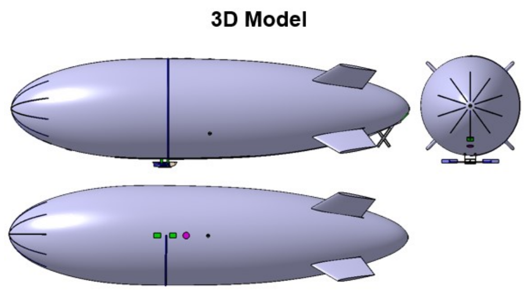


**Fig. 3** Airship scaled CAD Model.

The result was a scaled airship with the general parameters presented in Table 1. The dimensional values were obtained by the scaled CAD model, and forces were calculated considering International Standard Atmosphere (ISA) at sea level. For the avionics, the maximum weight of all electronic systems including batteries is 10 kgf. The Payload consists in the sensor e.g. camera, radio, sonar, and in the electronic system belonging to the sensor operational system. The Net Lift is the upward force that remains, ant it is balanced by the tether weight, estimated to be 4 kgf each 100 meters length, and tether tension.

**Table 1** Tethered Airship parameters.

| Parameter | Value | Unit |
|---|---|---|
| Length | 12.3 | m |
| Maximum Diameter | 3 | m |
| Volume | 60 | $m^3$ |
| Surface Area | 86 | $m^2$ |
| Avionics | 10 | kgf |
| Payload | 20 | kgf |
| Net Lift | 5 | kgf |

Once the dimensions and weights are defined, the process of design and fabrication of each component starts.

## 3 Design and Fabrication of Components

This section presents the design and fabrication of each main component of a tether airship, considering the established dimensions. Those components are envelope, gondola, fins, tail engine support and tether system.

At the end of this chapter, the prototype integration is presented and the comparison between actual and 3D model are made.

### 3.1 Envelope

The envelope is built with two layers. The internal one has the function of retaining the lifting gas, and the external one is designed to support high loads due to tether tension and aerodynamic forces. The envelop is divided in 10 equal parts, called petals, which are welded using a sealing machine.

The profile of the petals determines the shape of the airship, reflecting in the aerodynamic performance and airship efficiency. The petals were drawn in CAD and printed for cutting using a mounting template. Fig. 4 shows the design on the left and fabrication on the right of the envelope.

**Fig. 4** Envelope.

### 3.2 Gondola

The gondola is the structure fixed to the envelope that includes the payload of the airship, in addition to all the equipment needed to perform the flight, such as: propulsion system, batteries and embedded system. Fig. 5 shows the design on the left and fabrication on the right of the gondola.

**Fig. 5** Gondola.

The propulsion system is responsible for providing thrust force to the airship and it is composed of two sets of motor and propeller located at the end of the vectoring axis.

### 3.3 Fins

The design of the airship fins was carried out by scaling an YEZ-2A airship[4] model which determined the profile and sizing of the fins. Fig. 6 shows the design on the left and fabrication on the right of the fins.

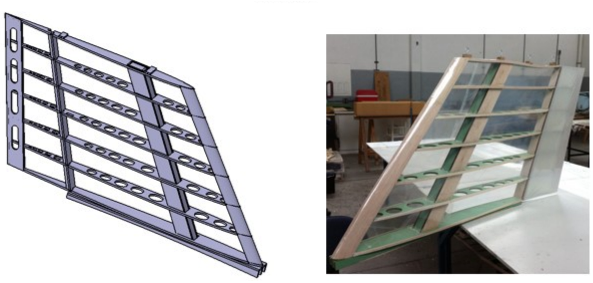

**Fig. 6** Fins.

### 3.4 Tail Engine Support

The tail rotor parts were manufactured by the water jet cutting process. The main frame is made of aluminum, reinforced with fiberglass tubes. The fixing is through balsa wood to support the envelope, Velcro and cables for its stabilization.

**Fig. 7** Tail engine support.

In this structure, 2 brushless motors are installed in opposite directions to promote lateral force on the tail of the dirigible in both directions. Each engine will have independent operation, providing a maximum lateral thrust of 3 kgf.

### 3.5 Tether system and prototype

The tether system is composed by eight lines made by Kevlar. Their dimensions are obtained by the distance from attachment point at the envelope to the confluence point, where all the cables are joined to a single tether that anchors the airship to the ground.

The conclusion of the mechanical design was achieved with the integration of all components and with the preparation of the airship anchored to flight by inflating with helium gas. The comparison between the model and the prototype is shown in the Fig. 9.

**Fig. 8** Tether system attached to the airship.

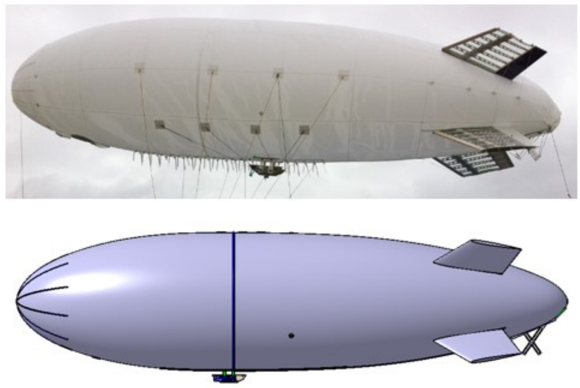

**Fig. 9** Comparison between design and prototype.

## 4 Flight experiments

The aim of the first flight experiment was to verify the airship dynamic behavior. The envelope was filled with helium gas and all components were attached. The tethered airship prototype is displayed in Fig. 10 where the envelope, gondola, fins and the tether system can be observed.

The altitude of the experiment was 650 meters, a ballast of 15 kgf was attached to the gondola in order to simulate the payload weight. Ballast in the nose less than 1 kgf was added for trimming purposes. The weight of Avionics was 9 kgf and the Net Lift was 12.5 kgf. Taking into account the weight of the tether and the variation of altitude, it was verified the possibility to operate at 100 meters of height from the ground station.

**Fig. 10** Tethered airship prototype.

Furthermore, the static equilibrium was achieved in this flight experiment and a stable behavior was observed in winds lower than 3 m/s. Oscillations in yaw direction was observed in winds between 3 and 6 m/s and improvements on the design of the tethered airship can be made in order to reduce the oscillatory behavior. This will be a further step that will optimize the tethered airship to be designed for working in a large range of windspeed, allowing to extend its autonomy, flying for extended periods due to low energy consumption for fighting against wind disturbances and for adding the capability of refueling or recharging batteries while tethered.

The preliminary design and fabrication were validated in this flight experiment and the exploration of the capabilities of this platform was initiated.

## 5 Conclusions

The development of a tethered airship was presented. The concept to have a platform specially designed and adapted for both performing navigation and being a station keeping while tethered in the ground was introduced. As ships need an anchor for holding a specific position, the same concept was proposed for an unmanned airship.

This paper also detailed the methodology used for conceiving a tethered airship, starting from sizing, design to manufacturing and integration. A preliminary flight test results were also presented. The concept of operation, considering trimming, assembling and flying a tethered airship was validated through flight experiments.

Now that the platform is established, improvements are suggested as future works: the adaptation of system identification methodologies for this platform aiming to have a high-fidelity model; improvements of the dynamic system stability by developing an active control or designing an optimal size of tail fins for guarantee passive stability in a large range of wind gust; developing an autonomous navigation system that considers the constrains imposed by the tether; expand the autonomy of airships by using a tether to perform refueling operations, to aid takeoff and landing in windy condition and to transform the airship in a steady station keeping for persistent in-flight operations.

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