

Structural Analysis of an Engine Chassis for a Disc-Shaped Airship with Thrust Vector Control

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ABSTRACT

This paper presents a structural analysis of an engine chassis for a disc-shaped airship demonstrator. The objective was to verify such design solutions for application in the European Union's MAAT (Multibody Advanced Airship for Transport) project.

In many airship designs, the engines are attached to the airship frame, located inside the balloon, in order to allow for thrust vector control. These airships have aerodynamic control surfaces to improve maneuverability.

For the demonstrator, three engines are considered, with a non-rigid internal structure for their attachment. The engines are located on a horizontal plane (the symmetry plane of the balloon), with two lateral engines and one in front of the balloon.

The chassis installation allows the engines to be attached either directly to the exterior envelope by using Kevlar connections, or to the central structural pipe. This chassis design has a simple construction, compared to typical structures addressed in the literature.

The structures have a kinematic device based on a servomotor, which provides the torque to tilt the engine. The critical condition is defined with the vertical wind that varies the load factor.

A finite element analysis is performed, considering the full structural model with different tilt angles. The Von Mises criterion is applied for the ductile and the Mohr-Coulomb criterion for the brittle materials.

The obtained results show that the stresses are within the safety limits. It is concluded that the presented structure can be applied to build the envisaged MAAT demonstrator.

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INTRODUCTION

Designs for Lighter-Than-Air (LTA) vehicles, commonly known as airships or dirigibles, have evolved over time. The first LTA vehicles were filled with hot air; today, they are filled with a lifting gas. New materials and related technologies have enabled the development of novel buoyancy air vehicles, airships, and tethered and un-tethered aerostats.

However, it is important to note that, in spite of this technological advancement, airship designs have remained relatively conventional. Only a few authors and/or private companies have progressed towards applying new design concepts for airships.

The reason is connected to the shape of the balloon. During the last century, the Parseval shape has been studied in great detail. In particular, the Zeppelin Company has maintained high quality standards by utilizing improved materials and structures. Zeppelin airships are the best-known examples of the classical shape. Until the 1930s, Zeppelin dirigibles

were widely used for both military operations and in the commercial air transport. The most famous Zeppelin of all time, named Hindenburg, burst into flames while attempting to land in Lakehurst, New Jersey [1].

During the last century, technological innovation for LTA vehicles has focused on the use of new materials, structures, and avionics, but the basic shape has not changed. New Zeppelins are filled with inert helium, and are only about one-quarter of the size when compared with the old giants. Three Lycoming engines deliver around 200 horsepower each. The airship frame is constructed from a combination of aluminum and carbon fiber, [1].

In typical passenger airships, the engines are connected to the internal structure of the balloon. For example, [Figure 1](#) shows the position of the engines for Zeppelin-like airships [1, 2, 3]. For the UAV models, which have a similar shape, the propeller engines are usually directly attached to the gondola, as shown in [Figure 2](#) [4]. They are partly steerable, in order to provide thrust and limited direction control. In addition, they serve to inflate the ballonets and thus, maintain the necessary ballonet overpressure [5, 6].



[Figure 1](#). Example of typical engine positions for Zeppelin-type airships [1, 3]



[Figure 2](#). Steerable ducted fans on a Skyship 600 [4]

For unconventional airships, major features are distinctively different when compared with the “conventional” type. Alteration may be made to the shape and component design, lifting gas, lift method, payload, or power source [7]. Some

examples are the lenticular airship of S. Doncieux et al. [8], shown in [Figure 3](#), and the patented designs of Balaskovic [9] and Henry [10].

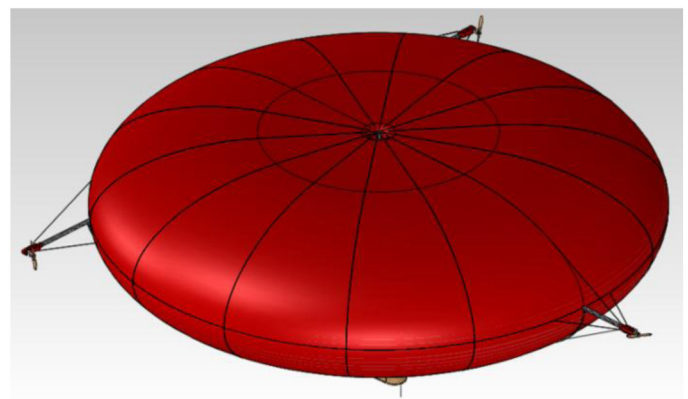


[Figure 3](#). Lenticular blimp [8]

The ERMETE research team is studying the feasibility of the low-altitude airship demonstrator as a part of the European Union's MAAT project [11, 12]. This is shown in [Figures 4](#) and [5](#). It is envisaged to be a demonstrator of a UAV blimp [13, 14], which is an unconventional airship having a disc-shaped form.

This shape comes with advantages and drawbacks. The advantage is that the circular shape has equal aerodynamic characteristics in all directions [15]. The disadvantage is that the large horizontal surface area causes high variations in the load factor, particularly when vertical wind is present. For conventional airships, international regulations require that “each landing gear retracting mechanism and its supporting structure must be designed for the maximum flight load factors with the gear retracted and must be designed for the combination of friction, inertia, and air loads, occurring during retraction at any airspeed.” [16, 17].

The aircraft has three engines for propulsion and control. It comes without the control surfaces, which are typical for the conventional airships, such as those presented by F. Goineau et al. [18], E. A. Kulczycki et al. [19], M. V. Cook [20] and M. Acanfora et al. [21]. The important part is the kinematic system, which allows the motor to be tilted between -90° and $+90^\circ$ (when measured from the longitudinal axis of the balloon).



[Figure 4](#). Demonstrator perspective view

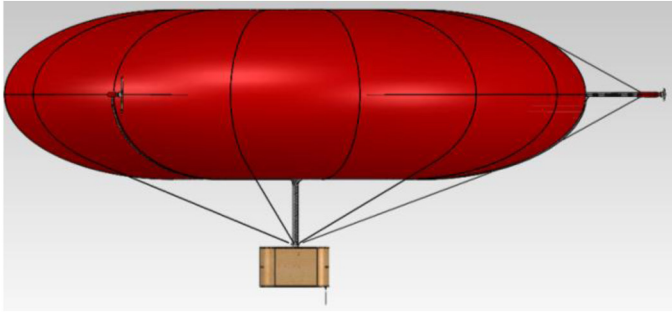


Figure 5. Demonstrator lateral view

The design idea is taken from the work by Munich Kuhn et al., whose demonstrator hybrid airship is shown in [Figure 6](#). This airship had a semi-rigid structure built from sandwich beams and longitudinal rods. The inner structure was attached to the hull membrane through the longitudinal rods and beams. Motor thrust was used for energy-efficient hovering and vectored thrust [7].

The present demonstrator has two rear engines and the front engine. This configuration provides a faster reaction of the airship when changing direction from a standstill, applying the required Thrust Vector Control (TVC). TVC works like the classic system as used for the conventional airships or tilt-rotors. TVC is the ability of the airship or other vehicle to control the direction of the thrust obtained by its engine(s) or motor(s) in order to control the attitude and/or angular velocity of the vehicle [22].

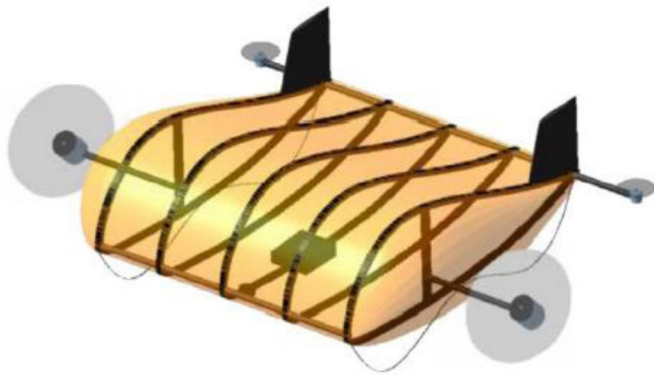


Figure 6. Demonstrator hybrid airship [7]

The requirements for the present demonstrator are different from those applied to the classic airships. The typical structure of the engines found in many airships is not appropriate for this type of airship. Unlike other airships, which are typically filled with helium, it is filled with a hydrogen as the buoyancy gas. Moreover, it does not have internal air balloons, which normally serve to control ascent and descent. In addition, the engines are not placed under the balloon itself. The position of the engines is defined by means of comparison, using the typical rules for the lenticular airships: they have all the engines on the horizontal symmetry plane, which is also the symmetry plane of the balloon [7, 9, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50]. This choice is mainly due to the possibility of canceling the nose up

moment, which would be provided by the engines if they were not aligned to the plane and expected to be compensated by the aerodynamic surfaces.

The frames cannot be constrained to any internal rigid structure within the balloon, as the airship cannot have a rigid internal structure to hold the frames of the engines. Instead, some special structural connections in Kevlar and carbon fiber strips can be applied. They directly fix the structure to the envelope of the balloon and to the center pipe.

For these reasons, a simplified structure has been developed in order to avoid trusses. The developed structure is made of the composite materials: e.g. carbon fiber in an epoxy resin matrix.

The structures presented here may be suitable for blimps in the case of absence of internal structure in the balloon.

Some lenticular airships use a pipe distribution [7, 9, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50]. This involves additional weight because of the metallic material used, such as aluminum and steel. Instead, this innovative solution has the advantage of being a simple construction and cost-effective, because all the parts are easily available on the market. In addition, the metallic materials can be easily produced with machine tools and assembled in less than a day.

It is found that the load factor is quite high for this airship, and thus an appropriate servomotor is selected to reduce it.

For the application of the selected servomotor, two possible structures have been analyzed. Specific attention has been given to the frames and kinematics of the engines. The analysis was based on the comparison of the stresses and displacements, which resulted from the finite elements simulations. The main parts are designed to use epoxy as a joining method for all the components. However, this does not exclude the possibility of using reinforcement bolts in order to avoid peeling; bolts and screws are also considered for the attachment of servo and motor.

The numerical model has been studied with Solidworks Simulation 2011 software, which allows simulating the links with preloaded bolts.

KINEMATICS MECHANISM AND STRUCTURE OF FRAMES

The frames are designed to be simple and conceptually similar. The binding element is the servomotor. The choice of the servomotor is bound to the flight conditions: in normal flying conditions, the torque is 5.60 N·m, but the situation changes when there is a vertical wind. The load factor must be considered for the airship design.

The total force W^* is directed according to the body axis Z_B . It acts on the center of gravity of the aircraft. It is given by [23]:

$$\begin{cases} W^* = n_z W \\ n_z = 1 + \frac{a_z}{g} \end{cases} \quad (1)$$

If the airship is designed for the maximum cruising speed (12.5 m/s) and the vertical wind is 10.6 m/s, then the acceleration of the aircraft will be $a_z = 15 \text{ m/s}^2$.

The required torque is defined by:

$$\begin{cases} \vec{W}_M = \vec{W}_E n_z \\ C_{\text{servo}} = \left| \vec{W}_M \right| x_{CM} \end{cases} \rightarrow C_{\text{servo}} = \left| \vec{W}_E \right| n_z x_{CM} \quad (2)$$

The required parameters are reported in Table 1, where the torque of the servo with and without wind is shown. Figure 7 shows nomenclature and conventions adopted for the transmission of forces.

Table 1. Physical parameters of the engine with propeller and torque of the servo.

W_E	39.24 N
x_{CM}	0.14 m
n_z	2.54 g
$C_{\text{servo without wind}}$	5.6 Nm
$C_{\text{servo with wind}}$	14.2 Nm

A possible servomotor is the Torxis Servo i00600, as shown in Figure 8. This is a super high-torque RC servo with 1600 oz-in of torque at 12 VDC, 60 degrees in 1000 ms or 3200 oz-in (22.6 N·m) peak. It has RC PWM input signal, closed loop position control, and 90 degree total travel with RC radio or 270-degree travel with a microcontroller input signal [24].

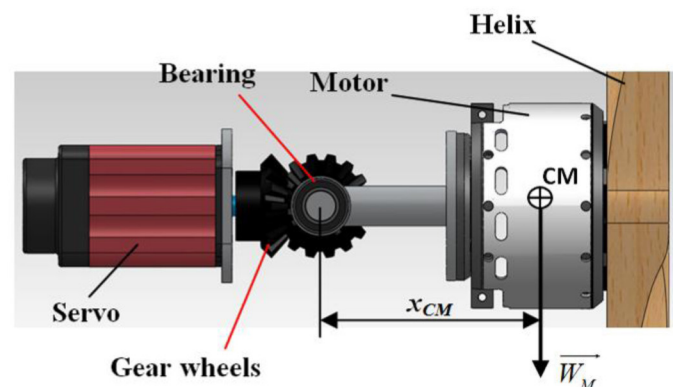


Figure 7. Nomenclature of the kinematic mechanism and force transmitted to the servo.

The frames of the front and right side engines are shown respectively in Figures 9 and 10.

Transparent cutaway views of the kinematics elements are shown in Figures 11 and 12.

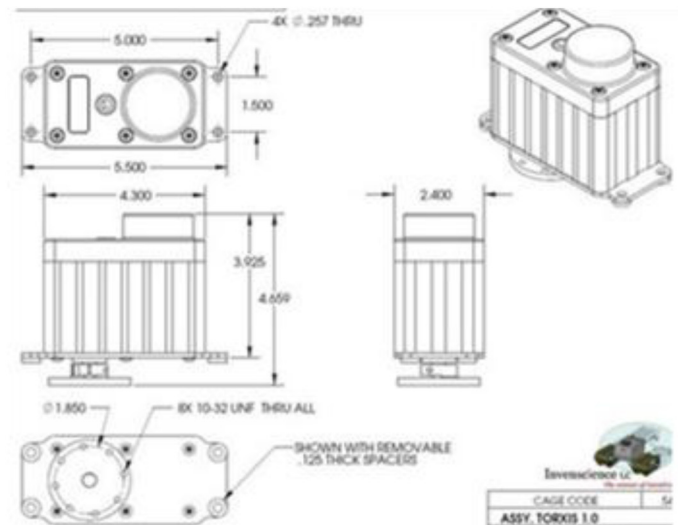


Figure 8. Torxis Servo i00600

All parts are marked with numbered bubbles to ease the distinguishing among the structural components.

For the case of the lateral engine, element 5 is not indicated with the bubble in Figure 12, which is the internal motor of the servo, while element 10 is the connecting flange of the servo with the flanged shaft, responsible for connecting it with the engine.

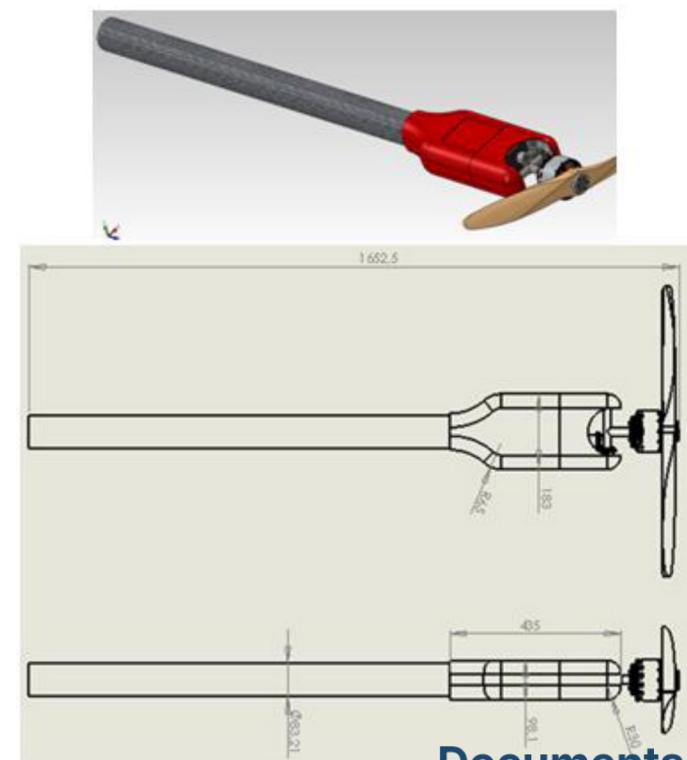


Figure 9. Structure of the front propeller. Dimensions in millimeters.