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# Conceptual Design of a Hybrid Airship

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## **AVISO**

*A presente dissertação foi realizada no âmbito de um projeto de investigação desenvolvido em colaboração entre o Instituto Superior Técnico e a Universidade da Beira Interior e designado genericamente por URBLOG - Dirigível para Logística Urbana. Este projeto produziu novos conceitos aplicáveis a dirigíveis, os quais foram submetidos a processo de proteção de invenção através de um pedido de registo de patente. A equipa de inventores é constituída pelos seguintes elementos:*

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(António José Nunes Marques)



# Dedictory

I want to dedicate this work to my parents, my family and my girlfriend, which without their support, encouragement and sacrifice I could not have finished this stage of my life.



# Acknowledgments

I want to give my gratitude to all that believe in me and gave me their support to finish my Master Thesis.

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# Abstract

Nowadays freight transportation is facing an increased concern about the environment pollution, infrastructures congestion and different measures are being implemented to try to make it more efficient and economical.

Because of that there is an increasing interest in airship technology and so new advances are being made in this type of transportation. Such as the Hybrid Airship that is overcoming the previous airships. These new technologies are paving the way for a new future in airships and freight transportation.

This work aims to demonstrate the technology of this type of transportation mode and some of its new advances. The fields of materials and structures, stability and control, propulsion system and the certification and legislation for an airship design are described.

Also, a conceptual design of a Hybrid Airship for the mission of freight transportation will be made and the airship behavior is also briefly described. To complement the work, the development of a prototype to test the theory proposed is presented.

**Keywords:** Hybrid Airship, Conceptual Design, Freight Transportation.



# Resumo

Hoje em dia o transporte de cargas está enfrentando uma crescente preocupação sobre a poluição do meio ambiente, congestionamento de infra-estruturas e diferentes medidas estão sendo implementadas para tentar torná-lo mais eficiente e económica.

Por causa disso, existe um crescente interesse na tecnologia de dirigíveis e novos avanços estão sendo atingidos nesse tipo de transporte. Por exemplo, o dirigível híbrido que está superando os dirigíveis anteriores. Estas novas tecnologias estão a abrir o caminho para um novo futuro para os dirigíveis e para o transporte.

Este trabalho tem como objectivo demonstrar a tecnologia deste tipo de meio de transporte e alguns de seus novos avanços. Serão descritas as áreas dos materiais e estruturas, estabilidade e controle, o sistema de propulsão e a certificação e legislação para o design de dirigíveis.

Também será elaborado um projecto conceptual de um dirigível híbrido para a missão de transporte de cargas e também será brevemente descrito o funcionamento deste dirigível. Para complementar será apresentado desenvolvimento de um protótipo para testar a teoria proposta.

**Palavras Chave:** Dirigível Híbrido, Design Conceptual, Transporte de Cargas.

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# List of Acronyms

EASA - European Aviation Agency

FAA - Federal Aviation Administration

INAC - Instituto Nacional de Aviação Civil



# List of Nomenclatures

Re - Reynolds Number

$\rho$  - Air Specific Density ( $\text{Kg}/\text{m}^3$ )

v - Velocity ( $\text{m}/\text{s}$ )

c - Width of the airship (m)

$\mu$  - Air Dynamic Viscosity ( $\text{Kg}/\text{m}\cdot\text{s}$ )

CL - Lift Coefficient

CD - Drag Coefficient

D - Drag (Kg)

V - Volume in ( $\text{m}^3$ )

Cf - Friction Coefficient

L - Length of the Airahip (m)

b - Airship Diameter (m)

I - Moment of Inertia ( $\text{m}^4$ )

d - Specimen width (m)

h - Specimen Thickness (m)

E - Young's Modulus or Elasticity Modulus (MPa)

F - Force (N)

l - Distance of the two supports of the Flexion Test (m)

f - Maximum Midspan Deflection (m)

Mf - Bending Moment (N.m)

Rt - Rupture Tension ( $\text{N}/\text{m}^2$ )



# 1 Introduction

## 1.1 Motivation

Nowadays there is an increasing concern about the environment pollution, infrastructures congestion and finding a means of transportation more efficient and economical. These are just a few topics that are paving the way for introducing airships in the markets.

With increasing market demand, the transportations of goods have been suffering changes, causing environment and socioeconomic problems. Air pollution, noise, infrastructure damage and traffic congestion are just some examples of those problems. Currently Freight Transport in congestive areas corresponds about 40% of total cost from origin to destiny. But despite the consequences of those negative impacts the transportation of goods are important for the economic vitality of those congestive areas and regions in which they are located, (França P. T. et al, 2005).

With the increasing of all of these demands the interest of Airships has been growing and they can offer operations characteristics that other transports struggle to provide. But like all, they also have their advantages and disadvantages, but with the developing of technologies in a variety of scientific fields they are surpassing all the inconveniences of previous models.

Air freight transportation with Airships can be the answer to achieve the desired results, but like all type of transportation there is a rising of market demand and population growing. The search for a new and clean energy sources is increasing due to the concerning of the limit of fossil fuels and due to the burning of those that are damaging the global climate. More and more it's important that the energy source used is environmental friendly and at the same time not harming our health and reliable.

For many years airships have been used primarily for surveillance, advertisement and leisure. But nowadays around the world many companies and countries increased their interest in airships, giving them a second look. That is caused by the increased development in technology that is being introduced, bringing airships to the market. Some of the developments are the use of composite materials, vectoring engines, satellite weather forecasting and computer assisted design. With these new technological advances airships create economic and environment incentives for innovation and giving answers for congestion and climate problems, (Prentice et al, 2005).

In terms of structures, Airships can be divided into three groups, non-rigid, semi-rigid and rigid. The most common shape in both three types is the cigar shaped form or axi-symmetric, which help them minimise the drag effect. But a new type of airship is being introduced and developed bit by bit. It's called a Hybrid Airship and it combines the characteristics of previous airships with new technologies and theories like the combining lifting power of

helium with aerodynamic lift obtained by its hull and the use of solar energy and vectored ducted fans to help improving the dynamic control of the airship.

With all these characteristics and others Hybrid Airships can also become an intermodal transportation system, becoming a better bridge between the other systems filling a gap that is trying to be improved.

## **1.2 Object and Objectives**

The main objective of this work is the development of a concept for a Hybrid Airship taking into account what is the main mission for it and how it will improve a congested area. A comparison with airships of nowadays, the existing technologies and possible future developments was made. The Areas of study where the airship structure and materials, how it can be controlled aerodynamically and the power section knowing, for example, the necessary power and size of the propellers.

Also to complement this design concept a prototype to test the proposed idea is presented. Its size and characteristics, the internal systems that will incorporate it, the materials that can be used for the prototype structure and a mechanical test in specimens to deduce the best one to use are also presented.

To do all this some mathematical formulas are presented in this work and the aid of computer software such as Excel, Catia V5 and Autodesk ForceEffect were used.

## **1.3 Dissertation Structure**

This dissertation is divided into four chapters.

In the first chapter an introduction of this work, the motivation behind it, the main object and the objectives to achieve and the dissertation structure are presented.

In chapter two a review in the field of freight transportation and the problems faced in the day to day proposing the concept of a hybrid airship to solve them. A background of airships and their materials and structures, their stability and control, the propulsive systems and their future and legislation and certification for a design of an airship are made too.

For the third chapter an introduction how a hybrid airship works, the development of the conceptual design for it in the fields of materials, structure, stability and control and powers system. Also it presents the prototype, its sketches, materials for the structure and internal systems and their positioning and weight distribution.

Finally in chapter four the work conclusions, with the dissertation synthesis, some concluding remarks and future work perspectives for this project.

## 2 State of Art

### 2.1 Introduction

In the past Airships were one of the most famous type of transportation in the first half of the twentieth century, being used for passengers transportation and military purposes like reconnaissance, surveillance and communications. They were launched in the 1890s by Count Ferdinand von Zeppelin, testing rigid airships, which led to the “Golden Age of Airships”, (Stockbridge C. et al, 2012:4).

Nowadays there is a crescent concern about the environment pollution, infrastructures congestion and finding a mean of transportation more efficient and economical. These are just a few topics that are paving the way for introducing airships in the markets.

More and more developments are being made in the field of airships. With the advanced research in new technologies and materials there are great breakthroughs in their infrastructures, in the materials used in all the components, their propulsion systems and in their stability and control.

Taking into account all these factors airships are improving their performance compared with their predecessors in technology, and becoming a mode of transportation that can counter deficiencies of the conventional ones bringing a long term economic benefit.

In this chapter we will see some more of the motives that are increasing the interest in airships and their evolution in the fields mentioned previously, with new applications derived from those.

### 2.2 Freight Transport

The Freight Transport System is the means that links people and companies, providing mobility for goods, transporting them from origin to destination. The objectives are to fulfil the demands with an efficient and quality service, however nowadays it has been hard, (European Commission Transport RTD Programme Fourth Framework Programme, 2001).

With increasing market demand, the transportation of goods has been suffering changes, causing environment and socioeconomic problems. Air pollution, noise, infrastructure damage and traffic congestion are just some examples of those problems. Currently Freight Transport in congested areas corresponds about 40% of total cost from origin to destination. But despite the consequences of those negative impacts the transportation of goods is important for the economic vitality of those congested areas and regions in which they are located, (França P. T. et al, 2005).

Freight mobility in congested areas should not be seen just as a problem of traffic and environment, but a management problem of an articulated socio-economic system, to give

the necessary answers for the problems in hands. It is necessary to underline that the freight transport, contributes significantly to the process of distribution of goods to the final consumers, playing an essential role in the maintenance of urban functions related to trade and social life in terms of economic, quality of life, accessibility and attractiveness of a region. This means that an efficient freight transport can be “friendly” for the environment and essential for the economy and health of a region. So it is important to distinguish different transport possibilities to achieve good results, (Crocco F. et al, 2010).

Air freight transportation with airships can be the answer to achieve the desired results, but like all type of transportation there is a rising of market demand and population growing. A forecast made by Boeing in 2010-2011 (Figure 1) shows that the world air traffic will triple in 20 years, (Tatievsky A. et al, 2011).

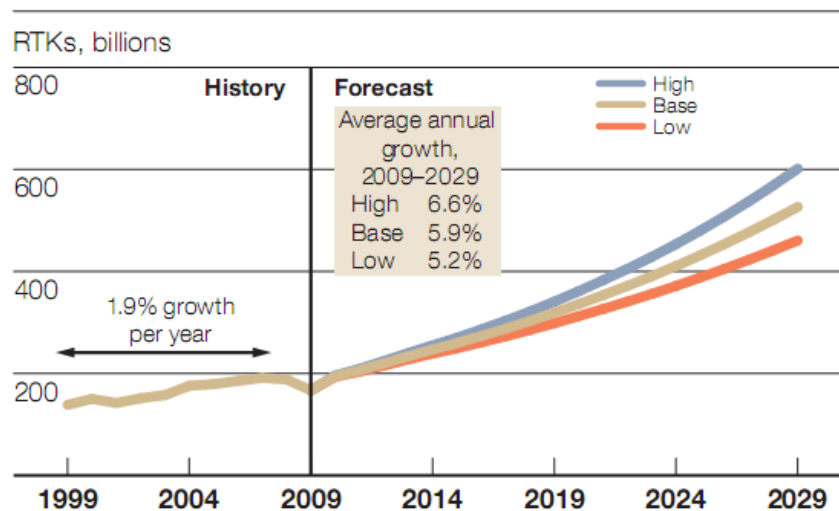


Figure 1. Boeing World Air Cargo Forecast 2010-2011, (Tatievsky A. et al, 2011)

Airships can be used in different applications where current transportation systems are not the best option in congested areas. They have characteristics which give them advantages over the others, making them a best alternative, such as:

- Being lighter than air fuel consumption is required only for cruising flight;
- Most of the lift comes from the lighter than air gases;
- Comparing with other type of transports, airships are more silent;
- They do not need infrastructures like roads and bridges;
- They are low producers of air pollution;
- In congestive areas they are faster;
- They can have lower consumption.

To show these and other advantages, next two tables which compare physical characteristics in table 1 and non-physical characteristics in table 2 with other types of

transportation are presented. The scale is divided into 5 parts and according to parameter; the weightage has been given to each entity of the table, (Prentice B. et al, 2012).

Table 1. Comparison between physical characteristics of different modes of transportation, (Prentice B. et al, 2012)

	Truck	Railway	Ship	Airplane	Helicopter	Airship
Cost of vehicle	2	4	4	5	3	3
Speed	2	3	2	5	4	4
Capacity	2	5	5	3	1	4
Range	2	3	5	4	3	4
Fuel consumption per km.	3	3	2	5	4	2
Infrastructure require	5	4	3	3	2	1
GHGs*	4	2	1	5	5	2
Maintenance Cost	4	3	3	4	4	2
Life Time	2	4	4	3	3	4

SCALE : 1- Very Low , 2- Low , 3- Medium , 4- High , 5- Very High

\*Refer to Green House Gases Emission

Table 2. Comparison between Non-physical characteristics of different modes of transportation, (Prentice B. et al, 2012)

	Truck	Railway	Ship	Airplane	Helicopter	Airship
Use in publicity	3	1	1	1	1	5
Reliability	2	3	3	5	2	4
Use in urban area	4	3	1	2	4	5
No of competitors	5	2	3	2	4	1
Traffic	5	3	2	2	2	1
Noise Pollution	5	3	1	2	2	1

SCALE : 1- Very Low , 2- Low , 3- Medium , 4- High , 5- Very High

With the right support and effort using airships for Freight transportation, they can lead the way for improve all the socio-economic factors, the lives of the people in congestive regions, not losing profits and not jeopardizing the environment.

## 2.3 Airships

For many years airships have been used primarily for surveillance, advertisement and leisure. But nowadays around the world many companies and countries increased their interest in airships, giving them a second look. That is caused by the increased development in technology that is being introduced, bringing airships to the market. Some of the developments are the use of composite materials, vectoring engines, satellite weather forecasting and computer assisted design. With these new technological advances airships

create economic and environment incentives for innovation and giving answers for congestion and climate problems, (Prentice B. et al, 2005).

Like all modes of transportation airships have pros and cons and so bellow there is a list of some of them. The Pros:

- Since airships are lighter than air vehicles, due to the use of helium an inert gas, they can lift vertically using energy mostly for forward movement. And unlike conventional types of vehicles, airships are relatively quiet and have good endurance.
- Since they do not need runways to take off and land their operating bases can be located strategically in congested regions. With the help of a high mooring mast they can be operated where other vehicles can't, being technically feasible. Flying at low altitudes is also a feature that can introduce airships in congested areas without interfering with other types of transportation, in fact operating at high altitudes adversely affects their payload capacity.
- Vertical operations can be performed by airships with low fuel consumption and with low altitude operations the cabin does not need to pressurize reducing the costs and weight.
- With low speed operation, and if a rigid structure is used, they can be safer than aircraft in handling operating hazards such as bird strikes, or accidental hits to fixed objects. Since helium is available globally and used as a lighter than air gas it makes airships a safe mode of transportation.
- Due to the use of lower propulsive power both air and noise pollution are less than other conventional types of transports.

However, compared to conventional modes of transports airships have some operating limitations. Some cons are:

- Due to their size airships are not an all-weather vehicle, being sensitive to direction and wind magnitude changes which can affect the reliability of them. Also they need large hangers to be stored.
- The payload capacity of an airship diminishes a lot with increase in operating altitude.

But new technologies are trying to overcome most of the deficiencies. New designs like Hybrid Airships introduce much more autonomous ground operation flexibility, along with better stability in flight, (Tatievsky A. et al, 2011).

Hybrid Airships can help broke boundaries and create new goals in the future with a reliable service in regions and areas where other modes can't. They offer the capabilities of reaching and open markets, where in the past, they could not compete leading the way for the revival of interest for airships.

### 2.3.1 Structures and Materials

In terms of structures, airships can be divided into three groups, non-rigid, semi-rigid and rigid. The most common shape in all three types is the cigar shaped form or axi-symmetric, which helps them minimise the drag effect.

Non-rigid Airships are usually called Blimps and they have no internal structure. The only rigid parts are the gondola, the fins and the engines, all connected to the hull skin. As mentioned previously airships use helium as their lifting gas. Blimps use the high internal pressure to maintain its shape. All the loads are distributed throughout the blimp's hull and to help supporting those loads they use a complex cable system. With this, blimps can gain some weight reduction but since the hull cannot handle big loads they are limited to slow flight speeds and small payloads. Inside the hull they have also ballonets that help them maintain the internal pressure and can be used to control also the airship's pitch attitude. These ballonets are filled with air and they can be inflated and deflated using a system of air blowers and valves. Compared with rigid airships, the cost of production and the manufacturing time are smaller, but in contrast special methods of handling and production are necessary for seaming such a long length of fabric and special attention must be given to the interaction of the rigid components and the hull, (Liao L. et al, 2009).

Between the non-rigid and the rigid we have the semi-rigid airships. Along the length they have longerons or keels providing some structure support and helps distributing the weight. The fins, the gondola and the engines can be attached to the keels reducing the role of the cable system and reduces loads applied to the hull. Similar to non-rigid airships, this type also maintains their shape by the high internal pressure and use ballonets to control that pressure.

Then we have the rigid airships where, unlike the other types, their shape is not maintained by internal pressure but using a full internal framework structure on which the hull envelope is connected. This structure can handle all the loads applied to the airship and all the systems can be mounted on it providing better access to the interior of the airship and it reduces the loads applied to the hull minimising the envelope material strength requirements. Inside it, a system of gas cells between transverse frames containing the lifting gas is used. Using this system the chances of incidents are reduced and safety is increased. The bigger challenges are the total weight of the internal structure, the manufacturing costs and the complex assembly structures which need to be carefully considered, (Liao L. et al, 2009).

In the following figure we can see an example of the three types of airships, (Khoury G. A. et al, 1999).

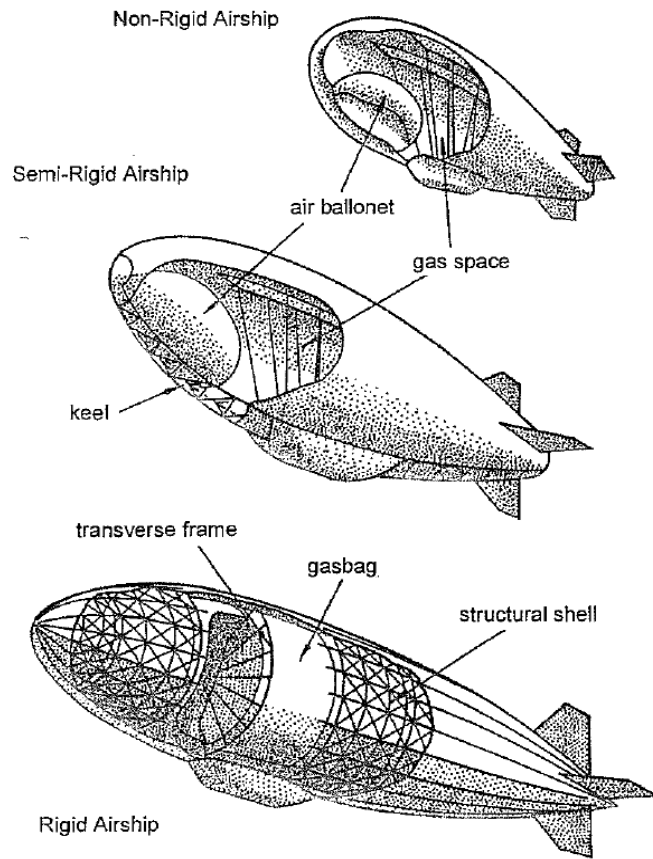


Figure 2. Airship structures, (Khoury G. A. et al, 1999)

Airships main lifting force source is the inert gas helium that has a lower density than the surrounding air. Compared to hydrogen it has about 7% less lifting force but is safer to handle. In figure 3, (Liao L. et al, 2009), we can see the difference in some gases, but between the inert ones, helium has the higher lifting capacity. The disadvantage of helium is that it is more expensive than hydrogen or methane.

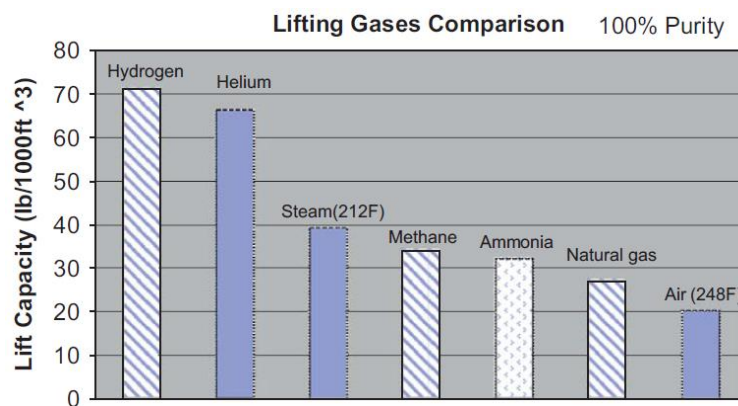


Figure 3. Lifting Gases Comparison, (Liao L. et al, 2009)

As previously mentioned non-rigid and semi-rigid airships have internal ballonets filled with air. When they change their altitude, the density of the lifting gas changes and it starts to expand increasing the internal pressure. When that happens, the ballonets deflate reducing the internal pressure and help the airships maintain their lifting capacity and shape not wasting the lifting gas. Usually rigid airships do not use ballonets, they use a system of individual gas cells and between each one they have enough space so when the lifting gas expands they have enough room to inflate. In figure 4 we can see an example of what happens to the ballonets when an airship gains some altitude, (Tatievsky A. et al, 2011).

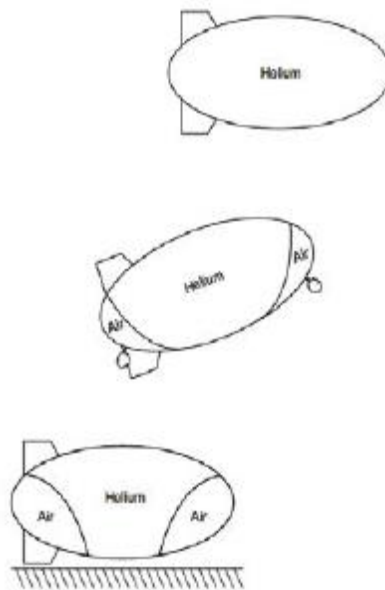


Figure 4. Ballonets deflating by changing the Airship altitude, (Tatievsky A. et al, 2011)

And then we have hybrid airships. This kind of airship does not have the common cigar shape. They combine the technology of traditional airships and the technology of fixed-wing, giving them the shape of an airfoil, and rotary-wing aircraft and with that they can use also aerodynamic lift created by the airflow on the hull and the thrust of lateral rotors. Both can provide the airship with better control and stability. “Hybrids airships overcome the disadvantages of airplanes for long take-off and landing runways or of helicopters for large rotors”, (Liao L. et al, 2009:89). An example of these three sources of lift can be seen in figure 5, (Tatievsky A. et al, 2011).

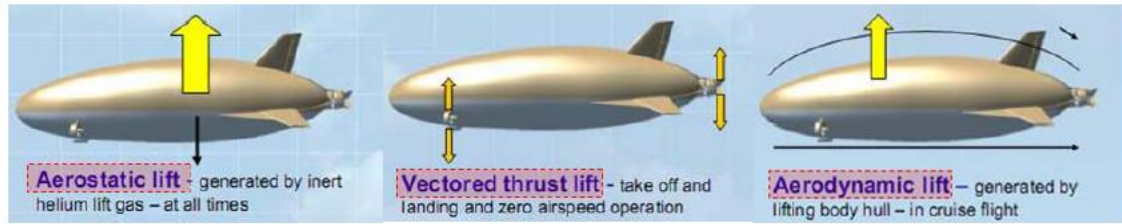


Figure 5. Hybrid airship: three sources of lift, (Tatievsky A. et al, 2011)

Progress in material development is improving vehicles and overcoming barriers that in the past were considered impossible due to the lack of knowledge of in field of materials and their characteristics. Materials are becoming stronger lighter and more efficient and with that they meet more and more the requirements of airships, of strength, weight, air tightness, weather stability, UV protection, conductivity and non-flammability. Materials have to consider a balance between competing demands such as highest tensile strength vs. lowest possible mass, maximum strength vs maximum adhesion, maximum material life vs ease of field repair, and minimum price vs all other demands, (Stockbridge C. et al, 2012).

Great advances are being made in the field of structural materials. And adopting those advances into airships structures, gondolas engine nacelles and systems casing, researchers can make them lighter and more resistant to external loads. Heavy metal structures are being substituted by lightweight carbon fibre rods and truss structures with high stiffness, high strength and sufficient durability. And promising alternatives such as carbon fibre reinforced polymer sandwich rods are being developed, consisting of a lightweight foam core, achieving some load carrying capability, covered by a relatively thin layer of composite material, (Schutze R., 1997).

In the case of non-rigid and semi-rigid airships the envelope is one of the main structural elements. With that designers need to pay special attention to the choice of materials, using the highest standard possible, considering the specific needs of the envelope hull and of course the inner ballonets. The basics characteristics or materials used for the envelope are as followed:

- High flexibility;
- High strength to weight ratio;
- High resistance to environment conditions;
- Low permeability to prevent leakage of the lifting gas;
- High fatigue and rupture strength.

The envelope consist on a laminated composite and are usually made of at least by three layers, a load bearing layer made of a tough material (like Kevlar or Vectran), a low permeability layer such as Mylar and an additional polymer coating (like Tedlar), (Tatievsky A. et al, 2011). Other materials like Dacron and polyester fabrics can also be used for it. The

inner ballonets do not have to endure some of the envelope loads, and so the main considerations for the materials for ballonets are flexibility and low permeability and lighter materials are used, such as coated nylon fabric and polyurethane plastic.

“The strength of the airship envelope is dependent not only on the strength of the material but on the design and strength of its seams and accessories, as well as the procedures for fabrication, acceptance, packing and final assembly” (Miller T. et al, 2002:3). The airship envelope needs to be tested and analysed for tear and tear propagation, like rigid airframes needs to be tested for crack and crack propagation. The usual tests made are the Cut Slit Tear Testing and Slit Testing on Inflated Cylinders and many samples need to be tested so the design data can be statically sound. In figure 6 and 7 we can see an example of these two tests, (Miller T. et al, 2002).

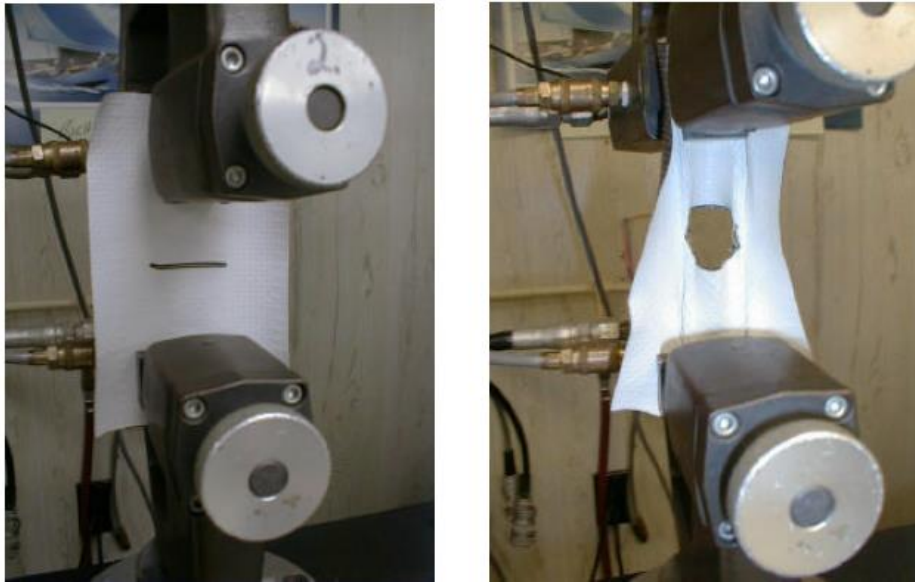


Figure 6. Cut Slit Tear Testing, (Miller T. et al, 2002)



Figure 7. Slit Testing on Inflated Cylinders, (Miller T. et al, 2002)

An essential area that helps choosing the materials is structural analysis in computational tools like Finite Element Analysis software. With this major flaws and failures can be

predicted by knowing the deformations caused by loads, stress distribution and bending moments, (Stockbridge C. et al, 2012).

But developments will not end here, in future years today's materials can become outdated and lighter and more resistance materials can boost airships to a new level. "The development of advanced materials will continue to enable previously impossible aerospace applications. Research continues on novel materials that minimize weight and improve strength, while addressing other critical properties", (McDaniels K. et al, 2009:1).

### 2.3.2 Stability and Control

To be able to maintain an airship airframe stable and having the capacity to control it is a very important point nowadays. "In the present context, perhaps the most significant development includes envelope shape and stiffness, mechanisms for control and propulsion and electronic flight control systems (EFCS)", (Khoury G. A. et al, 1999:73). The development of computer analysis and fluid dynamics software helps designers, in a more developed phase of an airship design, making them able to predict the deformations and reactions from the many loads applied and knowing the best response that an airship can give. When investigating the stability and control of an airship using a mathematical model it is necessary use the proper equations of motion and the proper main details of the airship to obtain the best results. Some of the first considerations are steady rectilinear flight, ignore the aero elastic effects, small disturbances, constant mass and a symmetric body with the centre of buoyancy and centre of gravity in the plane of symmetry. As we can see in figure 8 an airship like any other type of aircraft as three axes of freedom, (Khoury G. A. et al, 1999).

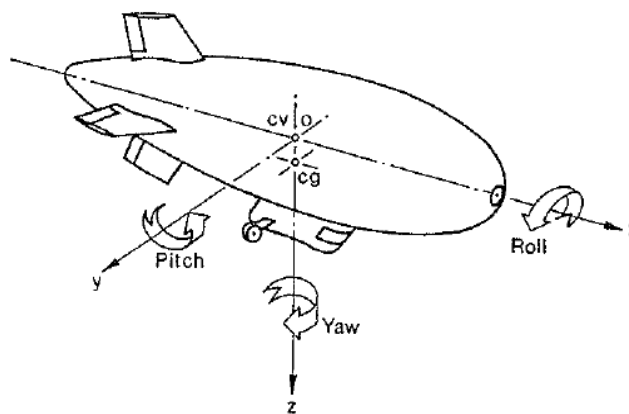


Figure 8. General configuration of body axes, (Khoury G. A. et al, 1999)

Pitch stability in the Y axis, yaw stability in the Z axis and roll stability in the X axis are three types of stability of an airship when in steady flight. But in the case of airships these three types of stability are independent of each other unlike the case of air planes where they are related with each other. A main condition in airships stability is the Static Equilibrium that it's achieved when the ascension forces are equal to the total weight.

Another way to test the stability and control is using wind tunnels with scale models where it can be tested the effects of changing some of the fins characteristics such as their area, aspect of ratio fin form and thickness. And it can be determined the Critical Speed and with that know when an airships loses its stability.

In the case of non-rigid airships the only way to control it is with its control surfaces (fins). But since the hull envelope is the only structural support they can't handle big loads which can result in dangerous situations. Another disadvantage is that they do not have any other mean of vertical thrust and so they need a small runway to take-off and land and the help of a ground crew between ten to twenty people. As we can see in figure 9 the ground crew preparing a non-rigid to take off (www.montrealgazette.com/business/Ground+crew+members+prepare+Navy+blimp+takeoff+Lakehurst+2012/9218859/story.html).



Figure 9. Ground crew members prepare blimp for takeoff, (www.montrealgazette.com/business/Ground+crew+members+prepare+Navy+blimp+takeoff+Lakehurst+2012/9218859/story.html)

Since semi-rigid and rigid airships have structural airframes they can use directional rotors that help them make vertical take-offs and landings. They give them a bigger freedom in manoeuvring and with that they can be more reliable and have a bigger control. The loads applied in the fins are better withstood since the fins are supported in the airframe and so the envelope does not need endure them.

For the case of hybrid airships as mentioned previously in addition to the lifting gas and rotor thrust technology, using small fixed wings and having the shape of wing airfoil the airship stability and control are improved and some drag is decreased.

Airships Stability and Control is a very important aspect to define. A poor design in these aspects can have unwanted consequences and many people can be hurt. It's important to refer that the bigger an airship gets more loads and moments are applied and all the control systems must be able to respond and give the proper and quicker reactions. Combining all the characteristics of hybrid airships make them the most reliable airship in terms of the response

of the stability and control systems. Many authors like Monk, Kornienko, Yamaski and Goto and Mueller have developed models to study the stability and control of airships, (Liao L. et al, 2009).

### 2.3.3 Propulsion System

The search for a new and clean energy sources is increasing due to the concerning of the limit of fossil fuels and due to the burning of those that are damaging the global climate. More and more it's important that the energy source used is environmental friendly and at the same time not harming our health and reliable.

Airships need also to make progresses in this area, but there is still a lack of authors presenting a state-of the art related specifically with propulsion concepts. With a crescent interest in Airship technology these must be a topic of important impact in the future. Since they have the ability of hover without the use of aerodynamic flow airships have the advantage to be used in areas where other types of transports have more difficulty and having lower energy consumption, (Ilieva G. et al, 2012).

The configuration for a propulsion system is composed by three components, a source of energy, the fuel, a prime mover, the engine, and the propeller which propels the airship. But in addition of providing power to propel the airship the engine have also another duty, which is providing power to the auxiliary systems like electrical systems and hydraulic systems to control the airship for example, (Khoury G. A. et al, 1999).

In airships the most usually types of engines are the internal combustion engines (ICE) which produce work by extracting energy with a number of thermodynamic cycles by adding fuel. There is the Otto cycle with a spark ignition, the Diesel cycle with a compression ignition. Apart of these two there is also the Joule cycle in the UK or the Brayton cycle in the USA for the gas turbine. Nowadays both Otto and the Diesel cycle present very good reliability due to their evolving over the years, but even presenting lower fuel consumption and being smaller in size they are heavier than turbine engines. In terms of thrust both propellers and ducted fans are being used. In today's propulsion systems the big disadvantage is the use of liquid fuel that related to the buoyancy compensation. As it is burn the weight reduces and it must be compensated adding a ballast weight.

Studies have being made with the configuration of vertical axis propeller adding the capability of increasing the load capacity. This configuration is simply a classic airship and is additionally supported by four rotors, like four helicopters, (Ilieva G. et al, 2012).

But compared to the previous configuration Solar Powered Airships, where the main power source being the sun, are most probably to be seen in the near future, by reducing the weight of the rotors and engines the load capacity of a smaller airship equals to a bigger one. And the power budget is strongly reduced and feasibility is easily achieved. The use of this

renewable source of energy opens the door for many applications involving long-duration airborne missions. But even so it is highly desirable the reduction of battery and solar cell weights since the electric power subsystems are still a significant part of the total weight of the propulsive system. The airship must be able to perform tasks for long day time periods and in night time periods, which means that a big quantity of energy must be collected during day time, taking account all the day periods of sun exposure and the variable angle of incidence that varies permanently, to meet all the missions requirements and also to perform the night missions. Whichever the case a continuous energy supply must be guaranteed and being the total weight of the propulsive system an important factor to consider in the airship total weight and power requirements, instead of carrying many batteries a different source of renewable energy can be used, (Ilieva G. et al, 2012).

Another type of energy source can be the use of Hydrogen fuel Cells for electrical engines, it's a technology that is still being suffering a significant development and it is expected to grow until at least 2020. It is yet to be determined the best configuration for the fuel cell and the operating conditions, working loads and desired size can give lead to different configurations. Hydrogen can be produced via water electrolysis, extracted from biomass via gasification or reformed from fossil fuels. It can be either stored in a fuelling station or produced on board, but the best option would be the on board storage and this is one of the most debated, so that this technology can become competitive with the current internal combustion engines. The current on board storage options are still heavier and larger than the current fuel tanks, it can be accomplished by metal hydrides, carbon nanotubes, compressed gas and liquid hydrogen, but is a goal that is being developed. In figure 10 we can see a comparison between tank weight and tank volume, (Veziroglu A. et al, 2011).

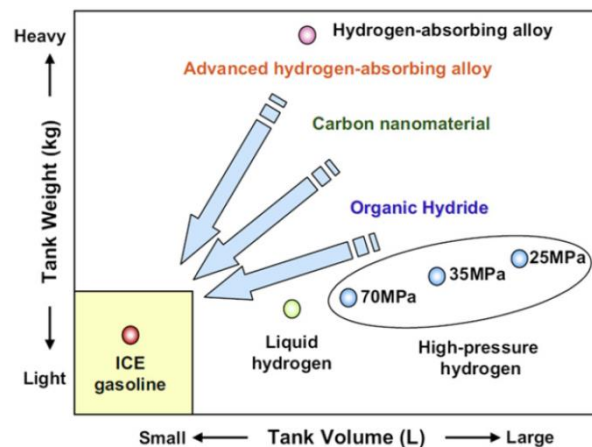


Figure 10. Hydrogen storage technologies and targets, (Veziroglu A. et al, 2011)

Even so Hydrogen fuel cells are still more expensive than fossil fuelled vehicles there would be a great impact in the environment and a significantly decreased of gas emissions. A recent research looked for a combination of fuel cells and electric batteries but an overall comparison of the characteristics of both shows that neither technology is definitely better

than the other. The big breakthrough of this technology is the impact in gas emissions that would drop to near zero improving our health, but being the down side the recent cost and not being competitive with the current technologies. It can be said that hydrogen powered fuel cell engines are on the right track and it is probably that we can see as a great advance in our life time driving the transport business to other levels, (Veziroglu A. et al, 2011).

In terms of thrust devices the most used in airships are the fixed-pithed propellers used when low weight, simplicity and low cost are preferable and controllable pitch propellers, adaptable to different thrust values and air speeds as a function of altitude with the objective of not degrading the propulsion system efficiency by preventing the propeller from stalling. To help directing the propeller thrust and reduce the blade tip losses, a ducted fan configuration presents a more efficient characteristics compared to a conventional propeller, especially at higher rotational speeds. Tip speed and intensity of the tip vortices contributes to noise production and they are reduced in ducted fans making them noiseless. A different concept of propeller was also presented which consist in certain number of small propellers distributed on the surface of the hull, each one with a small motor and a small battery. These configuration objectives are to achieve a better propeller efficiency, to reduce the total weight and size of the propulsion units and of the propellers and also a reduction on energy losses caused by the Joule effect in power lines, (Ilieva G. et al, 2012).

Unconventional propulsion systems in airships are being also developed and two of them are the Cycloidal Rotor and Fish-like movement in air. The first consist of several blades rotating around a horizontal axis, perpendicular to the direction of normal flight and the second consist in the undulation of the airship hull and a caudal fin and so the airship propels itself. These two configurations can be seen in figure 11, (Ilieva G. et al, 2012).

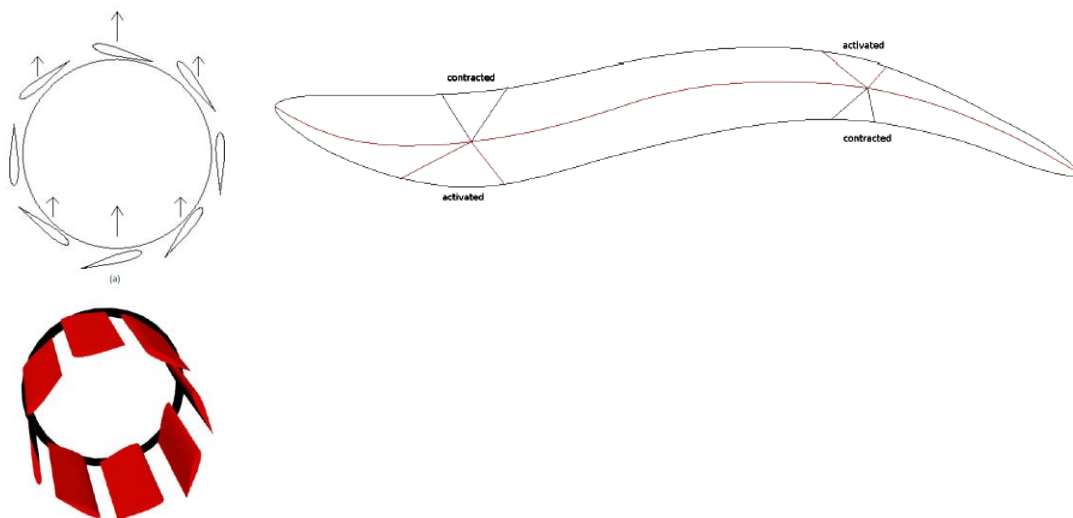


Figure 11. Cycloidal Rotor and Fish-like movement airship, (Ilieva G. et al, 2012)

For the case of Hybrid airships as previously mentioned is used a bigger propeller to give the necessary thrust for the airship and small ducted fans to increase the airship load capacity. This System can be powered by using a small engine for each one of the propellers, with a main power unit that provides energy for electrical motors or even with solar power which also provides electrical power.

The main concern of new propulsion technology is the reduction of the Greenhouse gas pollution and the primary objective is to identify which technology is the best suited to achieve this goal and decrease CO<sub>2</sub> emissions. In figure 12 is presented a wide range of possibilities for emissions scenarios, (Veziroglu A. et al, 2011).

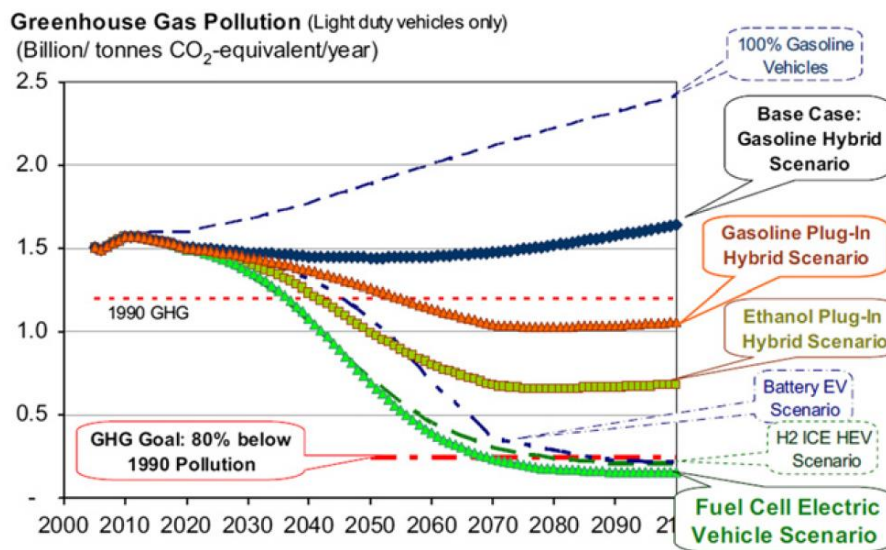


Figure 12. Greenhouse Gas Pollution scenarios, (Veziroglu A. et al, 2011)

The most promising technology that can accomplish the goals proposed is the solar powered airships. By using the energy of the sun this is an ecological friendly energy that can provide electrical energy for electric drivers, motors and to several places where power is needed.

“Whatever may be the propulsion concept it must be fitted, optimally, to the airship envelope shape. It can benefit, for its performance, from external aerodynamic flow features, such as a friendly boundary layer behavior. But it can also have its own contribute to the overall aerodynamic efficiency of the airship, in case it is adequately distributed around the hull”, (Ilieva G. et al, 2012:11).

### 2.3.4 Certification and Legislation

In the world of Aeronautics each country has its own authorities to certificate all the procedures from design, fabrication, maintenance and the airworthiness rules. With this they can assure that all aircrafts follow the correct requirements for safety and security. With the

use of similar procedures and continuous communication it can accomplish the correct certification for the use of aircrafts in different countries.

In terms of airships the Federal Aviation Administration is the authority that has the most documentation to regulate and certificate, but even so a big update must be taken to follow the developments in the different fields that involve airships. Their Regulations and Policies can be divided in three groups, the Title 14 Code of Federal Regulations, Advisory Circulars and Airship Guides. For the Title 14 it is evidenced parts 21, 43 and 91. Part 21 for the certification procedures for products and parts, part 43 speaks of the maintenance, preventive maintenance, rebuilding, and alteration and part 91 for general operation and flight rules. The most important documents presented by the FAA are the Airship Guides, the Transport Airship Requirements, FAA-P-8110-2 Airship Design Criteria and the LFLS Airworthiness Requirements for the type certificate of airships in the categories Normal and Commuter. The Transport Airship Requirements prescribe acceptable airworthiness requirements for the issue of type certificates for airships and it states that additional requirements for features or operational characteristics not indicated in this document can be stipulated. The LFLS Airworthiness Requirements for the type certificate of airships in the categories Normal and Commuter provide acceptable airworthiness requirements for the type certification of conventional non-rigid airships and have the design requirements to achieve a safety level equivalent in Title 14 Code of Federal Regulations part 21.17(b). And finally the FAA-P-8110-2 Airship Design Criteria indicates the design criteria necessary to provide proper levels of safety.

The European Aviation Safety Agency (EASA) follows the requirements of the Article 4 of the Basic Regulation for the design approval of products, parts and appliances designed, manufactured or used by all people and organizations under the EU Member States rules. For issuing the Type Certificates for airships EASA use the CS-30 and CS31HA protocol where it has all the requirements for airships certification specifications. And to provide all the specific airworthiness specifications for airships they use also the EASA.SAS.BA protocol. For the continuing airworthiness and maintenance of airships EASA use as guide the NPA No 2007-08 with the requirements for the Part M.

In Portugal the agency that acts as the organism which regulates all certification, safety and continuing airworthiness of aircrafts is the Instituto Nacional de Aviação Civil (INAC). But the only documentation related with airships is the Portugal advisory circular C.T.I 09-02 that defines an airship as an Aircraft type ELA1, only for two occupants with maximum gas volume of 1000 cubic meters, based on the EASA EC nº1056/2008.

As mentioned before if airships are to enter more and more in our everyday a lot of revision must be taken in all levels of certifications, safety and airworthiness requirements. Not only on these three organisms mentioned but also in all the organisms of all countries.

## **2.4 Conclusion**

Hybrid airships can help break boundaries and create new goals in the future with a reliable service in regions and areas where other modes cannot, improving all the socio-economic factors, the lives of the people in these congestive regions. They offer the capabilities of reaching open markets, where in the past, they could not compete leading the way for the revival of interest for airship without jeopardizing the environment. Using them for freight transportation they could lead the way for a new era with the right support.

This type of airship can offer a way to overcome some of the disadvantages of the previous airships, improving the fields of stability and control and power systems. But it must be taken into account that developments will not end here: in future years today's materials can become obsolete and lighter and stronger materials can boost them to a new level and the proposed hybrid airships of nowadays will be the bridge of a new generation of transportation.

# **3 Concept and Development of the Airship**

## **3.1 Introduction**

As presented previously the field of Freight Transport is facing a considerable number of challenges. Road Congestion, air pollution, sound pollution, infrastructures deterioration and so on. One of the main goals of this work is to present a new kind of transport that can answer most of the problems.

With the increasing of all of these demands the interest of Airships has been growing and they can offer operations characteristics that other transports struggle to provide. But like all, they also have their advantages and disadvantages, but with the developing of technologies in a variety of scientific fields they are surpassing all the inconveniences of previous models.

The first part of this work is to present a Conceptual Design of a type of airship that meets the requisites of Freight Transportation, taking into account all the fields, structure, aerodynamic, weight, stability and control and propulsion, which contribute to the development of a new project. The design of an aircraft usually has three classical phases, the Conceptual Design whose objective is to introduce a viable concept in all fields of the design. The Preliminary Design that comes after a concept is chosen where an iteration process and computer simulations are made to improve the previous phase. And finally the Detailed Design where all the detailed drawings are made, the fabrication process is prepared, materials and estimation of total costs are prepared. But as mentioned before this work will focus in the Conceptual Design where today technology, high strength materials, aerodynamic modeling, analysis and simulation techniques, can improve an airship making

them safer and reliable to use in congestive areas and in other applications, (Gamboa P., 2014). In figure 13 we can see the three phases that composes the design of an aircraft.

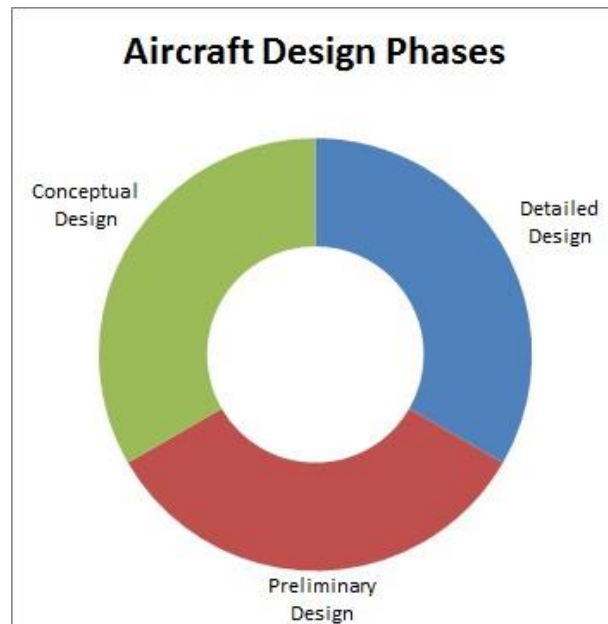


Figure 13. Phases of an aircraft design

Next a prototype to test the presented concept in the future will be presented, where materials, dimensions, distribution of weights, internal systems and prototype sketch were analyzed and prepared.

### 3.2 Airship Configuration and Design<sup>1</sup>

After analyzing all types of airships and their configurations the Hybrid Airship configuration was chosen. Compared with the other types of airships these offer a wider spectrum of solutions and characteristics that can be used in freight transportation. Like other airships it would use helium as a lifting gas and combined with a different configuration of the hull like a form of an aerodynamic airfoil, instead of the classic cigar shape hull, the airship can obtain about 30% of total lift, (Tatievsky A. et al, 2011). With that shape pitching up the nose provides the extra lift from the aerodynamic lift, but to help descend pitch down the nose can even reverse the lift direction. The aerodynamic configuration also improves its stability and control. In figure 14 is demonstrated the combination of these two lifts, (Jiron Z., 2011).

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<sup>1</sup> Parte da dissertação relevante para efeitos do processo de proteção de invenção referido no Aviso no início deste documento.

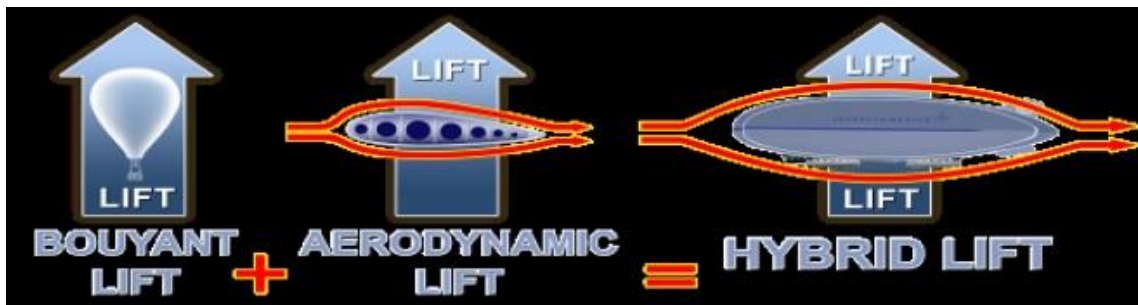


Figure 14. Combination between buoyant lift and aerodynamic lift, (Jiron Z., 2011)

In addition to this configuration it can also be used vectored ducted fans, which can help lift capability when the airship is hovering. And being vectored they can adjust the airship during flight, and with that increasing the stability and control of it. Another big advantage of using vectored ducted fans is the capability of vertical take-off and landing, which reduces the ground crew functions and numbers and increasing their safety.

With all these characteristics, and others, hybrid airships can also become an intermodal transportation system, filling a gap that is trying to be improved, becoming a better bridge between other systems. To demonstrate it, in figure 15 the relation of transportation cost per ton-mile and maximum speed is presented, (Jiron Z., 2011).



Figure 15. Cost per ton-mile vs Maximum speed, (Jiron Z., 2011)

One of the main challenges is to maintain the hydrostatic balance between being fully loaded and with no load. It is proposed a principle of being half loaded, where a system of air ballonets can perform a role of providing ballast to maintain the hydrostatic balance and also as a mean to help the weight distribution of the airship. The other half of the load capacity is obtained through the aerodynamic lift and the thrust of four vectored ducted fans.

Since it is used helium that expands with altitude it was considered that the top altitude for cruise flight is 1500 m assuring a safe control of the rising volume of the helium ballonets inside the airship structure. For the calculations performed it was considered that at sea level one cubic meter of helium is able to lift about 1.07 kg to 1.1 kg of payload.

A comparison process was made with other models of airships to analyze their size, total volume, lifting gas volume and weight and then an iteration process with those data to

formulate the size and capacity of the Airship of this work. After some deliberation it was determined that the Hybrid Airship proposed will have a lifting gas volume of 11870 m<sup>3</sup>, 75 m length, 30 m width and about 15 m of height and a payload capacity of 1500 kg. Since the airship's shape is based on an airfoil its height depends on the chosen airfoil. During this process it was noticed that the payload capacity of an airship does not have a linear growth with the airship length, in other words, the airship payload capacity grows exponentially with the increasing of the length of the airship. For example the length of the proposed airships is 75 m and by increasing just 5 m in length the payload capacity would increase to 5000 kg. In figure 16 is demonstrated a graphic illustrating the exponential growth of the payload with length. Also in figure 17 are presented sketches of the Hybrid Airship.

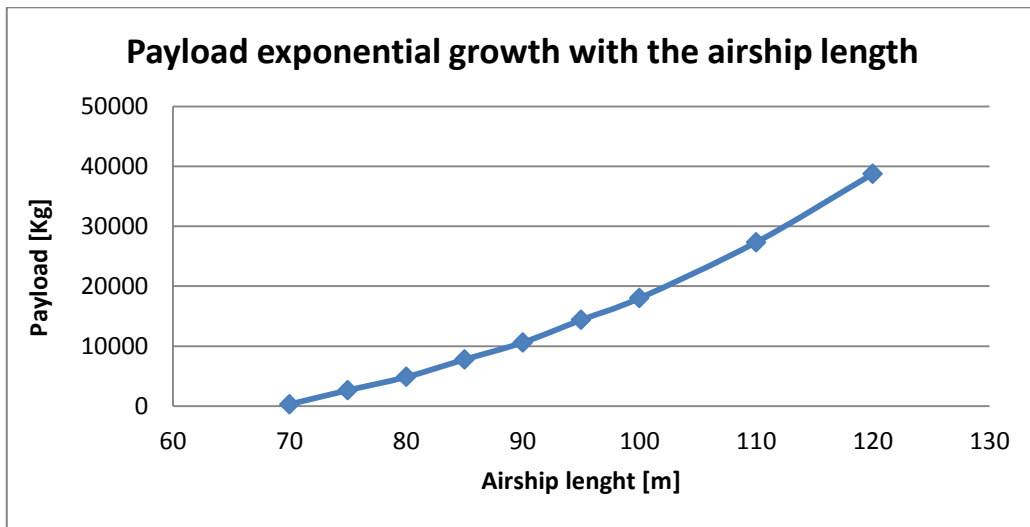


Figure 16. Airship payload vs length

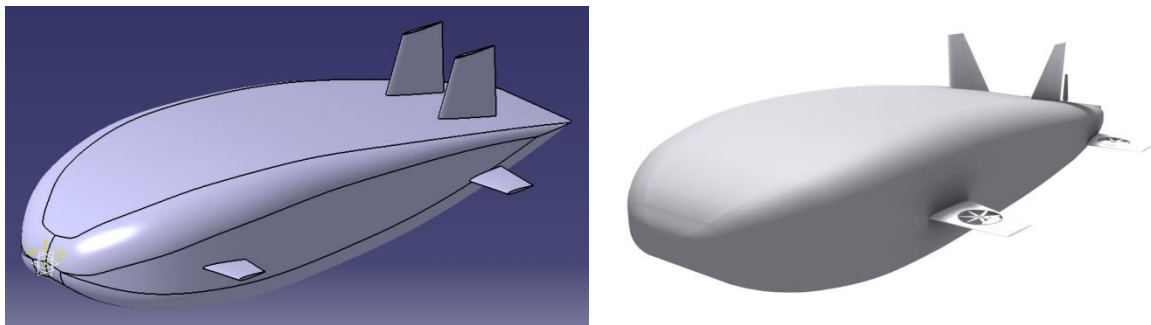


Figure 17. Hybrid Airship sketches

### 3.2.1 Structure and Materials

In terms of internal structure choice, it could have no structure or otherwise have two or three keels to have some systems supports or a full rigid structure. It was decided to propose a full rigid internal structure for the hybrid airship. All factors, advantages and disadvantages were weighted to ensure the best choice between the three options. Although the total weight of the airship, with a rigid structure, and the time and costs of production increase, higher standards can be reached in terms of mission efficiency and safety. The main advantages are as followed;

- Better support for all the airship systems;
- A system of small individual gas cells can be applied and with that increase safety if one of the cells tears just a small portion of the gas would leak;
- Create better access points for repairs and maintenance interventions and gain access to the internal systems;
- Easier production operations;
- Better resistance to all loads applied to the airship.

As mentioned, a rigid structure can offer a high number of hard points to support all systems inside and outside of the airship. The structure would be made of high strength and high stiffness truss structures of lightweight carbon fiber, ultra-light aluminum and to help support all type of torsion during flight a system of high strength composite tension cables. Since the internal gas cells do not need to endure the external loads and environment conditions the main characteristic is to prevent the leakage of the lifting gas, so they would be made of leak resistant polyurethane plastic. The main function of the external hull is to resist to environment conditions, ultra-violet light and weather wear, since it is supported in the rigid structure airframe and so it does not need to support the loads applied by external loads and loads made by the propulsion system. Two materials that can be used and have the effect desired are Mylar or Dracon. An example of the type of structure to use in the Hybrid Airship is represented in figure 18, ([www.aeroscraft.com/technology-copy/4580412172](http://www.aeroscraft.com/technology-copy/4580412172)).



Figure 18. Example of a Rigid Structure for a Hybrid Airship, ([www.aeroscraft.com/technology-copy/4580412172](http://www.aeroscraft.com/technology-copy/4580412172))

### 3.2.2 Airfoil Shape of the Hull

For the Hull shape it was opted to use the form of an aerodynamic airfoil, but since the airship would travel with low speeds, with a cruise speed about 14 m/s (50 km/h approximately), one of the choice criteria for the airfoil was the performance in those ranges of speed. So following are the criteria for the choice of the airfoil for the airship:

- Low Speed airfoil;
- A thicker airfoil;
- Simple, without very sharp curves;
- And the trailing edge not being too thin.

With these criteria six airfoils were chosen, GEMINI, MB 253515, FX 63-137, S 822, NACA 2518 and NACA 2420, (Selig M. S. et al, 1995). But in addition, simulations were made to verify their behavior in the cruising speed, with the software XFLR5. To use this software the number Reynolds for the specific speed is necessary. It is an important factor because with it we can study the efficiency of the airfoil and to calculate it the following formula was used, where  $\rho$  is the specific density of air at sea level,  $v$  is the air velocity (cruising speed),  $c$  is width of the airship and  $\mu$  is the air dynamic viscosity.

$$Re_y = \frac{\rho \cdot v \cdot c}{\mu} \quad [1]$$

After analyzing the data for the six airfoils the Naca 2420 were the airfoil that matches better with the criteria proposed. The airfoil is illustrated in figure 19 and the other airfoils can be seen in Annex, from figure 39 to 55.

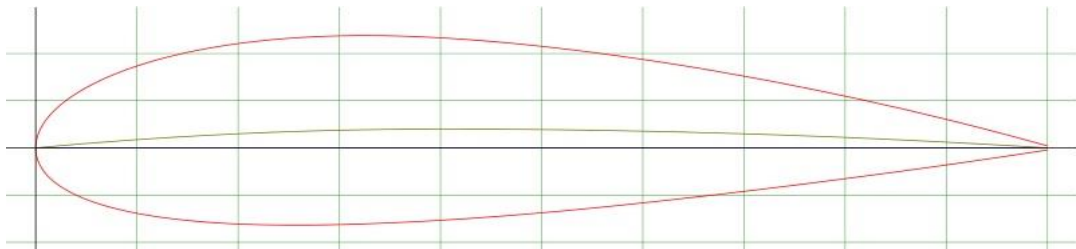


Figure 19. Airfoil Naca 2420

The NACA 2420 has a relative thickness of 20% and compared with the other airfoils is the simpler. In terms of Reynolds number, the lift coefficient and drag coefficient of all airfoils presented similar behaviors for the Reynolds of 70000000. NACA 2420 has a lift coefficient around 0.3 and a drag coefficient around 0.0055, both for an angle of attack of zero degrees. Having this value for the lift coefficient indicates that the airship can make some aerodynamic lift even with a low angle of attack in low speeds. From the six airfoils the FX 63-137 presents higher values for both lift coefficient and drag, but it has a more complex shape. In figure 20 we can see the behavior of the airfoil NACA 2420, for the respective

Reynolds number, the variation of the angle of attack (Alpha) vs the lift coefficient and in figure 21 for the drag coefficient. In Annex are represented the other five airfoils.

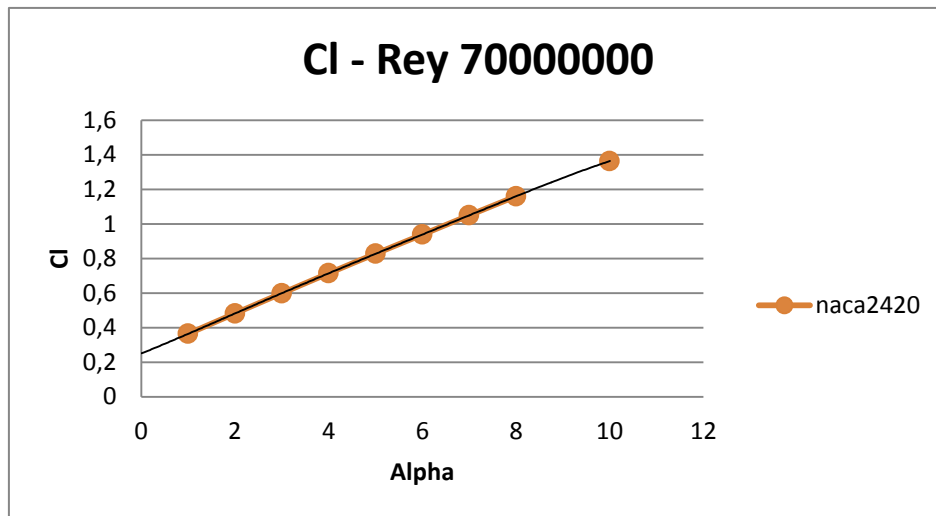


Figure 20. CL vs Alpha for Reynolds number 70000000

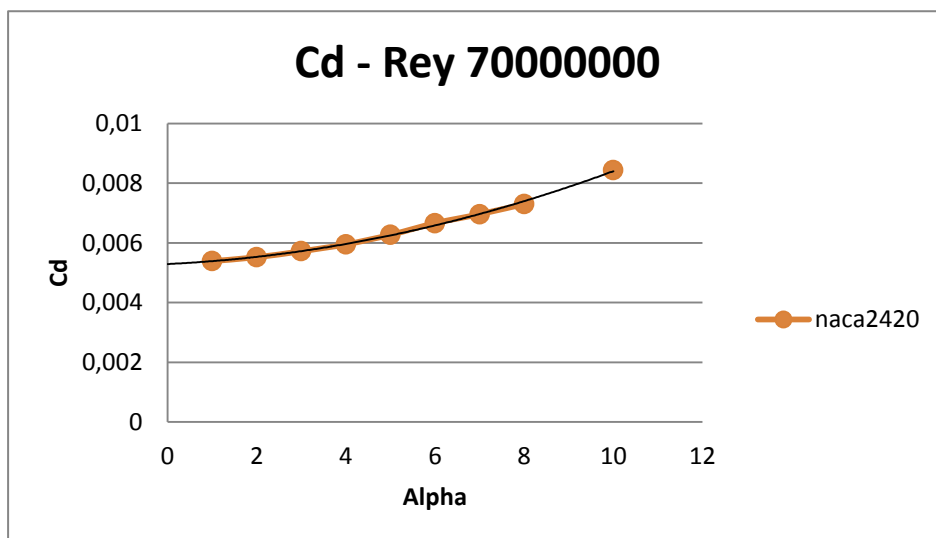


Figure 21. CD vs Alpha for Reynolds number 70000000

Having the form of the airfoil NACA 2420 the airship will have a better flow of the air around it which will increase stability and increase the lift capacity in flight

### 3.2.3 Vector Ducted Fans

In each side of the airship there are two vector ducted fans with variable pitch. These types of propellers will help the airship to maneuver during flight, with the additional help of the fins where they are mounted, and when the airship is hovering they will help to control it when subjected to external disturbances. With this, the airship can be better controlled during landing and take-off in any axis. An example how can they help to do so is illustrated in figure 22.

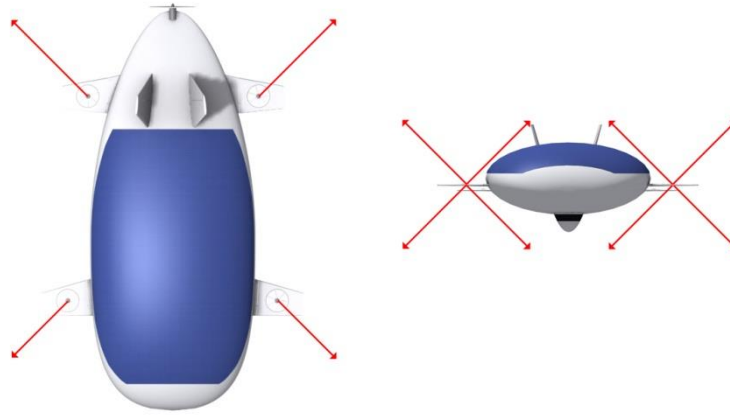


Figure 22. Sketch of how the propellers can help in the control of the airship

But another main function of these propellers is to help the airship to lift some payload, when necessary, in vertical take-off and landing. To calculate the diameter and the power needed it was decided that each one should be able to lift 250 kg, more than necessary. And to do so it was used the Rotor Disk Momentum Theory that tells that the tips of the rotor will create a circular surface, with zero thickness, which will accelerate the air through it. The disk is just an approximation of the real rotor and it is considered that there are an infinite number of blades, but is enough to give us an initial idea of the necessary power. All the calculations were made as if the airship were at sea level. It was determined that for a propeller with a diameter of 2 m that can lift 250 kg, to hover is necessary approximately 46 kW and for a vertical speed of 8 m/s 57 kW are needed.

As mentioned previously the vector ducted fans will increase the stability and control of the airship and they produce less noise than the other type of propellers which is good to decrease the noise pollution. In figure 23, an example of this type of propeller is illustrated.



Figure 23. Sketch of Vector Ducted Fans

### 3.2.4 Power Section

As for the Power Section of the Propulsion System a different concept from today's airships is proposed. Instead of using separate combustion engines that give the necessary power to the propellers and energy for all the electric and hydraulic systems of the airship,

the power section would consist of five electric motors, four for the ducted fans and one for the cruise propellers, and to power them a photovoltaic cell array would be installed on the upper half of the airship hull, but at the same time it would be supported by a generator capable of providing the necessary power. This generator can be a gas turbine generator or if the advances in technology could make it possible a Hydrogen Fuel Cell Generator.

The necessary power for the electric motors to use in the ducted fans, as mentioned in the previous chapter, is about 60 kW for each. For the cruise propeller, the necessary motor power can only be estimated by knowing the drag made by the airship. So to calculate the airship drag the following steps were made, (Hoerner S., 1965).

The formulas used are for the classical airship shape, so an equivalent sized airship with the same length and total volume was estimated. The value of the Drag can be obtained by the following formula, where  $C_{DV}$  is the drag coefficient,  $D$  is the drag and  $V$  is the volume.

$$C_{DV} = \frac{D}{0.5 \cdot \rho \cdot v^2 \cdot V^{2/3}} \quad [2]$$

The formula used to calculate the drag coefficient will depend on the value of the Reynolds number and for the proposed velocity of 14 m/s, the Reynolds is over  $10^5$  the formula used was as follows, where  $b$  is the diameter of the airship,  $L$  is the length and  $C_f$  is the friction coefficient in rough surfaces for turbulent flow.

$$C_{DV} = C_f \cdot \left[ 4 \cdot \left( \frac{L}{b} \right)^{1/3} + 6 \cdot \left( \frac{b}{L} \right)^{1.2} + 24 \cdot \left( \frac{b}{L} \right)^{2.7} \right] \quad [3]$$

The friction coefficient was determined the graphic in figure 24, (Hoerner S., 1965), where  $k$  is the size of the grain of the surface and it was stipulated that its value where  $0.5 \times 10^{-6}$  m and its value is 0,0012.

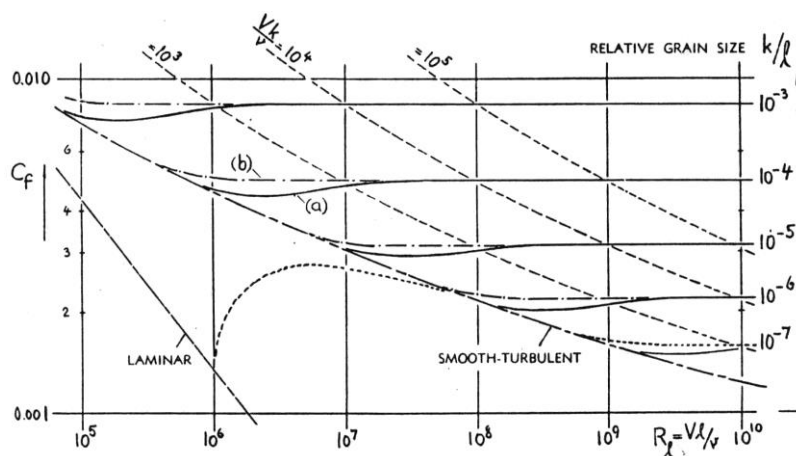


Figure 24. Graphic for the Friction Coefficient determination

It was then calculated, for a velocity of 14 m/s, that the drag coefficient would be approximately 0.00984 and therefore the Drag is 6762 N approximately.

Knowing the drag and using also the Rotor Disk Momentum Theory for a rotor diameter of 3 m the necessary power for cruise is 192 kW. So for the cruise propeller is proposed the use of an electric motor, at least, with 250 kW. This propeller would have variable pitch to have better efficiency over a wider speed range.

With the revived interest for this kind of transportation in the future, or maybe they already being developed and tested, more efficient and reliable technologies for the propulsive system can boost hybrid airships to be used and provide a better service for congested areas and in other markets.

### 3.3 Prototype<sup>2</sup>

Like all new concepts to test the idea proposed a prototype must be built. Like the airship presented previously this will also have a rigid structure, internal ballonets with helium and will have also the form of the airfoil presented previously.

#### 3.3.1 Structure and Materials

One of the main topics that were analyzed was the structure for the prototype. It must be rigid to be similar to the main concept, but the material must be different. To make it easier to transport, the structure will be divided into six sections and with that it will also facilitate the assembly of the prototype. After a few discussions and ideas it was decided that the prototype must have 8 keels and the distance between each section, the frames, should have a distance of 1 m and the number of frames depends on the length of prototype.

The proposed size for the prototype will have a length of 8 m, 3 m of width and since the height will depend on the airfoil NACA 2420 it is expected that it will have approximately 2 m. Having the length of 8 m it will have seven sections, which results in eight caves. It was estimated that the volume of helium will be approximately sixteen square meters, which will have a total lifting force of 154.34 N at an altitude of 500 m, the altitude of the University of Beira Interior approximately, a total payload of 15.74 kg. To help avoid the torsion of the structure and help endure all the external and internal loads a system of cables will be installed bracing the internal cross-sections of the structure of the prototype.

For the structure material it will be used a sandwich configuration. For the core it can be used a foam like Depron which has a density of 33 kg/m<sup>3</sup> or Airex C70-40 which has a density

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<sup>2</sup> *Parte da dissertação relevante para efeitos do processo de proteção de invenção referido no Aviso no início deste documento.*

of  $40 \text{ kg/m}^3$  and both have 6 mm of thickness. At the top and bottom it will have a carbon fiber fabric of  $100 \text{ g/m}^2$  which is represented in figure 25.

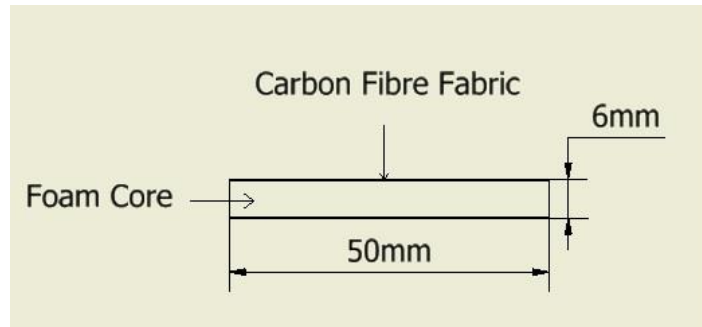


Figure 25. Sketch of the prototype structure section

To compare the two options for the foam core proposed, two specimens were prepared with both depron and airex. Each one was made with a different technique, but both used epoxy resin to glue the materials. For the depron specimen the cure was made in vacuum and the dimensions were 0.315 m length, 0.05 m width and weighting 0.0081 kg. A cure by compression was made for the airex specimen and it had 0,295 m of length, 0.086 m width and it weighed 0.0318 kg. Then a bending test was performed to determine the mechanical properties of each one, using the international norm C393 where the specimen is supported in two points with 0.01 m distance and a force is applied in the middle. For both cases, the velocity of the tests was 1mm/min. In figure 26 and 27 is found the results of each test and is illustrated a graphic of force vs distance.

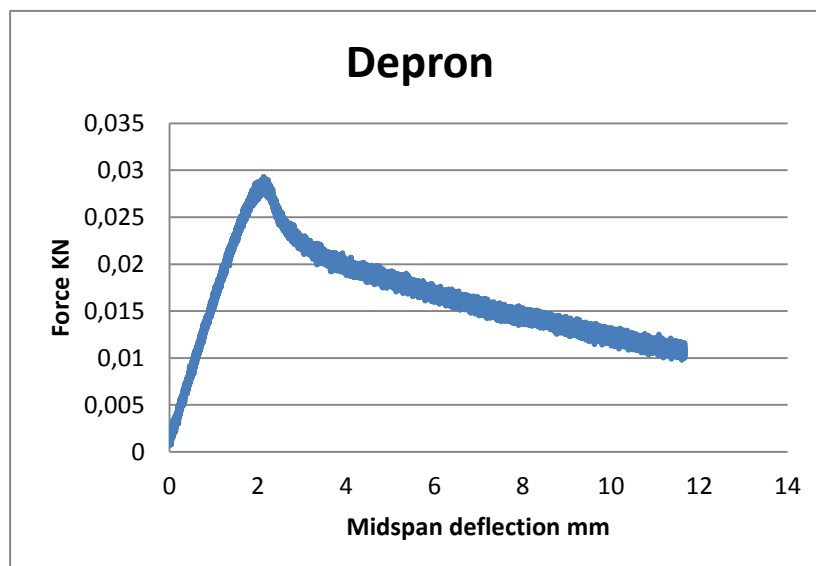


Figure 26. Force vs Midspan deflection for the depron specimen

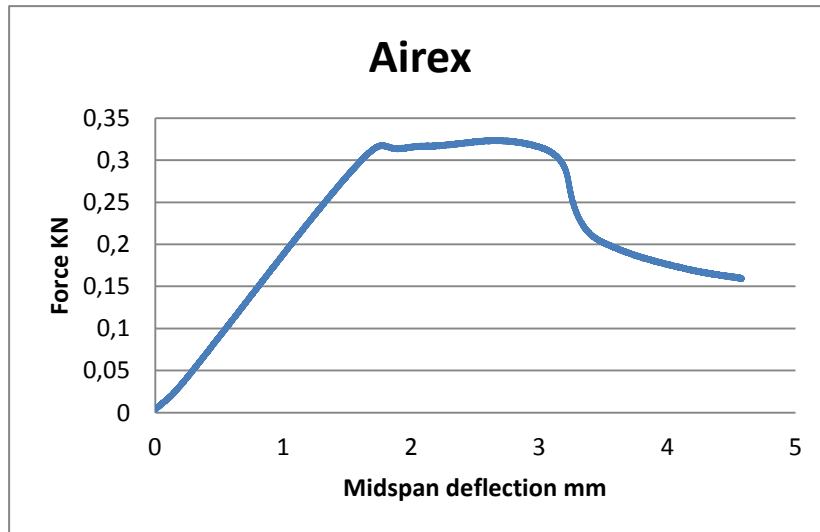


Figure 27. Force vs Midspan deflection for the airex specimen

From these graphs it was determined that the total force supported by Depron and Airex before starting breaking down was 28 N and 320 N and the max midspan deflection of the specimen was 1.9 mm and 1.8 mm, respectively. Then it was calculated the Young's modulus (E), or elastic modulus, the rupture tension (Rt) and the ratio between each and the weight per unit area of the specimens. For that the following formulas were used:

$$I = \frac{d \cdot h^3}{12} \quad [4]$$

$$E = \frac{1}{48} \cdot \frac{F \cdot l^3}{f \cdot I} \quad [5]$$

$$Mf = \frac{F \cdot l}{4} \quad [6]$$

$$Rt = \frac{Mf \cdot h/2}{I} \quad [7]$$

$$\frac{E}{Kg/m^2} \quad [8]$$

$$\frac{Rt}{Kg/m^2} \quad [9]$$

where F is the maximum force supported, f is the maximum midspan deflection, I the second moment of area of the cross-section, d and h the width and thickness of the specimen, l the distance between the simply supporting points of the test and Mf the bending moment. For Depron and Airex the results for the Young's modulus were 42.64 MPa and 299.07 MPa, rupture tension 1166667 N/m<sup>2</sup> and 7751938 N/m<sup>2</sup> respectively. And the ratio of the young's modulus with Kg/m<sup>2</sup> was 82.9 MPa/kg/m<sup>2</sup> and 238.6 MPa/kg/m<sup>2</sup> and for the rupture tension were 2268519 N/kg and 6184487 N/kg, respectively. In figure 28 is illustrated the test made in the Airex specimen.

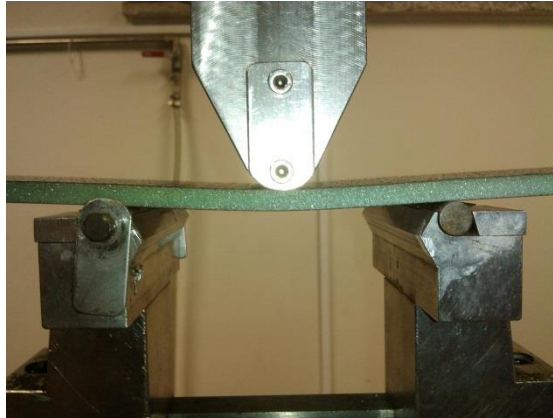


Figure 28. Airex bending test

### 3.3.2 Internal Systems and Weight distribution

As for the internal systems that the prototype will have they can be divided into five categories: control system, propulsion system, data collection system, power system and eventually an emergency gas releasing system. The control system has the function of controlling all the aerodynamic surfaces, being able to control the prototype pitch, roll and yaw and within this system are the servos and their signal receiver. To control the propellers that will help stabilize and propel the prototype will be the function of the propulsion system and it consists of a control panel, five electric motors, four small variable pitch ducted fans and one cruise variable pitch propeller. Within the data collection system it will be a data acquisition system and a telemetry system that will transmit all the data and help analyze it. For all this to work, energy is needed and so a pack of batteries form the power system and they will deliver energy for the electric motors and all the electronics in the prototype. Finally for safety reasons an emergency gas releasing system must be incorporated so that, in the event of another system's failure or an incident occurs, the helium inside will be released and the prototype will land and will not fly away.

To analyze the weight distribution a free body diagram must be made and for that the position and force of the systems components, structure and helium must be estimated and the prototype is presented as a beam with 8 m. In table 3 is presented the main hardware and their longitudinal position as well as their estimated weight.

Table 3. Systems Hardware Longitudinal position and Force

	Position (m)	Force (N)
Fore Horizontal Stabilizers	2	4,9
Aft Horizontal Stabilizers	6	4,9
Vertical Stabilizers	7	4,9
Fore Electric Motors	2	10,297
Aft Electric Motors	6	10,297
Cruise Electric Motor	7,9	5,149
ForePropellers	2	4,9
Aft Propellers	6	4,9
Cruise Propeller	8	2,452
Fore Servos	2	2,942
Aft Servos	6	2,942
Vertical Stabilizers Servos	6,5	0,98
Batteries and Panels	0,5	28,773

Because of the shape of the prototype, it is difficult to predict and represent the distributed load of the helium. So to simplify the representation of the helium distributed force, the prototype was virtually divided into three parts, as presented in the sketch of figure 29. The total volume of helium was divided in those three parts and so h1 has two sixths of helium, h2 three sixths of helium and h3 one sixth. So instead of having just one distributed force for all the helium, there are three distributed forces representing the helium divided into those three parts.

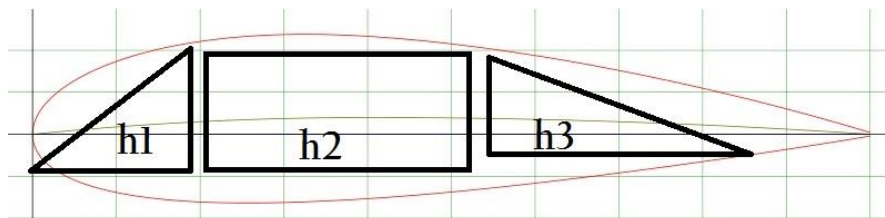


Figure 29. Sketch of the three distributed forces of helium

These three distributed forces can be represented in the form of three point forces and their longitudinal positions and values are 1.778 m, 4.667 m and 7.111 m and 51.72 N, 77.57 N and 25.05 N, respectively. As for the structure, it is estimated that it will weight approximately 10.85 kg, or 106.4 N, and for the same reasons it was virtually divided like the helium, having three distributed forces and they are represented as three point forces having the following values and longitudinal positions, 35.57 N, 53.2 N and 17.73 N and 1.778 m, 4.667 m and 7.111 m, respectively.

Having all the information needed, free body diagrams can be drawn. In the next diagrams all the longitudinal positions have the reference point A. In figure 30 is presented the distributed forces of helium, in figure 31 is presented the diagram of all the forces where F1

is the first part of the structure, F2 the second and F3 the third, F4 is all the hardware of table 3 positioned 2 meters from point A, F5 all the hardware positioned at 6 meters, F6 the vertical stabilizers, F7 the cruise electric motor, F8 the cruise propellers, F9 the servos for the vertical stabilizers and F10 the batteries. Because of the small value of some forces in figure 32 is presented a zoom in of those forces.

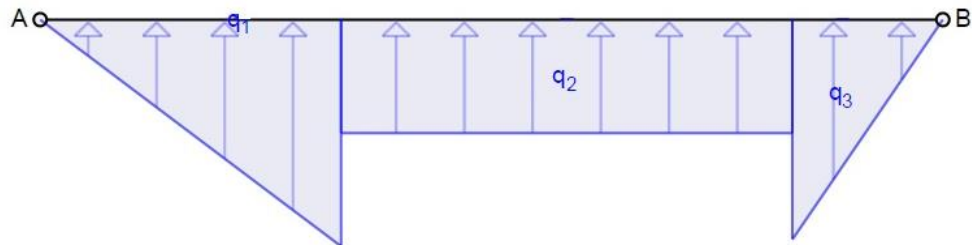


Figure 30. Free Body Diagram of the distributed forces of Helium

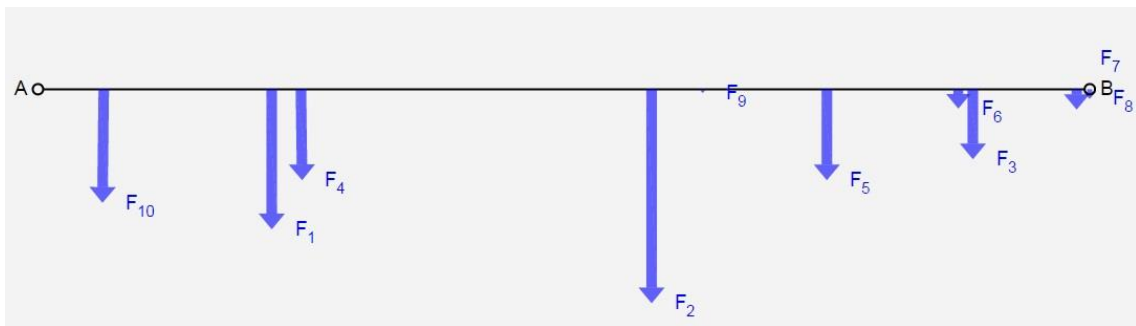


Figure 31. Free Body Diagram of the prototype systems hardware



Figure 32. Zoom of the small Forces

Also in figure 33 is presented the forces of figure 31, but also the localized forces of the distributed forces of the helium, were F11 is the first part of helium, F12 the second and F13 the third.

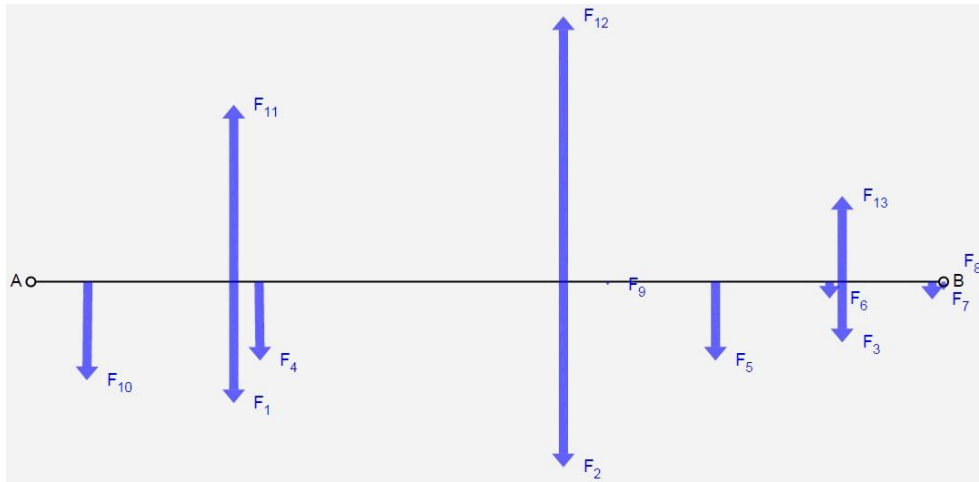


Figure 33. Free Body Diagram of all the forces in the prototype

All the previous estimations were also made when having a front view of the prototype, but having a front view the prototype can be separated with a symmetry line and so the free body diagram represents only half of the front view and it will be presented as a beam with 2.45 m. In table 4 are the systems hardware positions with point A as reference, force and relation with the diagram and in figure 34 the free body diagram with all the forces including the localized forces of the distributed forces of the helium and structure, and where F2 is all the forces localized at 2.05 m from point A, F3 the forces localized at 0,5 m and F4 all the forces localized at Point A.

Table 4. Systems Hardware positions and Force

	Position (m)	Force (N)	Diagram
<b>Structure</b>	0,55	53,201	F1
<b>Horizontal Stabilizers</b>	2,05	4,9	F2
<b>Vertical Stabilizers</b>	0,5	2,452	F3
<b>Horizontal Stabilizers Motors</b>	2,05	10,297	F2
<b>Cruise Electric Motor</b>	0	2,574	F4
<b>Horizontal Stabilizers Propellers</b>	2,05	4,9	F2
<b>Cruise Propeller</b>	0	1,226	F4
<b>Servos</b>	1,65	0,981	F5
<b>Servos</b>	2,05	1,961	F2
<b>Vertical Stabilizers Servos</b>	0,5	0,49	F3
<b>Batteries and Panels</b>	0	14,386	F4
<b>Helium</b>	0,55	77,572	F6

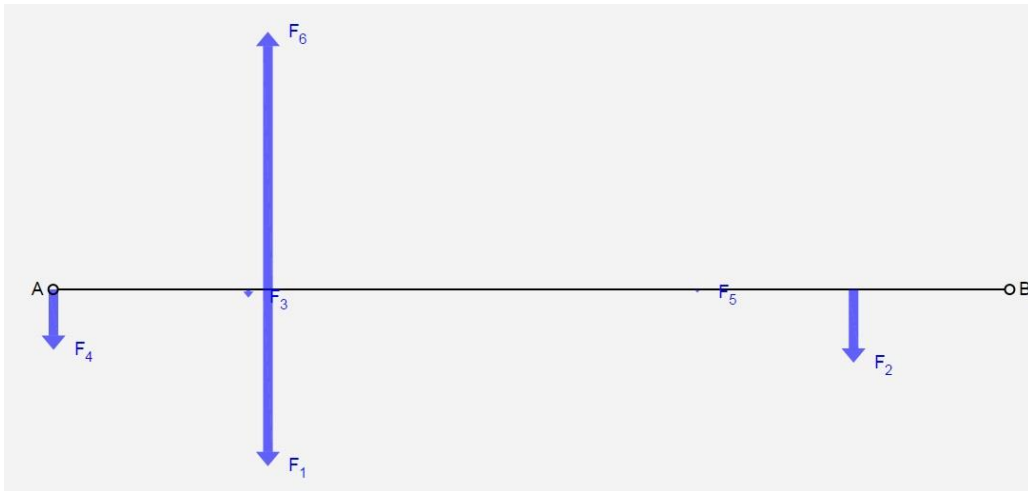


Figure 34. Free Body Diagram front view

### 3.3.3 Sketches

Next in figures 35, 36 and 37 are presented three views of the internal prototype structure sketches, where it can be observed the keels and the different sections that create the frames. Also in figure 38 is presented another view of the section of the structure that presents a final reinforcement with carbon pultruded rods, with a width of 6 mm and 2 mm of thickness.

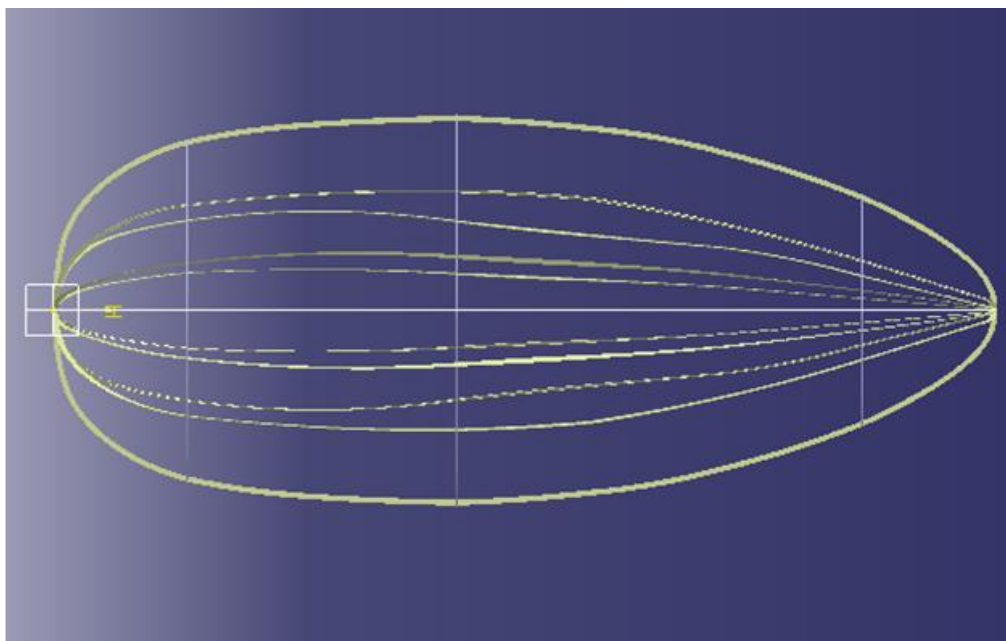


Figure 35. Sketch of the top view of the prototype structure

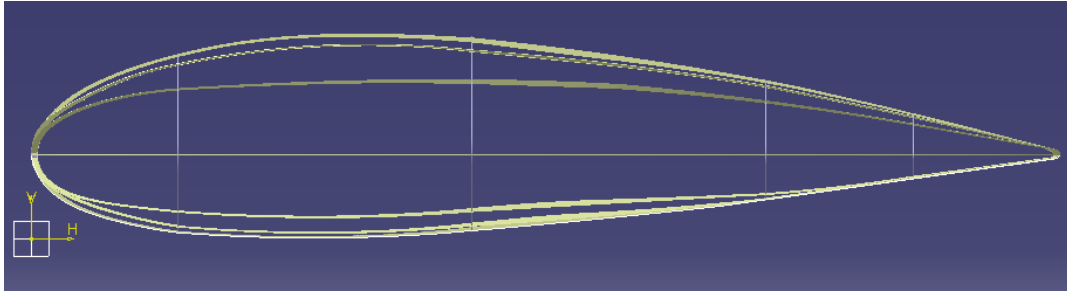


Figure 36. Sketch of the side view of the prototype structure

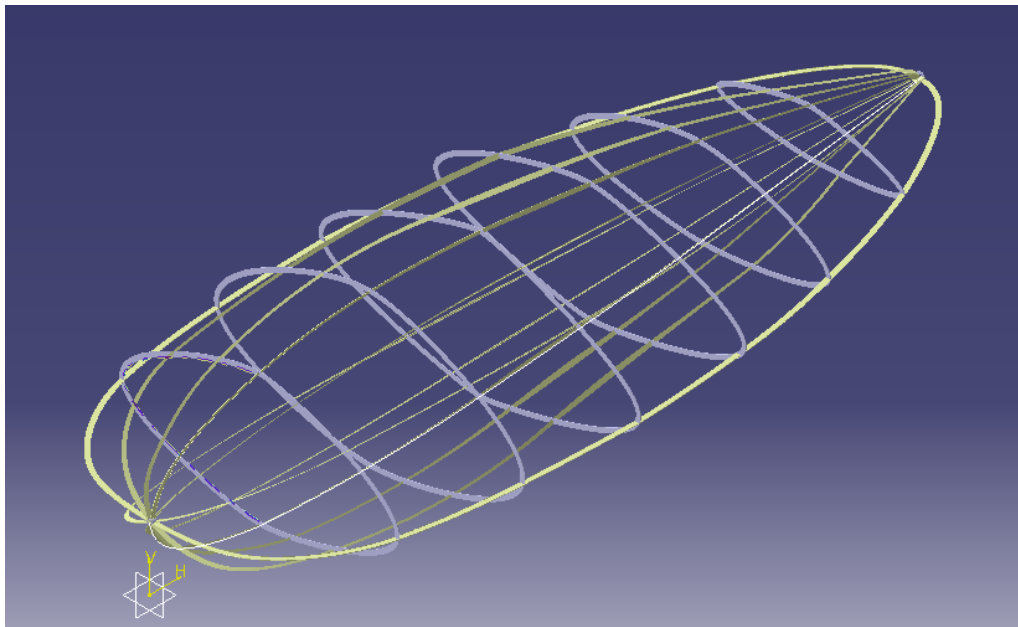


Figure 37. Sketch of the profile of the prototype structure

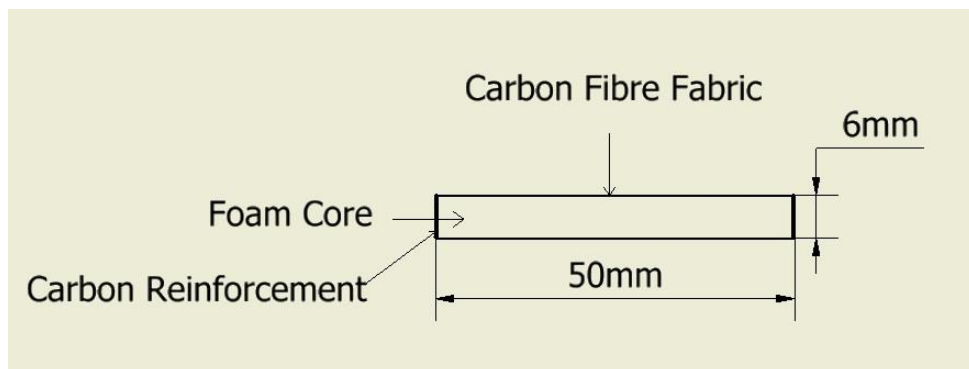


Figure 38. Sketch of the carbon pultruded rods reinforcement in the prototype structure

### 3.4 Review of the Results<sup>3</sup>

Reviewing the characteristics of the concept for the hybrid airship, comparing the size of it and estimated payload it can be said that the airship is a little over sized for the respective payload, but it can be a beginning of a new era for transportations and like previously demonstrated the payload of the hybrid airship grows exponentially with increasing size, which can take this kind of hybrid airships far in the future. Regarding the necessary power, comparing with today's airships it is really acceptable the presented value not being an exaggerated power. Also an important consideration is the size of the cruise propeller: with a diameter of three meters the rotation speed will not be very high which will increase the efficiency.

Regarding the prototype for the hybrid airship and its proposed structure, comparing the results of the depron foam and the airex foam it is clear that the foam that presents the best mechanical characteristics is airex, where the depron only supported 2.8 kg, airex supported 32 kg and it presents better values for Young's modulus and rupture tension. The Young's moduli were 42.64 MPa and 299.07 MPa, rupture tension 1166667  $N/m^2$  and 7751938  $N/m^2$  respectively. And adding the carbon reinforcement the strength of the structure will increase to even better results. Also comparing the ratio of the young's modulus and rupture tension with  $Kg/m^2$ , they present higher values for both specimens of airex.

Analyzing the prototype, its lifting capability and all the weight of the structure and internal systems, it will behave like the concept presented previously where the systems will have the payload, 7.509 kg, and the prototype will lift with the help of the four ducted fans. To take off they will require lifting approximately half of the payload, 4.121 kg, with a combined thrust power of 40.414 N and for each 10.104 N, approximately 1 kgf.

### 3.5 Conclusion

When developing a new concept for any type of aircraft it is important to understand the mission that the aircraft will perform. Looking at the type of mission that the airship would operate, which is the freight transportation in congested areas, it can be said that with just a few developments in the areas of materials and propulsion systems this type of airship, the hybrid airship, can represent the next step for a better future for all in the field of freight transportation. A future with lower environment pollution, a better transportation infrastructure that will not affect so much the every day to day and an increase of profits and efficiency.

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<sup>3</sup> *Parte da dissertação relevante para efeitos do processo de proteção de invenção referido no Aviso no início deste documento.*

After the production of the prototype it can be tested and we will verify how it will behave having the hull with the shape of an airfoil and the lifting capacity created to support half of the payload during flight, as expected. Regarding the structure and the tests made with the two foams, to confirm the results presented previously further tests can be made. And since the airex foam have such high resistance and load capacity, to try and reduce some of the weight for the prototype samples with airex foam with a width of 40 mm can be made and perhaps they will still behave better than the depron specimens with 50 mm of width.

## 4 Conclusions

### 4.1 Dissertation Synthesis<sup>4</sup>

In the area of freight transportation many difficulties still exist and some of them were presented. But to overcome them a concept of a hybrid airship was proposed and analysed.

In chapter two was described the present state of some fields of airships. Materials and structures, stability and control, propulsion systems and certification and legislation, as well as the evolution and possible future of some of them are addressed. On those fields was presented how they were concerning hybrid airships and also a little description of how they work. With all this it can be said that this kind of airships can help brake boundaries and create new goals in the future with a reliable service in regions and areas where other modes cannot, improving all the socio-economic factors, the lives of the people in this congested regions. They offer the capabilities of reaching and open markets, where in the past, they could not compete leading the way for the revival of interest for airship without jeopardizing the environment. Using them for freight transportation they could lead the way for a new era with the right support.

Then, in the third chapter the hybrid airship characteristics and how it operates were described in more detail. The conceptual design of a hybrid airship was presented for the specific mission of freight transportation, as well as the type of structure that might have the form of the airship hull and how it could improve the stability and control with the use of horizontal stabilizers and vectored ducted fans. This type of propellers can also help to taking off and landing. The necessary power for the ducted fans and cruise propeller and their size, some sketches and the airship characteristics of size and payload were also presented.

Still on the third chapter a prototype was proposed so that the concept of this airship can be tested. Sketches were drawn, its characteristics presented, not forgetting that its form will be similar to the prior concept using an aerodynamic airfoil. The types of materials that

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<sup>4</sup> *Parte da dissertação relevante para efeitos do processo de proteção de invenção referido no Aviso no início deste documento.*

can be used for the structure were also mentioned and a bending test was performed to compare their mechanical characteristics.

Promising results were obtained both in conceptual design of the hybrid airship and the prototype that will test this new concept.

## **4.2 Concluding Remarks**

In this work the proposed objectives were reached showing that the technology of this type of airships can make a difference in the freight transport field in congested areas. But in order to reinforce these new concept improvements need to be done in the design of the airship. For that it will be necessary more time and persons assigned for each field of the airship's technology, materials, stability and control and power system.

It is very important to note, as previously mentioned, that the design of an aircraft depends on the type of mission that it will perform. When the characteristics of the mission change, what it is considered an optimised solution for one may not be the most correct for another mission.

Regarding the prototype it is a step that will confirm how this airship will perform, and if all goes as predicted it will be the necessary proof to boost this study for higher objectives for the future.

## **4.3 Prospects for Future Work**

In the design of the airship an iterative study can be done to improve its precise size and form as well as to confirm its lift at cruising speed, and the shape and dimensions of all the stabilizers, both horizontal and vertical.

As mentioned in chapter three the choice of the materials for the prototype is an important step in its development. So, further tests should be made to better compare the two foams proposed. Since the airex foam presents the best mechanical characteristics, to improve the structure weight, bending tests can be made with an airex specimen with a width of 40 mm. In this way it will be determined if it still presents better results than the depron specimen with a width of 50 mm.

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# Annex 1 Numerical Results of Airfoils Analysis

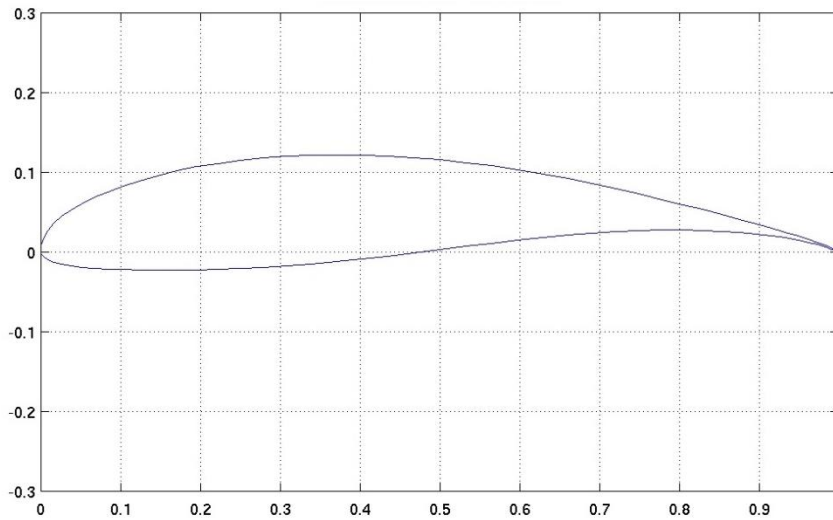


Figure 39. Airfoil fx63137, ([www.aerospace.illinois.edu/m-selig/ads/coord\\_database.html](http://www.aerospace.illinois.edu/m-selig/ads/coord_database.html), last access 20 September 2014)

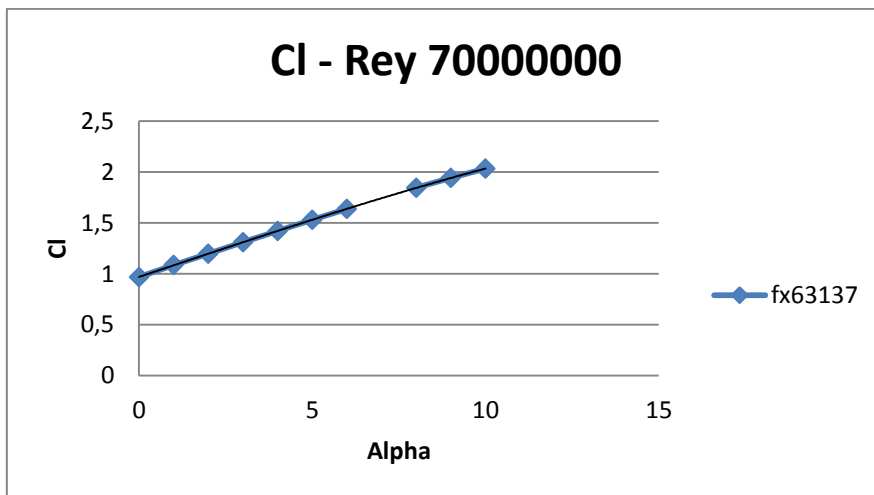


Figure 40. CL vs Alpha for Reynolds number 70000000 fx63137

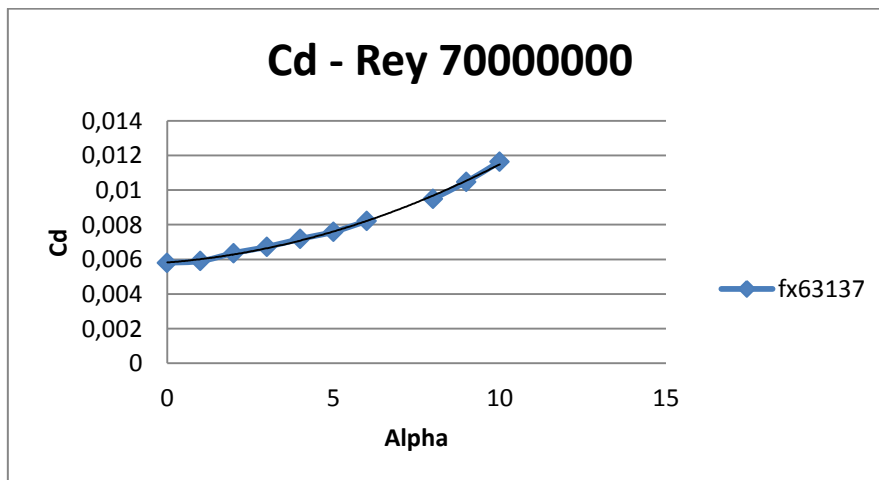


Figure 41. CL vs Alpha for Reynolds number 70000000 fx63137

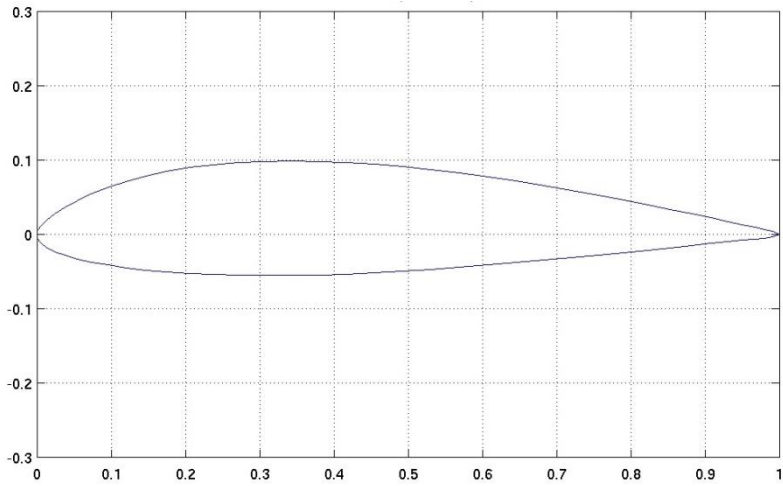


Figure 42. Airfoil geminism, ([www.aerospace.illinois.edu/m-selig/ads/coord\\_database.html](http://www.aerospace.illinois.edu/m-selig/ads/coord_database.html), last access 20 September 2014)

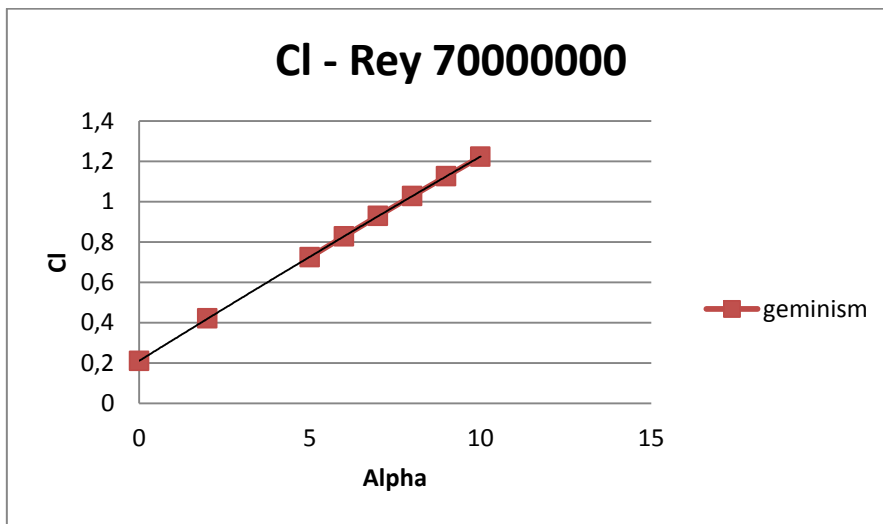


Figure 43. CL vs Alpha for Reynolds number 70000000 geminism

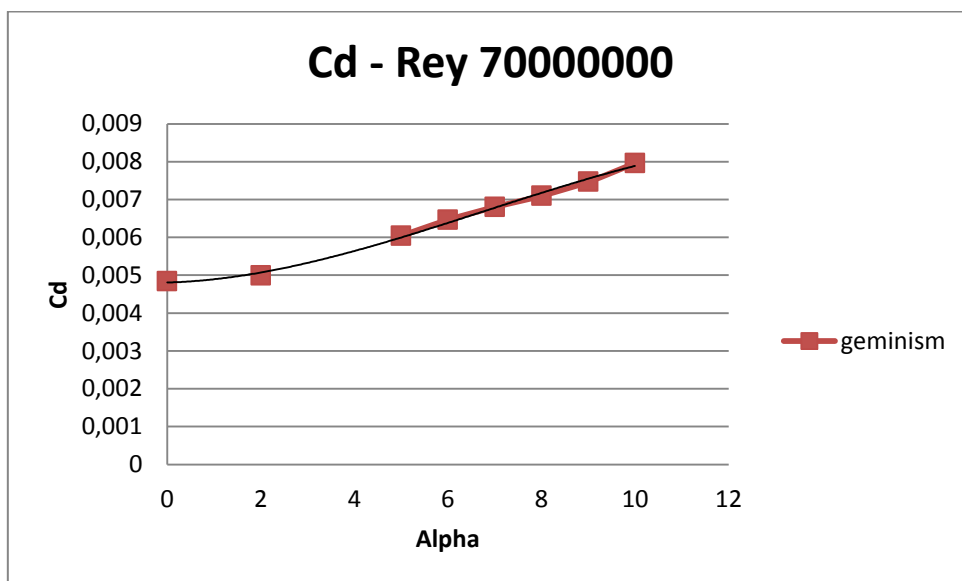


Figure 44. CL vs Alpha for Reynolds number 70000000 geminism

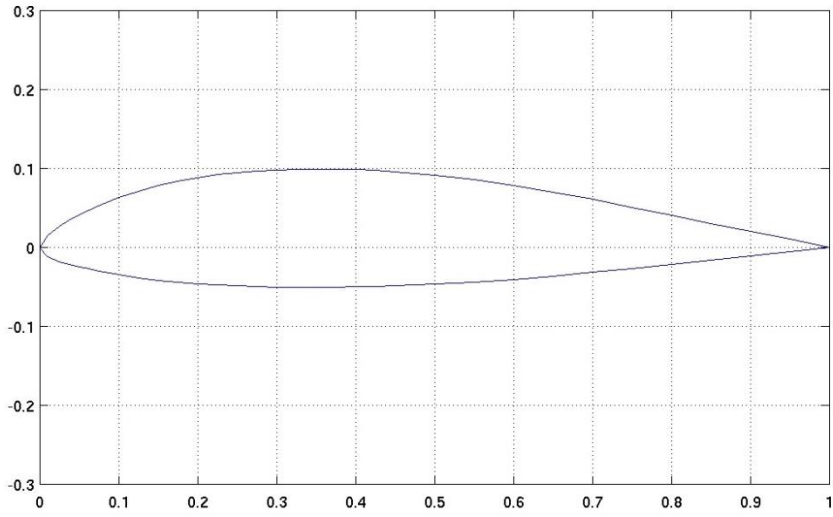


Figure 45. Airfoil mb253515sm, ([www.aerospace.illinois.edu/m-selig/ads/coord\\_database.html](http://www.aerospace.illinois.edu/m-selig/ads/coord_database.html), last access 20 September 2014)

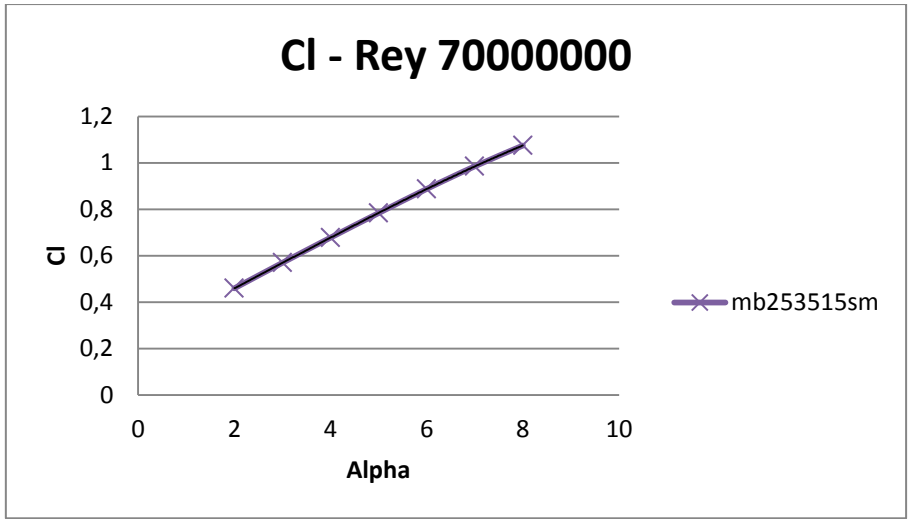


Figure 46. CL vs Alpha for Reynolds number 70000000 mb253515sm

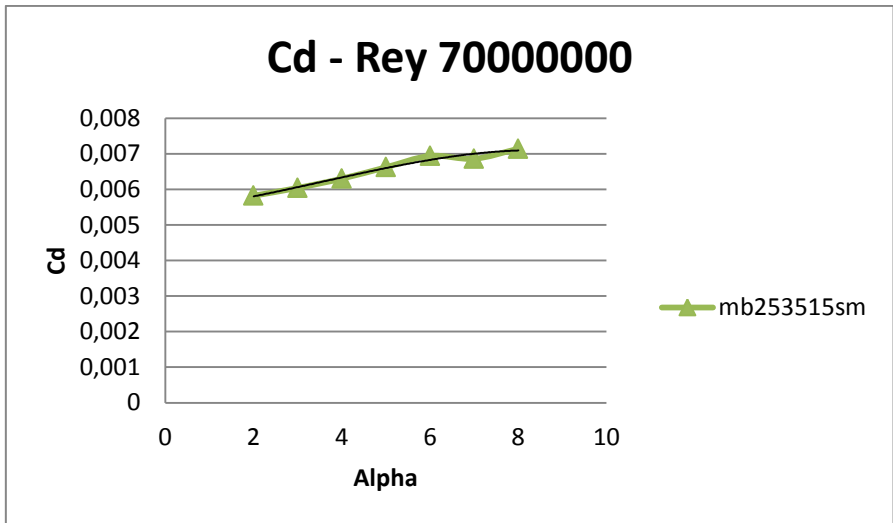


Figure 47. CD vs Alpha for Reynolds number 70000000 mb253515sm

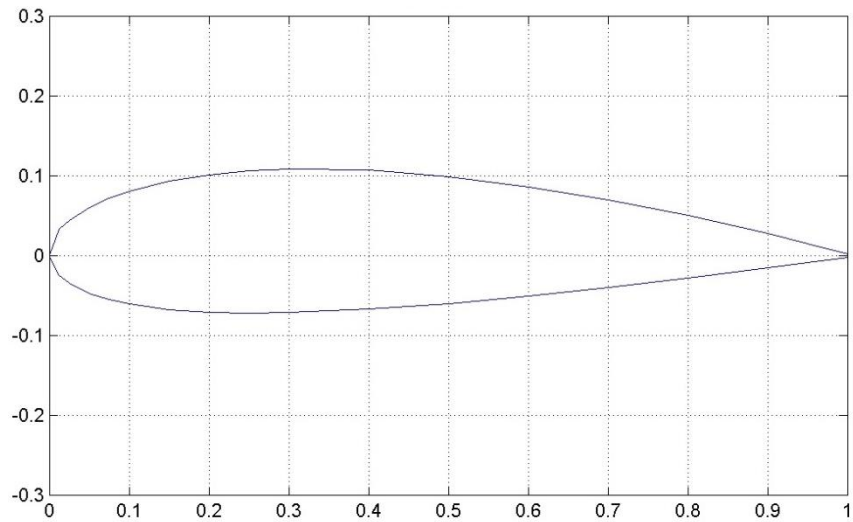


Figure 48. Airfoil naca2418,( [www.aerospace.illinois.edu/m-selig/ads/coord\\_database.html](http://www.aerospace.illinois.edu/m-selig/ads/coord_database.html), last access 20 September 2014)

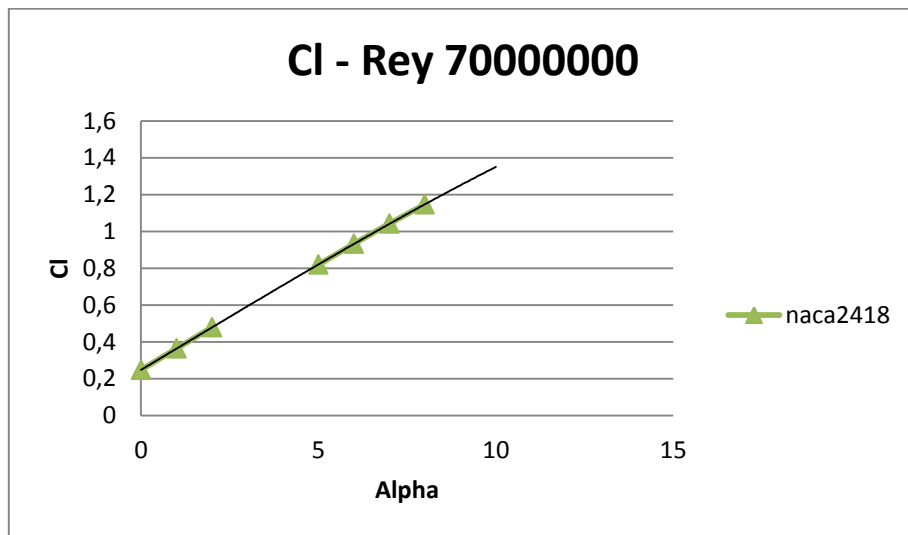


Figure 49. CL vs Alpha for Reynolds number 70000000 naca2418

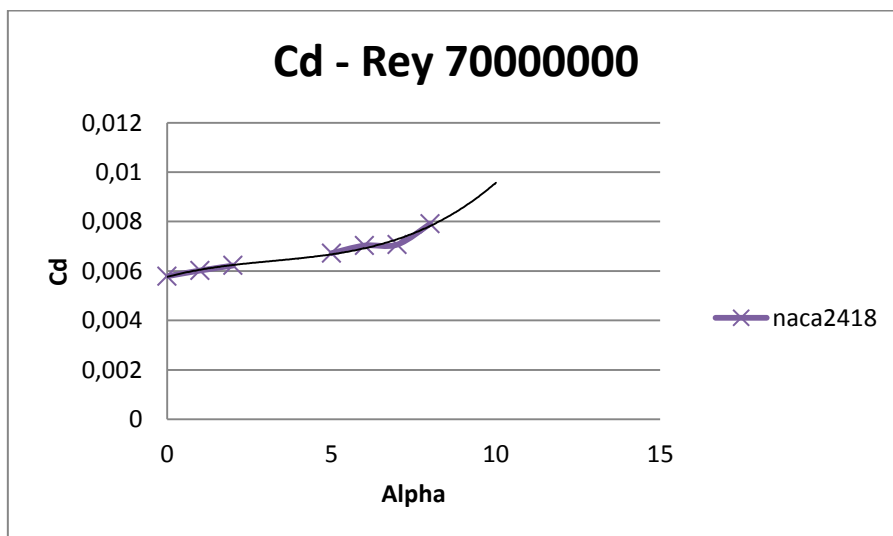


Figure 50. CD vs Alpha for Reynolds number 70000000 naca2418

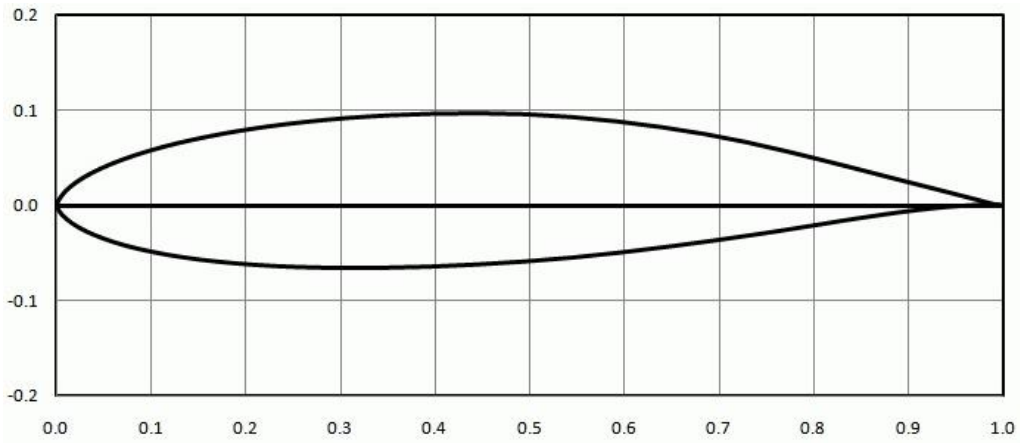


Figure 51. Airfoil s822, ([www.aerospace.illinois.edu/m-selig/ads/coord\\_database.html](http://www.aerospace.illinois.edu/m-selig/ads/coord_database.html), last access 20 September 2014)

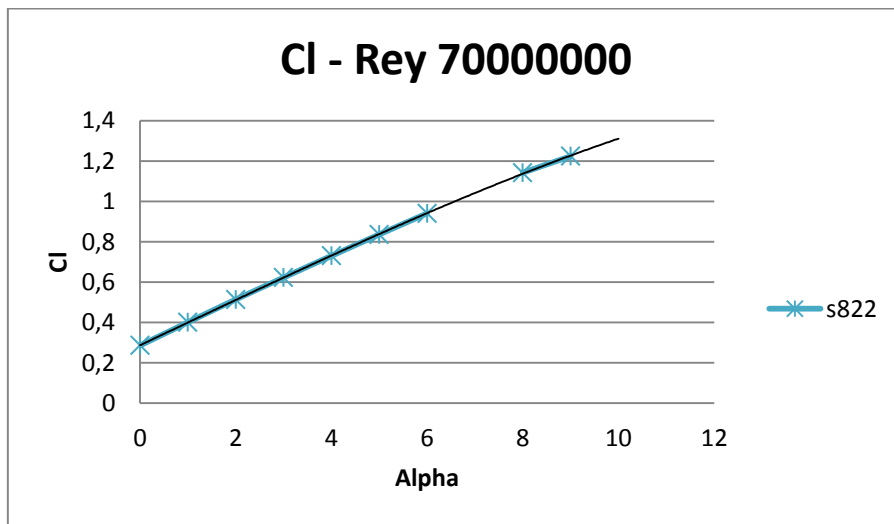


Figure 52. CL vs Alpha for Reynolds number 70000000 s822

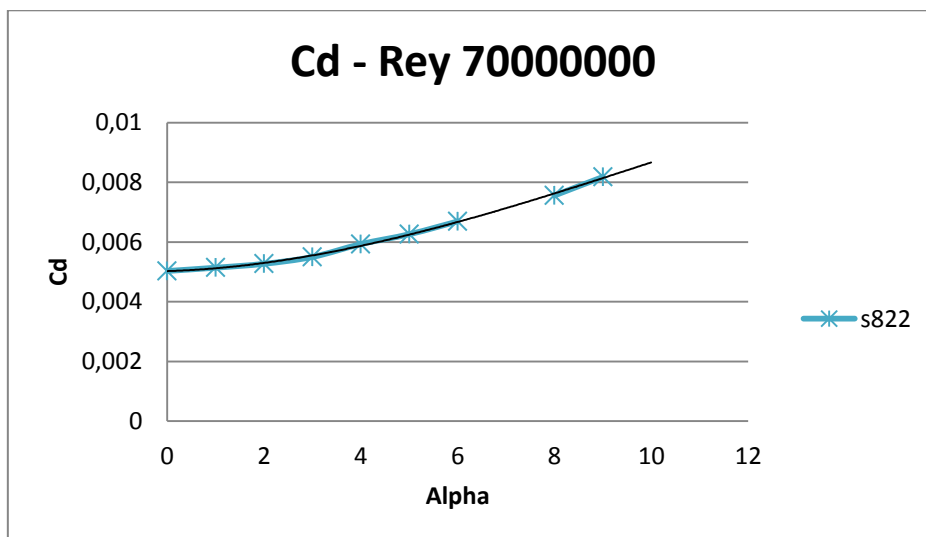


Figure 53. CD vs Alpha for Reynolds number 70000000 s822

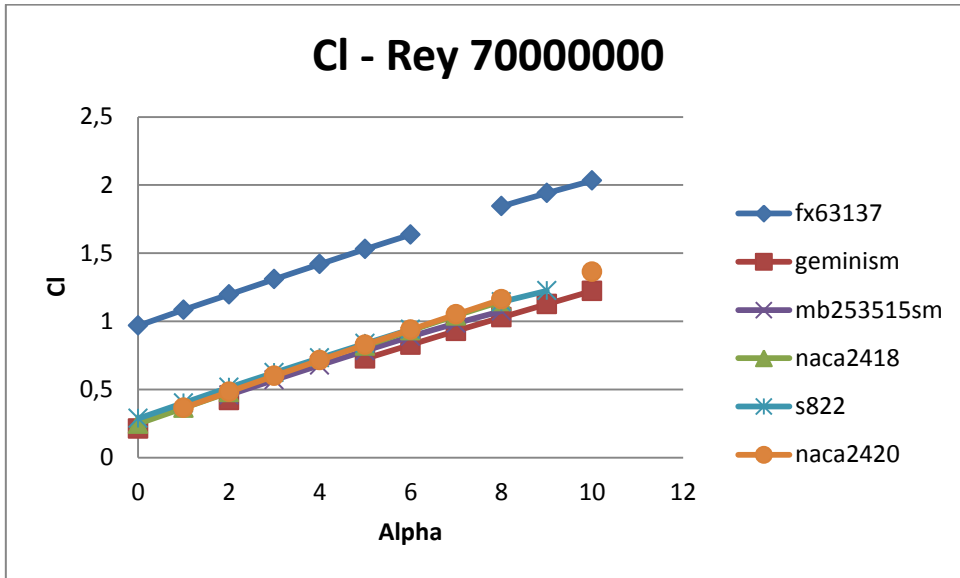


Figure 54. CL vs Alpha for Reynolds number 70000000 for all arifoils

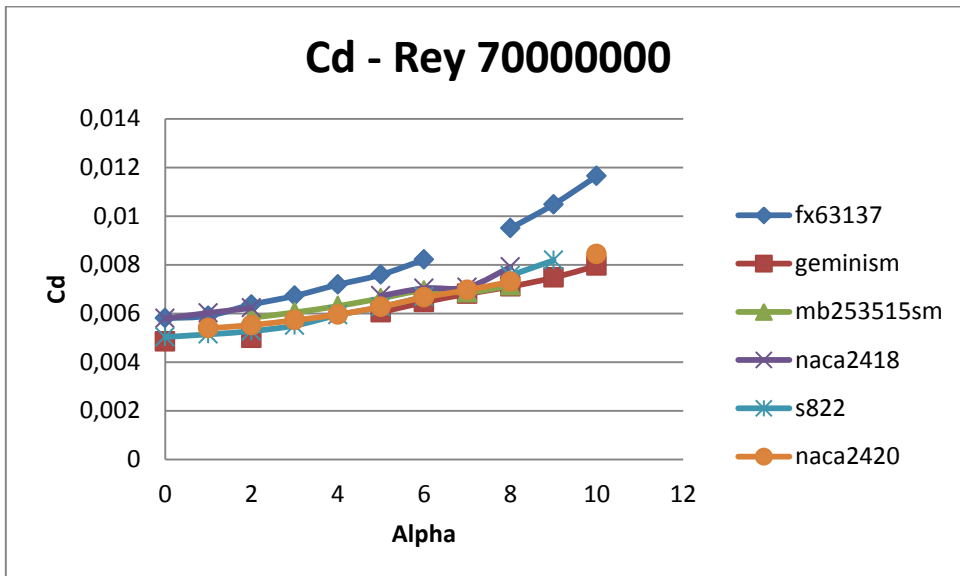


Figure 55. CD vs Alpha for Reynolds number 70000000 for all arifoils

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# 18TH ATRS WORLD CONFERENCE

## AIRSHIPS AND AEROSTATS TECHNOLOGY. A STATE OF ART REVIEW

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### ABSTRACT

Nowadays new airships or Light than Air (LTA) aircrafts and aerostats are being tested and used for military and civilian purposes all over the world. This revived interest about airships and aerostats brings a multitude of new technical concepts resulting from a deep interdisciplinary research so that the actual state of art about them paves the way for renewed horizons regarding its use and operation in the next future.

With those technological improvements it is expected that airships will become soon a competitive mean of transport for linkage mainly with areas only served by weak or degraded transport infrastructures. Regarding the principles of sustainable development of air transport, airships are also the most environmentally friendly vehicles with lower fuel consumption and higher endurance. Therefore they are conquering new still unexplored markets.

This work aims to present a state of art review about history and use of airships and aerostats, and to evidence how technological improvements in the recent past may impact positively its performance and thus its use in different scenarios in future.

**KEYWORDS:** Airships and aerostats, Technological improvements, Air transport sustainability

**CLASSIFICATION:** Aviation and Economics Development, Aviation Case Study, Inter-Modal and Air Travel Alternatives

## **1. INTRODUCTION**

The rebirth of this mean of transportation capable of overcoming some disadvantages of the conventional ones brings interesting economic benefits in the medium and long term scenarios as they may offer the same services at lower costs while stimulating new commercial and industrial activities.

The background of airship technology comes from the XVIII century. Since then all these years were of scientific and empirical improvements. Nowadays these constitute the basis of a sustainable future in several related emerging technologies making possible the use of airships in even more safety contexts.

Also those improvements brought a multitude of technical new concepts as a result of an interdisciplinary research and effort. Consequently the state of art about airships paves the way for the reappearance of its use within renewed scenarios which require the most environment-friendly air vehicles with lower fuel consumption and higher endurance.

All over the world there are several countries where airships are being used for military and civilian purposes as Canada, Brazil, and Australia among others. India, for example, prepares the use of airships for the connection to remote areas with poor surface infrastructure which only can be reached by air or walking due to seasonally bad weather conditions.

This paper is organized as follows: 1) a brief introduction on the theme; 2) a state of art review about technological characteristics and operational constraints; 3) a description of some technological problems and related solutions; 4) a brief overview about airships potential; 5) a brief description of the related legislation; and 6) some conclusions.

## **2. STATE OF ART REVIEW**

### **2.1 Technological Characteristics**

As the envelope constitutes the main structural element of airships it requires particular care since the design phase until the end of its operational lifetime. The envelope should

be designed to fulfill some key requirements such as to resist to loading forces in flight and on the ground conditions, i.e., those which may limit the resistance of the envelope. This procedure is crucial to minimize any leakage of the lifting gas (0.3 liters/m<sup>2</sup> per day) and also to withstand adverse climatic agents such as ice, wind, snow, UV radiation and extreme temperatures.

Also the choice of materials is crucial for the exit of the airships construction and use and thus should follow the highest standards as stated by Miller and Mandel (2002).

Since a few years ago several research works sustain the importance of the use of renewable energy systems as electrical propulsion and energy storage, photovoltaic systems, and residual heat removing systems.

In 2001 NASA's Glenn Research Center conducted a research work about propulsive systems in airships involved in long-term missions (Miller and Mandel, 2002). This project tried to optimize the design of the vehicle thus maximizing its efficiency, as it was necessary to consider the energy and propulsive systems and the aerodynamic performance as a whole simultaneously to guaranteed the minimum weight of all the systems aboard and to ensure the proper balance between the generation/storage of solar energy and the energy consumption in the propulsion, taking into account seasonal variations of wind and sunlight, mission objectives, maximum weight of the vehicle, and latitude and altitude of flight too.

Different operating altitudes provide airships with different technical characteristics. Based on the operational altitude airships can be divided into three main categories (Figure 1).

Modern airships are equipped with advanced avionics and electronics systems which ensure safe operation and good maneuverability in all flight phases as Fly-By-Wire (FBW) and Fly-By-Light (FBL) controls.

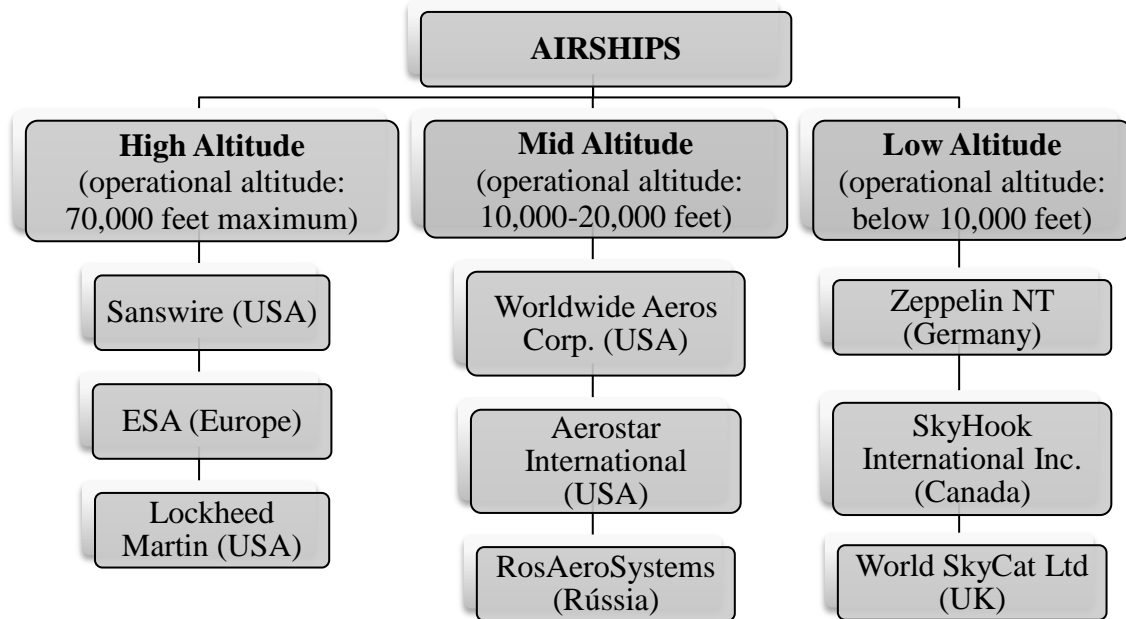


Figure 1. Airships Operational Altitude and Related Investment Companies

Flight data processors and flight control systems constitute management systems for data exchange as the Onboard Managing Data Exchange System (ODEMS). If necessary airships use modern navigation systems to enable night operations too such as Ground Position System (GPS) - based, infrared vision systems and meteorological sensors.

Airships design and construction as well as its flight operations follow all safety standards imposed by international authorities (as International Civil Aviation Organization, ICAO) as any other aircraft.

Figure 2 resumes a state of art review about some related technological characteristics: structures, materials and new construction techniques; and propulsion systems, control and stability.

## 2.2 Operational Constraints

There are two main constraints related to the operation of airships: the bouncy control and the climatic factors.

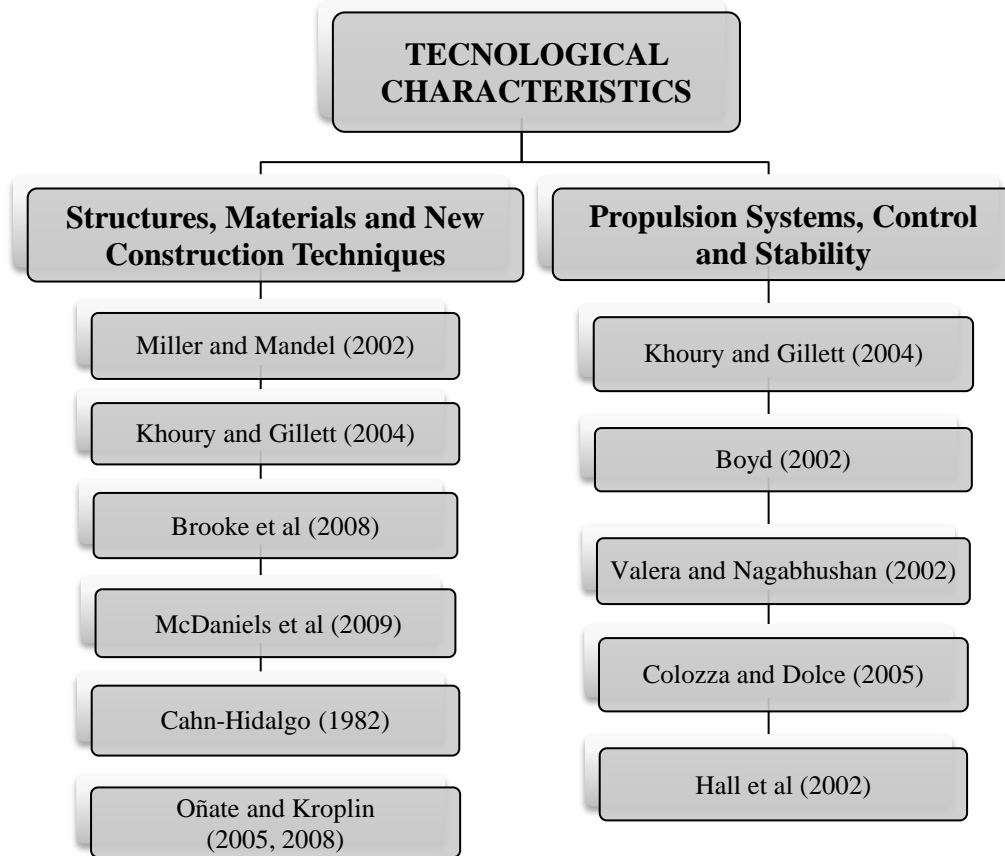


Figure 2. State of Art Review Related to Some Technological Characteristics

The buoyancy control always has been a primary problem but advances in the airship's technology are finding workable solutions to ensure safety flight conditions. Airship balance is affected by several factors such as: fuel consumption, differences in the barometric pressure, temperature changes in the surrounding air and/or in the lift gas, precipitation, humidity, etc. Nowadays the buoyancy control can be achieved through mechanisms of weight compensation.

Another operational constrain is related with climatic factors. Statistically more than 20% of aircraft incidents/accidents are due precisely to climatic factors (Table 1). All means of transportation are more or less affected by them but its influence over airships operations is more evident: the ratio volume/weight is high making it very sensitive to wind effects; and the higher drag factor relatively to its low thrust force hinders the maneuverability and the control against adverse air currents. However modern airships are equipped with specific equipments which enable safety flights under the requirements of ICAO.

Table 1. Key Climatic Factors Affecting Transportation Modes

Climatic Factors	Transportations Modes				
	Maritime	Road	Rail	Air	Airship
Thunderstorm	Little affected	Little affected	Affected	Affected	Affected
Heavy rain	Little affected	Affected	Little affected	Affected	Affected
Strong wind	Affected	Little affected	Little affected	Affected	Much affected
Storm	Much affected	Much affected	Affected	Much affected	Much affected
Ice	Affected	Much affected	Little affected	Much affected	Much affected
Hail	Little affected	Affected	Little affected	Much affected	Affected

### 3. TECHNOLOGICAL PROBLEMS AND SOLUTIONS



There are some major technical problems which may affect the lifecycle of airships among which we selected the following: should it be rigid, semi-rigid or non-rigid; how to maintain it on the ground; which gas should be used to fill in for lift; and which sources of energy must be used. Below we propose some solutions for each of them.

#### 3.1. Should it be rigid, semi-rigid or non-rigid?

The advantage of using the RIGID structure is that it has low Drag (that means less fuel consumption), high stability and easy to manufacture/low production cost; and the advantage of using the NON-RIGID structure is that it has more lifting power than the rigid one (Figure 3).

In our opinion the best option is to choose a SEMI-RIGID structure which has the quality of both (Figure 4). It will be cost effective as well as with high lifting power.

*Rigid Airship:  
Envelope, Shape, &  
Stability Not Dependent  
On Internal Pressure*

	RIGID	NON-RIGID
LOCATION OF PAYLOAD	Internal to envelope	External to envelope
PAYLOAD SIZE (weight & volume)	less than non-rigid	more than rigid
DURABILITY	Punctures (holes) do not jeopardize structure integrity	Punctures in envelope cause immediate pressure and integrity loss. Must be patched quickly.
GROUND HANDLING	Envelope shape and internal payload minimize cross-wind input	Gusty winds necessitate more ballast, tethering
TIME TO PRODUCE	Components are fabricated in parallel, and quickly integrated at once	Component fabrication & integration must be done in series
COST	Production cost is low due to fast production time	Production cost is high to sequential production

Figure 3. Rigid and Non-Rigid Airships (Pevzner, 2009)

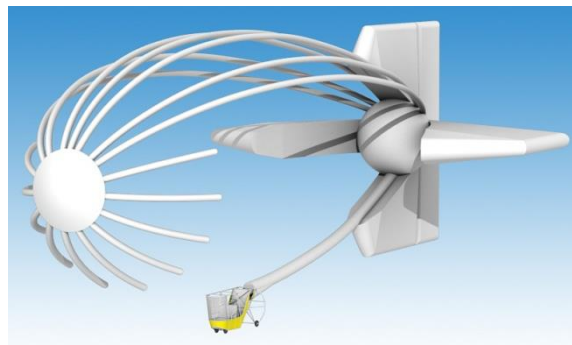


Figure 4. Semi-Rigid Airships (Apexballoons, 2013)

### 3.2. How to maintain it on the ground?

To solve this problem we propose at least three solutions: a water tank; a vector thrust model; or a mobile ground weight.

3.2.1. **A Water Tank:** it is possible to use a water tank inside of the airship. During flight the ballast tank will be empty and whenever landing or suspending the ballast tank will be refilled. The disadvantage of this method is that it is necessary to install an extra weight inside the airship and this will require a more complex ground infrastructure for water refilling as well as this will decrease the safety factor (Figure 5).

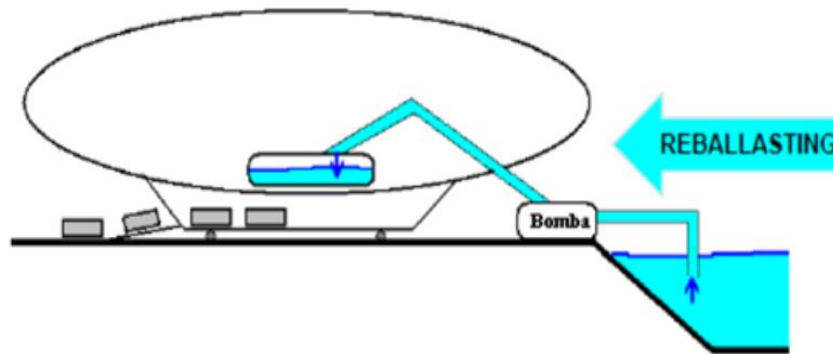


Figure 5. Refilling System of the Ballast Water (Pevzner, 2009)

3.2.2. **A Vector Thrust Model:** it is possible to use a propulsion system (vector thrust model) to compensate the buoyancy force responsible for the lift itself. But since it will be necessary to produce thrust in negative direction of buoyancy it will be required more fuel consumption too. Thus this is not a cost effective method. But even so the system may be used for some in flight or landing/suspending maneuvers (Figure 6).



Figure 6. Vector Thrust Model (Prentice and Hochstetler, 2012)

3.2.3. **A Mobile Ground Weight:** it is possible to use a mobile ground weight for maintaining the airships as in a horizontal position as possible whenever it is on the ground. Also it is possible to use an hydraulic system for the same purpose. Since it will be a mobile system it will not require any complementary and complex infrastructures. Hence it will be not only a cost effective but also a safe solution (Figure 7).



Figure 7. Mobile Ground Weight (Modern Airships, 2013)

In our opinion the best solution to maintain the airship on the ground is the use of a Mobile Ground Weight.

### 3.3. Which gas should be used to fill in for lift?

Hydrogen has the highest lift force per unit of volume but it is an highly inflammable gas too (Table 2). So it isn't possible to use hydrogen.

Table 2. Gas properties (Boon, 2004)

Gas	Density (kg/m <sup>3</sup> )	Lifting Force (N/m <sup>3</sup> )	Comment
Hydrogen	0.085	11.2	Inflammable, relatively cheap
Helium	0.169	10.2	Inert, relatively expensive
Hot Air	0.906	3.14	Inert, very cheap, relatively poor lift
Methane	0.756	4.5	Inflammable, relatively cheap

Helium is the next candidate as it has an important lifting force per unit of volume and it is an inert gas too. Thus Helium seems to be the best option as a lifting gas for the airship.

### **3.4. Which sources of energy must be used?**

There are several studies about the application of renewable energy systems (electric propulsion and energy storage, photovoltaic systems, and residual heat removing systems) within airships design. The general concept is to optimize the design of the aircraft thus maximizing its efficiency, considering the energy and propulsive systems and the aerodynamic performance as a whole simultaneously to guaranteed the minimum weight of all the systems aboard and to ensure the proper balance between the generation/storage of solar energy and the energy consumption in the propulsion, taking into account seasonal variations of wind and sunlight, mission objectives, maximum weight of the vehicle, and latitude and altitude of flight too.

The idea is that solar energy is attached directly to the electric motors driving the airship propellers. Electric motors which substitute superconducting magnets in place of traditional copper wire are used to reduce the weight of the motors. The surplus of electricity generated during daylight operations is used for the electrolysis of water and thus the production of oxygen and hydrogen which in turn are stored to be used in night operations or under bad weather conditions. Exhaust water produced by fuel cells as well as condensed water from the ambience are kept onboard as ballast: to be pulled off or used aboard as needed to adjust or maintain the airships' buoyancy. Bio-Diesel powered electric generators may be used as a back-up system of solar and fuel cells.

There are several airships using solar energy as Nanuq (Figure 8) a so called Solar Ship designed to carry payloads up to 30 tons of cargo for distances up to 6,000 km and at speeds up to 120 km/h. When Nanuq is empty it requires take-off and landing runways of 60 m and 100 m long, respectively, and even when it is fully loaded a runway of 200 m long is enough for the take-off (Solarship, 2012).

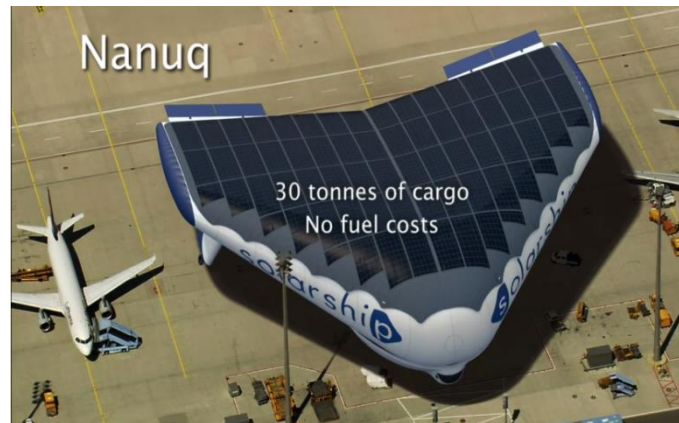


Figure 8. Nanuq Airship (Technewsdaily, 2013)

The main advantages of a solar powered airship are:

- It may fly to any location without need traditional airports to operate from;
- It doesn't need long runways and landing and take-off as these operations may be done quite vertically and from everywhere: unprepared fields, ice-fields, desert sands, heavy shrub-lands, lakes, rivers, or even the ocean;
- It can fly over oceans, mountains, i.e., all around the world;
- It is slower than commercial jets but faster than trucks, trains, or ships; and
- It can carry hundreds of passengers or several tons of cargo.

#### 4. AIRSHIPS POTENTIAL

Airships require neither complex nor expensive infrastructure for landing and take-off. So they have a wide range of applications from civil to military purposes:

- **Surveillance and Monitoring:** airships may realize long-range missions and perform long endurance flights without refueling; when equipped with adequate radio navigation aids they may act as platforms for surveillance/monitoring missions too (Bilko, 2007);
- **Transportation of General, Heavy, Indivisible and/or Perishable Cargos:** airships provide more economic operational costs than those of commercial aircrafts and with less maintenance costs too; Storm and Peeters (2011) underline how airships may compete with the railway for long distances -

because its ability to link point-to-point nodes, with road in the tourism sector for distances over than 200 km, and with the cruises in the maritime for distances between 200 km and 1,000 km;

- **Transportation of Passengers:** using airships tourists may overflight landscapes and/or protected environments;
- **Defense:** in this particular airships have been used not only for surveillance and monitoring but also for the transportation of troops and general cargo; during the World War II airships were used to carry tanks – for example the Turtle Millennium class Airships carried up to 8 Abrams M-1 tanks (60 tons each) at a time and put them down quite anywhere ready to fight, while Lockheed C-5 Galaxy Aircrafts only carried 2 tanks at a time and required specific airfields for landing and take-off (Knoss, 1998).

Since ever environmental concerns may influence the choice of/among transportations systems. Storm and Peeters (2011) stated that the environmental impact of the airships operating at moderate speeds (between 100 km/h and 150 km/h) is similar than that of the railway, thus classifying them as a green transport system.

## 5. LEGISLATION

The rebirth of airships evidences either the lack of legislation about its operation in several countries - i.e., the incapacity of some national regulators to establish operational standards, or the amount of different rules which may impact negatively over some international flights:

- ICAO recommends its member states to follow the Annex 2 about Rules of the Air;
- FAA recommends its members to follow the FAR Part 91 about General Operating and Flight Rules;
- European Aviation Safety Agency (EASA) follows the so called Acceptable Means of Compliance and Guidance Material to the rules of the air, and has Specific Airworthiness Specifications (SAS) for airships as well as requirements to emit Airships Type Certificates (ATC); also in Europe there are some Airship

Transport Requirement (ATR) which mean that some performance tests are needed to prove structural strength of the envelope of the aircraft when operating under bad weather conditions (Szirmai *et al.*, 2012);

- In Portugal the national Civil Aviation Authority (INAC) emitted a Technical Information related to airships (INAC, 2011) although for non commercial use - which is a transcription of PART M of EC Regulation No. 2042/2003 of EASA (2011); later INAC inform the aeronautical community about the EC Regulation No. 923/2012 an up-to-date document of EASA too.

## 6. CONCLUSIONS

The background of airship technology comes from the XVIII century. Since then all these years were of scientific and empirical improvements so nowadays these constitute the basis for a sustainable future in several related emerging technologies making possible the use of airships in even more safety contexts.

Also those improvements brought a multitude of technical new concepts as a result of an interdisciplinary research and effort. Consequently the state of art about airships paves the way for the reappearance of its use within renewed scenarios which require the most environment-friendly air vehicles with lower fuel consumption and higher endurance.

The buoyancy control always has been a primary problem but advances in the airship's technology are finding workable solutions to ensure safety flight conditions. Another operational constrain is related with climatic factors. However modern airships are equipped with specific equipments which enable safety flights under the requirements of ICAO.

There are some technical problems which may affect the lifecycle of airships among which we selected the following: the choice among rigid, semi-rigid or non-rigid structures; how to maintain it on the ground; which gas should be used to fill in for lift; and which sources of energy must be used. We sustain that the best options for each of them are, respectively: to choose a Semi-Rigid structure; to use a Mobile Ground Weight system; to use Helium as lift gas; and to chose Solar Powered solutions.

Airships require neither complex nor expensive infrastructure for landing and take-off. So they have a wide range of applications from civil to military purposes: surveillance and monitoring; transportation of general, heavy, indivisible and/or perishable cargos; transportation of passengers; defense, etc.. See as since ever environmental concerns influence the choice of/among transportations systems. Storm and Peeters (2011) precisely stated that the environmental impact of the airships operating at moderate speeds is similar than that of the railway, thus classifying them as a green transport system.

The rebirth of airships evidences either the lack of legislation about its operation in several countries - i.e., the incapacity of some national regulators to establish operational standards, or the amount of different rules which may impact negatively over some international flights. Consequently, and in parallel with the improvement of the technical specifications of airships is necessary to ensure interoperability of its flight operations in international flights across the planet.

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