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Operations of a Hybrid Airship Over Congested Areas

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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:

- *Rosário Macário, Instituto Superior Técnico;*
- *Vasco Reis, Instituto Superior Técnico;*
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- *Pedro Gamboa, Universidade da Beira Interior;*
- *João Neves, Universidade da Beira Interior.*

As partes da presente dissertação relevantes para efeitos do processo de proteção de invenção estão devidamente assinaladas através de chamadas de pé de página. As demais partes são da autoria do candidato, as quais foram discutidas e trabalhadas com os orientadores e o grupo de investigadores e inventores supracitados. Assim, o candidato não poderá posteriormente reclamar individualmente a autoria de qualquer das partes.

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Abstract

On 24th September 1852, Jules Henri Giffard, French inventor and engineer, makes the first flight in the history of airships, 51 years before the first flight of the Wright Brothers. At that moment he opened a window in the history of aviation, particularly in the field of airships. This type of aircraft belongs to the family of aerostats, having a lighter than air gas filing an envelope providing lift and its own means of propulsion.

The main focus is the study of current aeronautical legislation regarding visual flight rules, building requirements for airfields supporting the operation of the aircraft, in particular, regular surface-level airfields as well as a new type of aircraft deck. A case study was made for the city of Lisbon, Portugal.

This legislation review has the main objective of pinpointing lacunae for this special type of aircraft and respective support infrastructure, providing answers to the challenges identified and thus allowing for an update in legislation. An effort is also made to use and update existing helicopter legislation and adapt it for hybrid airships, thus allowing a safe operation of the aircraft.

Keywords

Hybrid Airship, Aircraft Operations, Aeronautical Legislation, Infrastructures, Flight Rules.

Resumo

Em 24 de Setembro de 1852, Jules Henri Giffard, um inventor e engenheiro francês, realiza o primeiro voo da história dos dirigíveis, 51 anos antes do primeiro voo dos Irmãos Wright. Naquele momento, ele abriu uma janela na história da aviação, mais particularmente no ramo dos dirigíveis. Este tipo de aeronave pertence à família dos aeróstatos, possuindo um gás mais leve do que ar que enche um envelope que permite a sustentação e meios próprios de propulsão.

O principal foco deste estudo é rever a legislação aeronáutica actual no que toca a regras de voo visuais, requisitos de construção para aeródromos que suportam a operação do dirigível, em particular, aeródromos de superfície assim como um novo tipo de plataforma de pouso. Um caso de estudo foi feito para a cidade de Lisboa, Portugal.

Esta revisão tem como objectivo apontar lacunas da legislação para este tipo especial de aeronave e respectivas infraestruturas de suporte, providenciando soluções aos desafios encontrados, permitindo assim uma actualização de legislação. Também é feito um esforço no sentido de actualizar legislação específica de helicópteros, e adapta-la para dirigíveis híbridos, de modo a que a operação possa ser feita de forma segura.

Palavras-chave

Dirigível Híbrido, Operação de Aeronaves, Legislação Aeronáutica, Infraestruturas, Regras de Voo.

Table of Contents

List of Figures

List of Tables

List of Acronyms

ANAC	Agência Nacional da Aviação Civil
AIP	Aeronautical Information Publication
ATC	Air Traffic Control
CO_2	Carbon Dioxide
CTR	Controlled Traffic Region
d	Length of the Airship
D	Length of the Helicopter
EASA	European Aviation Safety Agency
ECCAIRS	European Coordination Centre for Accident and Incident Reporting Systems
FAA	Federal Aviation Administration
FATO	Final Approach and Take-off Area
G	Length of the Gondola
GPS	Global Positioning System
h	Hours
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
kg	Kilograms
km	Kilometers
L/min	Liter Per Minute
m	Meters
N	North
NAV	Navegação Aérea de Portugal
NOTAM	Notice to Airmen
TLOF	Touchdown and Lift-off Area
VMC	Visual Meteorological Conditions
VTOL	Vertical Take-Off and Landing
W	West
º	Degrees

Chapter 1. Introduction

1.1 Motivation

My motivation for the writing of this dissertation came initially by an invitation by Professor Jorge Silva, to join a working group composed of two Portuguese universities, teachers and faculty colleagues of Aeronautical Engineering from University of Beira Interior and teachers and students of the Universidade Técnica de Lisboa, with the aim of developing a hybrid airship to be used in congested areas. The proposed work was for me to prepare the required procedures for the operation of the airship within those areas, including landing, takeoff, cruise flight, safety and infrastructure support. Much of this motivation came from a long-standing story of my childhood, being born in the island of Santa Maria in the Azores archipelago, I was fascinated by aviation from an early age, and heard the stories of the Zeppelin Airships flights delivering mail and letters to the island, and these letters had stamps that are now relics and have great value, so as soon as I heard this story as a child, I asked my grandfather if he had such a letter, and the answer was "No".

The difficulty inherent to the development of this work was another aspect that motivated me, airships are no longer a way of transporting people and freight, being replaced by the plane and the helicopter. They are only recently being used for touristic flights, television broadcasts or advertising, thus opening up a gap in specific legislation for this type of aircraft which this thesis shall review, propose and develop.

1.2 Statement of the Problem

According to the International Civil Aviation Organization (ICAO), an aircraft is defined as "(…) any machine that can derive support in the atmosphere from the reactions of the air other than the reactions of the air against the earth's surface" [1:1]. And may be sub classified into three distinct branches: "Lighter than air”; "Heavier than air" and "Hybrid" (Figure 1).

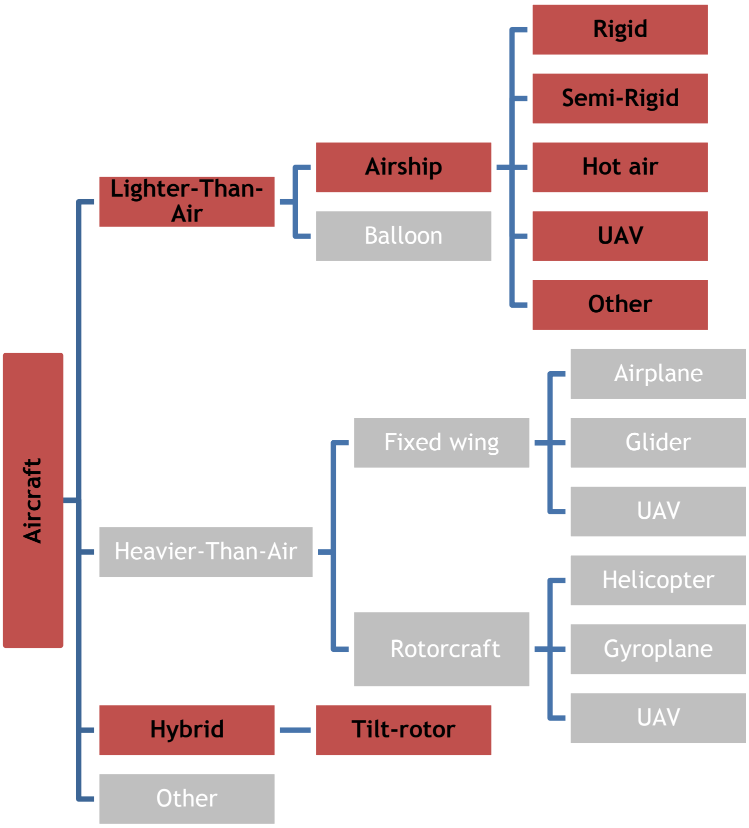


Figure 1 - Aircraft Categories, (Adapted from [2]).

The aim of this dissertation is the development of operational procedures for an aircraft of the type: "Hybrid: Lighter-Than-Air/Heavier-Than-Air -> Airship-Rigid/Helicopter" with the ability to hover and Vertical Take-Off and Landing (VTOL). With a length up to 100 m and a payload up to 2.000 kg, to perform VFR (Visual Flight Rules) flights during daytime, over congested areas "meaning, any area which is substantially used for residential, commercial or recreational purposes" [3:3] , as the city of Lisbon, Portugal.

Developed procedures are based on the proposals made available by ICAO for the development of all structures supporting the operation and flight of the aircraft; these regulations are more general than the ones published by Agência Nacional de Aviação Civil (ANAC), which regulates and oversees civil aviation in Portugal, where the case study will be implemented.

Given the lack of information and specific regulations for this type of aircraft, the development model for the operation will be partially based on the operational procedures of helicopters and their support infrastructures, thus presenting and proposing specific amendments to this type of vehicle legislation.

1.3 Dissertation Structure

The first chapter presents the motivation for this project and the setting in which it takes place.

The second chapter presents the current legislative state for airships, hybrid airships and helicopters, as well as airship and hybrid airship flight characteristics and support infrastructures. Lastly, it provides support infrastructure for helicopter operation.

The third chapter elaborates the two kinds of infrastructures which will serve as the basis of operation of the hybrid airship.

The forth chapter implements the infrastructures developed in the previous chapter and demonstrates the aircraft's movement over the congested areas for the presented case study, located in Lisbon, Portugal. The problems that arise from operation in the area are further elaborated upon, and the viability of the operation is then concluded upon.

The fifth chapter contains the thesis synthesis, final considerations and future research perspectives that this thesis provides the reader with.

Chapter 2. State of Art

2.1 Introduction

In this chapter, a review of the available legislation for the operation of the hybrid type aircraft is made. As such, a careful selection of the best documents that allow the development of infrastructures and flight regulations for this type of aircraft has been made so that safe operational procedures can be developed. Next, the flight modes of both the new hybrid airship as well as regular airships is presented. Also infrastructures for a regular airship operation will be described. Finally, surface level and elevated infrastructures, common in helicopter operation, will be presented since they are the base for the case study.

2.2 Legislation

The International Civil Aviation Organization ICAO was founded by their comprising state members in an effort to lay out the foundations upon which international civil aviation could evolve in a safe and regulated fashion. The 19 annexes advanced by ICAO do not establish legislation. They pose merely as guidelines, technical requisites and norm proposals. These serve as guidance for the corresponding legal authorities of the comprising states of ICAO to create their own legislation with. As established by the Chicago Convention of 1944.

The European Aviation Safety Agency (EASA) encloses 32 countries and holds executive and regulating functions, as well as providing technical counseling to the European Commission and their state members.

The following are its main tasks [4]:

- Drafting aviation safety legislation;
- Inspections and training to ensure uniform implementation of European aviation safety legislation in all Member States;
- Airworthiness and environmental type-certification of aeronautical products, parts and appliances;
- Approval of aircraft design organisations world-wide and of production and maintenance organisations outside the EU;
- Coordination of the European Community SAFA (Safety Assessment of Foreign Aircraft) programme;

- Coordination of safety programmes, data collection, analysis and research to improve aviation safety.

The Federal Aviation Administration (FAA) is the regulatory and fiscal civil aviation authority in the United States.

Its goal undertaking is as follows [5]:

- Safety regulation;
- Airspace and Air traffic Management;
- Air Navigation Facilities;
- Civil Aviation Abroad;
- Commercial Space Transportation;
- Research, Enginneering and Development;
- Other Programs.

Many countries, such as Brazil, while not subscribing to any particular organization, abide by a large volume of documents produced by this agency. It is especially noticeable that FAA regulations differ from EASA's, for the aircrafts operating in the United States of America comply with diverging operational requisites from those imposed in Europe.

The ANAC was established in 1944, following it's dissociation from Aeronáutica Militar. They serve as the administrative and fiscal civil aviation authority in Portugal. It mainly follows ICAO and EASA's recommendations, Portugal being a member state of both associations. It chiefly promotes the safe, efficient and sustained development of civil aviation activities through regulation, certification, licensing and fiscal monitoring [6].

Adequate stipulation of infra-structures is missing, as well as appropriate regulation for current airships and the hybrid airships now being developed. This precipitates the need to adapt legislation from other aircraft in order to fill the gaps in these particular airships. Adapting regulation of infra-structures meant to harbor other aircraft, such as helicopters, is centered on the fact that the new generation of hybrid airships is comparable to helicopters in their operational capabilities. The most important parallel we can draw between the airship and the helicopter is as follows: Both are capable of hovering, flying vertically and landing in a small surface area.

Current airship legislation is solely registered in general aircraft operation documents (Rules of the Air), explaining priorities/giving way relationships between all different assortments of flight craft. When it comes to airfields specific to airships, the ability for airships to operate in any field without any signaling is noteworthy, as any field is eligible for the operation of these airships, provided there's enough room for doing so within safety parameters. The grass areas present in some airfields have previously served for operation areas for airships. The same has been the case for their respective parking areas. It should be stressed that legislation pertaining the construction of a pertinent landing area for airships in leveled ground and/or elevated structures does not exist. Table 1 shows the existing legislation for airfields; Airship decks; Heliports; Helidecks and Rules of the Air as specified by the entities ICAO, EASA, FAA and ANAC.

Table 1 - Current Legislation (ICAO, EASA, FAA and ANAC).

	Aerodromes	Airship decks	Heliports	Helidecks	Rules of the Air
ICAO	Annex 14, Volume I, (Aerodrome Design and Operations) [7]	None	Annex 14, Volume II, (Heliports) [8]	Annex 14, Volume II, (Heliports) [8]	Annex 2, (Rules of the Air) [1]
EASA	Certification Specifications (CS) and Guidance Material (GM) for Aerodromes Design CS-ADR-DSN [11]	None	Annex 14, Volume II, (Heliports) [8]	Annex 14, Volume II, (Heliports) [8]	Acceptable Means of Compliance and Guidance Material to the rules of the air [13]
FAA	AC 150/5300-13A (Airport Design) [12]	None	150/5390-2C (Heliport Design) [9]	150/5390-2C (Heliport Design) [9]	FAR Part 91: General Operating and Flight Rules [14]
ANAC	Decreto-Lei n.º 55/2010 [10]	None	Decreto-Lei n.º 55/2010 [10]	Decreto-Lei n.º 55/2010 [10]	REGULAMENTO DE EXECUÇÃO (UE) n.o 923/2012 [15]

Document analysis shows us that all described entities possess specific recommendations for infrastructures. These include: Airfields for conventional aircraft and helicopter operation in surface level as well as helidecks. Rules of the air, derived from ICAO recommendations (Annex 2, Rules of the Air) are also displayed to exist in a specific document.

It is pertinent to restate that EASA and ANAC subscribe in full to the ICAO documents for heliports construction.

FAA produced different documents with recommendations for both rules of the air and the construction of infra-structures. These documents are still within ICAO guidelines, the United States of America being a member of this association.

For the case study that follows this introduction, ICAO international regulations will serve as the framework upon which we base our analysis for both the flight of hybrid airships as well as the construction of their respective support infra-structure. This method is presented, and indeed suggested to be the best option when analyzing the case study, for the great amount of leeway that the recommendations provided by ICAO allow us to work with. Furthermore, a great portion of countries, including the country where the case study takes place, Portugal, abide by the rules and stipulations suggested by this institution.

The documentation for the creation of support infrastructures to the operation of the hybrid airship is based on the transfer operation an helicopter is capable of performing. The latter being capable of operating over congested areas, landing and take-off over small areas of surface and elevated structures. VTOL and great maneuverability are operational requirements for these transfer operations.

Concisely, the hybrid airship possesses similar mobility capabilities as well as the VTOL capacity of an helicopter. This led us not to perform a preliminary study for the creation of new documentation for the purposes of constructing airports for the operation of hybrid airships, as the existing parallel legislation for helicopters is an adequate approximation.

This prompted suggestions to the alteration of the document (Annex 14, Volume II, Heliports), which would allow infra-structures to comply with the same safety requisites as it enables helicopters to operate with.

The proposed documents to be adapted are:

- Surface-level and upper deck aerodromes for Hybrid Airships (Annex 14, Volume II, Heliports): "Contains Standards and Recommended Practices (specifications) that prescribe the physical characteristics and obstacle limitation surfaces to be provided for at heliports, and certain facilities and technical services normally provided at an heliport. It is not intended that these specifications limit or regulate the operation of an aircraft" [8:1].

- Rules of the Air (Annex 2, Rules of the Air): "The Standards in this document, together with the Standards and Recommended Practices of Annex 11, govern the application of the *Procedures for Air Navigation Services - Air Traffic Management* (PANS-ATM. Doc 4444) and the *Regional Supplementary Procedures* - Rules of the Air and Air Traffic Services, contained in Doc 7030, in which the latter document will be found subsidiary procedures of regional application" [1:v].

2.3 Flight and Operation

2.3.1 Flight Characteristics

2.3.1.1 Common Airship

Airship flight is based upon Archimedes Principle. According to which “Any object, wholly or partially immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object" [16]. Airships are filled up with a gas that is lighter than the surrounding medium fluid. Thusly, hydrogen and helium are typically used to fill up the aircraft envelope, as the lift the aircraft gains is in direct proportion to the difference in weights both displayed and displaced by the aircraft in the surrounding fluid. It is by this mechanism that lift and higher elevation is obtained, as represented in Figure 2.

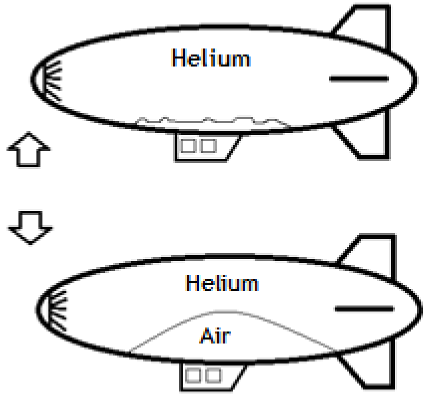


Figure 2 - Airship Flight Mode.

To lose altitude, airships fill up the envelope with the surrounding air, ergo reducing the carried low density fluid volume percentage values as well as increasing its own respective density.

Proportionately, the aircraft loses lift as the displaced fluid weight to aircraft weight ratio diminishes. To achieve higher altitudes however, airship aircrafts expand their carried helium volume by expelling heavy air carried in the envelope, thus maximizing lift. These aircraft are yet to significantly diverge from their original shape "cigar shape", which makes them susceptible to roll when maneuvering in crossed winds. Airships have their movement control surfaces located in their back ends (Figure 3), which enables them to adjust pitch and yaw. Alternatively, pitch can be controlled by dynamically configuring the aircraft volume, and yaw can be controlled by adjusting the thrust provided by the rotors.

Figure 3 - Airship Surface Controls, [17].

The gondola is attached to the airship envelope, and its function is to accommodate the controls of the aircraft, passengers, cargo and at times the engines (Figure 4).

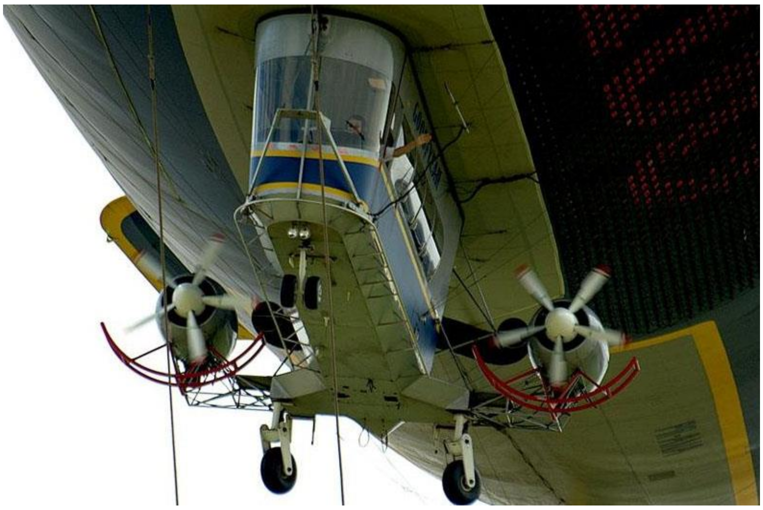


Figure 4 – Gondola, [18].

Horizontal movement of the airship is generally made possible by the piston and propeller engines, sometimes fixed to the gondola as shown in Figure 4. Alternatively, in the new airship generation, they're fixed in the envelope. The latter allows them to rotate 90 degrees around the axis, promoting better stability in the landing and take-off procedures. It also allows for a faster climb, as displayed by the "Zeppelin NT" airship, which possesses these engines in the rear, allowing for yaw control and alternated vertical and horizontal motion (Figure 5).

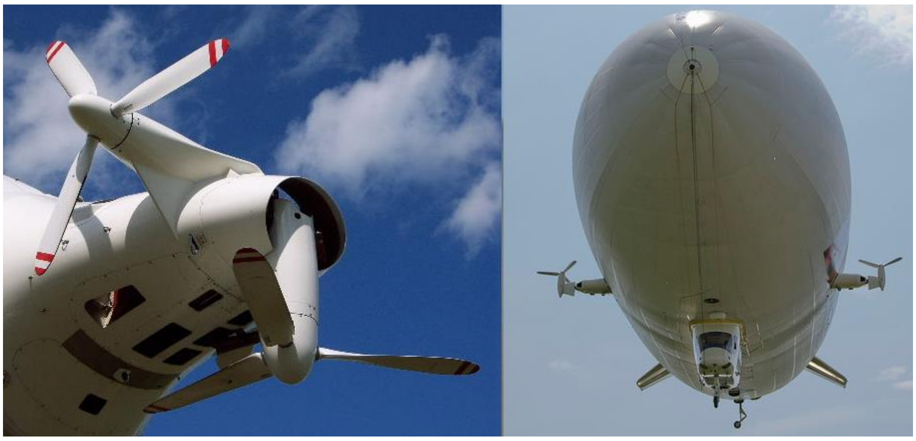


Figure 5 - Back Rotors, [19], Main Rotors, [20].

2.3.1.2 Hybrid Airship[1]

Hybrid airships constitute a kind of aircraft that encompasses two distinct branches of common aircraft taxonomy: “Heavier-Than-Air” and “Lighter-Than-Air”. And two sub-branches “helicopter” and “rigid airship”. The branch dedicated to hybrid airships already exists, but to date only encloses “Tilt-rotor-airplane-helicopter”.

Its nonexistence, in aircraft taxonomy, is owed to the fact that hybrid airships are still in development and prototype testing phase such as (Hybrid Air Vehicles HAV-3, 2012; Lockheed Martin P-791, 2006; Aeroscraft, 2013).

The main features of this type of aircraft allow for superior operational capabilities when compared to regular airships (Figures 6, 7, 8 and 9).

Figure 6 - Airfoil-Shaped Body, (http://www.popularmechanics.com/technology/aviation/airships/4242974).

Figure 7 – Hélium Envelope and Vertical Thrust Provided by Vectoring Engines, (http://brickmuppet.mee.nu/futurism/archive/2007/11).

[1] *Parte da dissertação relevante para efeitos do processo de proteção da invenção referido no Aviso no início deste documento.*

Figure 8 – Thrust Vectoring Engines, (http://lifereallymatters.com/airships-future-air-travel/).

Figure 9 – Improved Body Shape and Thrust Vectoring Engines, (http://www.popularmechanics.com/technology/aviation/airships/4242974).

2.3.2 Operation Features

2.3.2.1 Mast

The mooring mast (Figure 10) allows for an airship to dock on a tower, immobilizing the aircraft. However, the new generation of hybrid airships will allow docking without the need for a mooring mast in surface operations. The docking is made through the connection of a cable present on the front of the airship body to the mast. There are two types of masts, fixed and reduced mobility. The fixed mast completely immobilizes the airship, in turn, the reduced mobility mast, allows the airship to move in relation to a center point to compensate for wind.

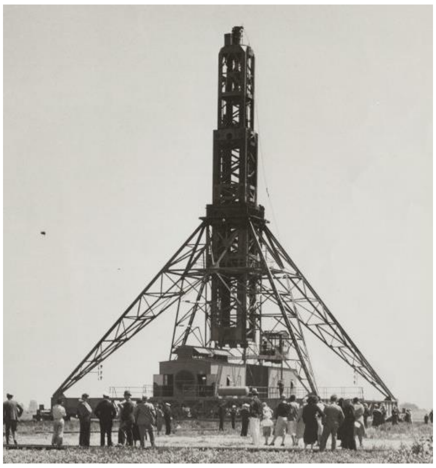


Figure 10 - Fixed Mooring Mast, [21].

The airships can dock, on air, land or water (Figure 11), but always with the help of ground personnel. The mooring mast proved to be a good solution, because you don't have to park the aircraft inside the hangar for the handling operations.

Figure 11 -Sea Mooring, [22], Air Mooring, [23], Ground Mooring, [24].

Mobile mooring masts integrated into vehicles (Figure 12) are the most versatile solution, since they allow landing on any part of the aerodrome, as well as any aerodrome for that matters. They also improve wind adaptability.

Figure 12 - Mobile Mooring Mast, [25].

The idea of docking an airship in a tall structure is an old dream, a good example is the attempted docking of an airship in the historical Empire State Building in the United States of America (Figure 13). This attempt ended up in failure, since the weather at 381 m of altitude didn't allow a successful docking. After many studies, a conclusion was drawn that this type of operation was unfeasible, regardless, an airship from the US navy, the USS Los Angeles, attempted the manoeuvre, being successful for just 3 minutes, after which the docking ropes had to be cut in order to avoid a disaster [26].

Figure 13 - Mooring Mast, Empire State Building, [27].

2.3.2.2 Aerodromes

These are ground structures that allow for take-off, landing and parking of the airship. There are some aerodromes for airship docking, most of them located in the United States of America. These USA aerodromes have grass surfaces, since the airship doesn't have to touch the ground for landing unlike conventional airplanes, and is smoother than an helicopter. The surface area of some aerodromes is similar to those of heliports (Figure 14), with a circular shape or traditional landing field, always regarding the minimum safe distances established between the airship and surrounding obstacles. These distances have to take in consideration the size of the airship. Also some aerodromes with asphalt or concrete surfaces, may be used for airship operations, since they present large landing areas (Figure 15).

Figure 14 - Airship Aerodrome WingfootLake, EUA, (Google Earth).

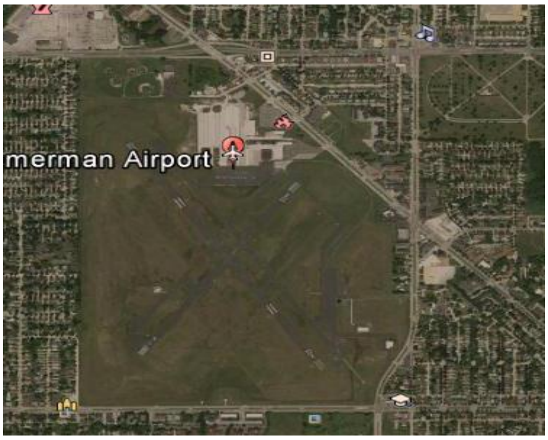


Figure 15 - Aerodrome Timmerman, EUA, (Google Earth).

In the first case the aerodrome of Oberschleissheim, which is used for operations in Munich (Figure 16) doesn't have a special landing area, which is made in the grass of the airfield, with the docking made by a mobile vehicle (Figure 12). In the second case the aerodrome of Friedrichshafen (Figure 17), possesses a fixed mooring mast and a specialized circular landing area. Worthy of note, this last aerodrome is the birth place of the German airship industry.

Figure 16– Aerodrome Oberschleissheim, Germany, (Google Earth).

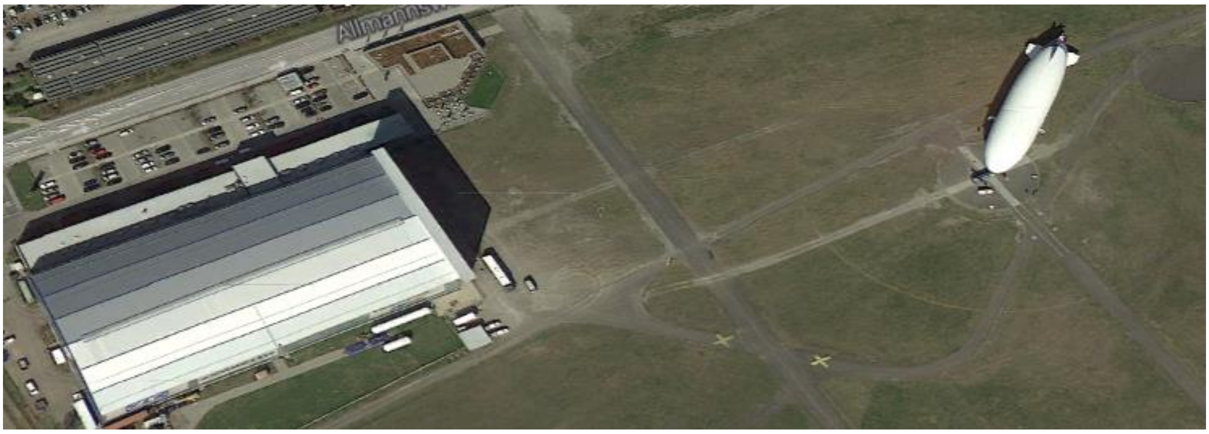


Figure 17 - Aerodrome Friedrichshafen, Germany, (Google Earth).

2.4 Helicopter Operation Infrastructures

2.4.1 Operation on Surface-level Heliports

According to ICAO, the definition of heliport is as follows: "An aerodrome or a defined area on a structure intended to be used wholly or in part for the arrival, departure and surface movement of helicopters" [7:5].

This kind of airports, both located at surface level or sea platforms, as displayed in (Figure 18), have the capacity for an helicopter to land and take off in an abridged area, simultaneously offering a surface capable of withstanding the dynamic load present in the landing and parking of an helicopter. The surface previously detailed contains signaling markings and must be cleared of obstructions both within and around it, allowing the aircraft to operate within total safety margins while executing landing and take-off operations.

This infrastructure is thus endowed with lights, wind sacks, and surface markings for flight operation (VFR and IFR). It is utilized for private, civilian and military use as well as medical emergencies.

Figure 18 - Surface-Level Heliport Vancouver Port, Canada, [28].

2.4.2 Operation on Elevated Heliports

Due to its great vertical landing and take-off capabilities, helicopters require a smaller landing surface. A special operational niche was created for these aircraft to land in platforms, roofs and ships.

As defined by ICAO, an elevated heliport is a “Heliport localized in an elevated structure” [8:1-2]. Currently, the use of this sort of infrastructures avails greater transport accessibility into large urban centers, ships, ocean platforms as well as quickly materializing transport for urgent medical supplies for hospital centers (Figure 19).

Figure 19 - Elevated Heliport Platform, University Hospital Aachen, Germany, [29].

This assortment of heliports contains surface markings, signaling landing and security zones (Figure 20), wind sack and signaling lights for reduced visibility scenarios including night flights.

Figure 20 - Markings on Elevated Heliport Platform, Dehli, Índia, [30].

2.5 Conclusion

The lacking of specific legislation for airship support infra-structure rests on the fact that the operation of this kind of aircrafts is reduced to a small niche of operators including, but not limited to, the German Zeppelin or the American Goodyear. It is thusly not necessary to spend funds in an attempt to elaborate airship-specific legislation. It follows that these entities approve the operation of these airships by granting them special authorizations and permits, while imposing general safety regulations in the take-off and approximation areas, as well as for the movement of the airship and general airborne behavior.

It is worthy of note that the hybrid airships are not even mentioned at all by the regulatory entities, precisely because they're still in pure development stages and experimental flight, so as to demonstrate their operational abilities.

The most adequate solution is then found to be the adaptation of existing helicopter regulations into suitable hybrid airship regulations. This is because they were created especially for helicopters, owing to both their unique ability for executing VTOL maneuvers as well as their extremely high mobility. This differentiates both flight craft from fixed-wing aircraft in general. It is then a solution pertinent in both saving time as well as permitting cheaper execution.

Chapter 3. Airship Port Surface-level and Upper Deck

3.1 Introduction[2]

ICAO's (Annex 14, Volume II, Heliports) [8], contains layouts for helicopter infrastructures, encloses planning, design and operation of heliports. It is consequently used as the framework and support for posterior adaptation into suitable hybrid aircraft documentation, by virtue of the inexistence of hybrid airship infrastructures, coupled with the fact that ICAO does not constitute an arrangement of laws but rather recommendations to be followed as seen fit. Ergo, they're not draconian in nature, and allow us to perform this kind of work.

The hybrid airship possesses rotors which assist in landing and lift-off. Owing to this, the general failure of a rotor is made good by the other rotors coupled with the envelope. For this reason, we then designate the hybrid airship, for clearing areas and surface areas purposes, as a Performance Class 1 helicopter. This is done utilizing ICAO's very own designation, which perfectly suits the case, Performance Class 1 helicopter being "A helicopter with performance such that, in case of critical power-unit failure, it is able to land on the rejected take-off area or safely continue the flight to an appropriate landing area depending on when the failure occurs" [31:1:1-4].

The width of the rotor extremities and airship length (Figure 21), is important for surface dimensioning as well as defining obstruction clearance areas. The hybrid airship does not possess a single rotor; it diverges from the helicopter in that it carries others. This contrasts with the helicopter, the aircraft the original document was based on, and for this reason, we found it suitable to utilize the width between rotors when dimensioning the operation areas.

The aircraft has to couple with the port upper deck. This dictates that the gondola size is used when dimensioning the areas present in the upper deck, so that the hybrid airship does not exert a high dynamic load in the landing area (Figure 22).

Airship port upper decks are high so that the obstruction clearing limits do not intercept any obstacles. This dictates the airship must perform maneuvers above the FATO in order to achieve the safety altitude which enables it to proceed to then climb without requiring further VTOL.

[2] *Parte da dissertação relevante para efeitos do processo de proteção da invenção referido no Aviso no início deste documento.*

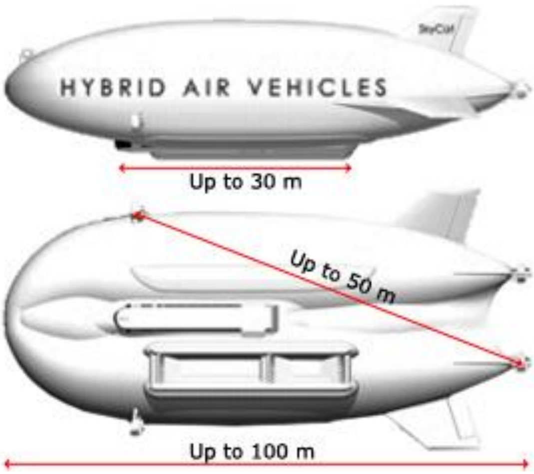


Figure 21 – Hybrid Airship Length; Rotor Length; Gondola Length (Example), (http://www.theengineer.co.uk/in-depth/the-big-story/meet-lemv-the-first-of-a-new-generation-of-advanced-military-airship/1003418.article).

Figure 22 – Airship Port Upper Deck,
(http://home.comcast.net/~bzee1b/Zeppelin/DBZ_6293.jpg, http://www.domusweb.it/en/news/2012/04/01/best-of-the-week.html).

3.2 Physical Characteristics[3]

The Airship port surface-level has physical characteristics, defined based on the size of the areas indicated in Figure 23.

For the Airship port upper deck, the FATO and TLOF zones are the same size (Figure 24) but the safety area is different. Its dimensions are stipulated in Table 2 and Figure 26.

[3] *Parte da dissertação relevante para efeitos do processo de proteção da invenção referido no Aviso no início deste documento.*

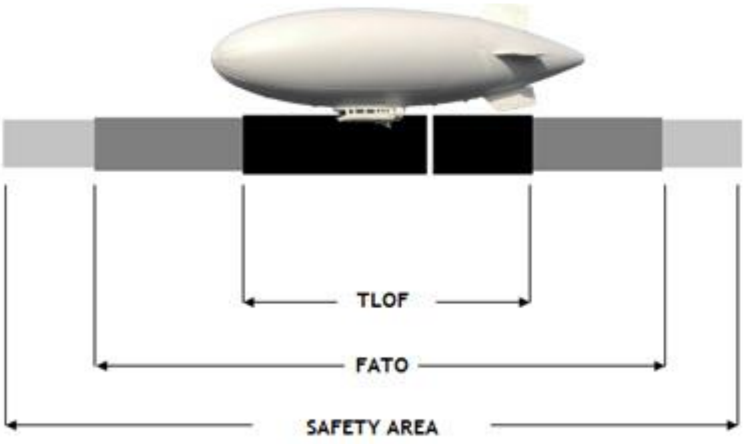


Figure 23 - Airship Port Surface-level Operational Areas, (http://www.portlandroundballsociety.com/page/4/).

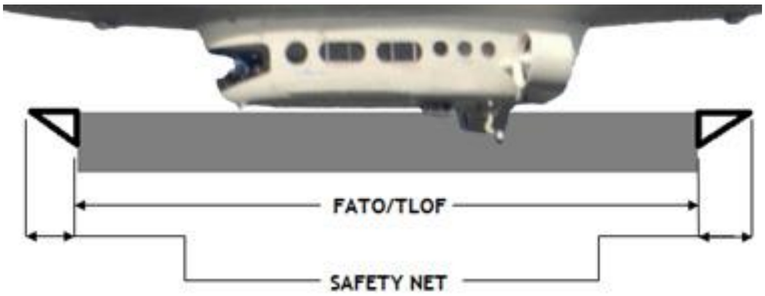


Figure 24 - Airship Port Upper Deck Operational Areas, (http://www.portlandroundballsociety.com/page/4/).

- **Final Approach and Take-off Area (FATO)**

A FATO is an area over which the hybrid airship completes the approach maneuver to a hover for landing or commences movement into forward flight in the take-off maneuver.

- **A Touchdown and Lift-off Area (TLOF)**

Whenever it is intended that the undercarriage of the airship will actually touch down on the surface of an Airship port or leave the surface to achieve a hover, a touchdown and lift-off area shall be provided. The area is intended to serve and be dynamic load bearing when located within the FATO.

- **Safety Area**

A Safety Area is provided around a FATO to:

- Reduce the risk of damage to a hybrid airship to move off the FATO by the effect of turbulence or cross-wind, mislanding or mishandling;

- Protect hybrid airships flying over the area during landing, missed approach or take-off by providing an area which is cleared of all obstacles except small objects which because of their function must be located on the area.

Table 2- Dimensions of the Operational Areas (D- Helicopter Length; d- Airship Length; G- Gondola Length), (Example).

	FATO	TLOF	SAFETY AREA
ICAO surface heliports measurements for class 1 performance helicopters [8:3:1-3]	1D	0,83D	2D
Airship port surface-level	1d 75 m	0,83d 62,25 m	2d 150 m
ICAO helidecks measurements for class 1 performance helicopters [8:3:14-15]	1D	1D	Safety net none the less 1,5 m
Airship port upper deck	1,5G 33 m	1,5G 33 m	Safety net 33 to 34,5 m

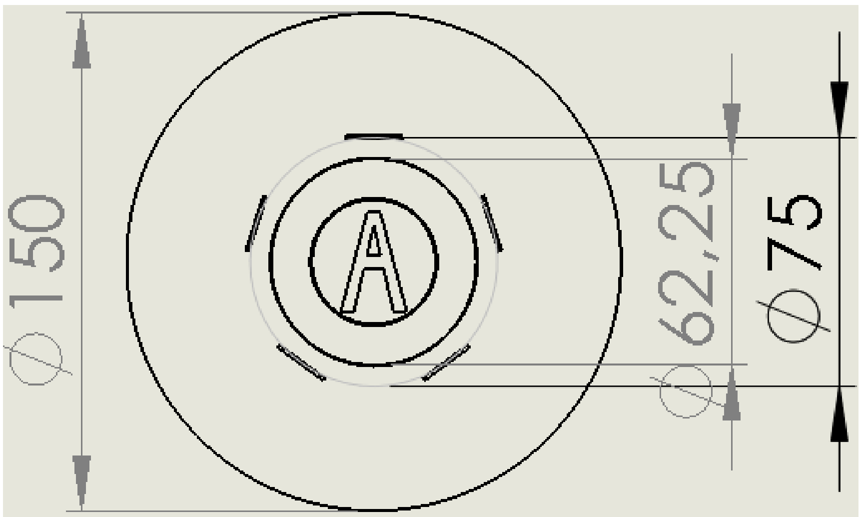


Figure 25 - Airship Port Surface-level Operational Areas Dimensions: Safety Area "150 m"; FATO "75 m"; TLOF "62,25 m". Top View, (SolidWorks).

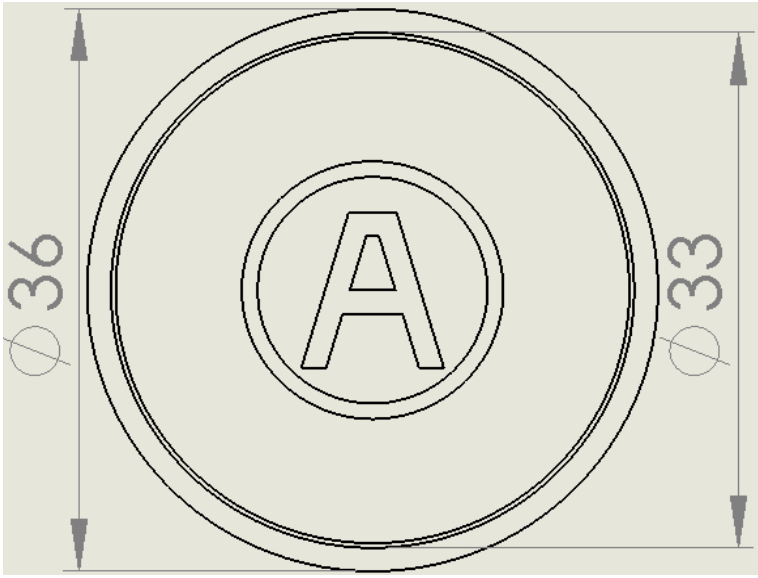


Figure 26 - Airship Port Upper Deck Operational Areas Dimensions: Safety net "33 to 34,5 m"; FATO/TLOF "33 m". Top View, (SolidWorks)

3.3 Obstacle Limitation

3.3.1 Dimensions and Slopes of Obstacle Limitation Surfaces

Both promote a volume of airspace around and above the Airship ports for a hybrid airship in normal flight to safely operate in. Such surfaces promote the safe operation of the hybrid airship while maneuvering for take-off and landing.

The take-off and approach slope must not be intersected by any obstacle, but can include obstacles inside the volume; they must also be made present in approximation charts, containing topographical plans of the area, buildings, power pylons, wind turbines, communication towers among others. They must be endowed with luminous signaling.

These obstacle limitation surfaces are meant for landing and take-off in Airship ports. They were developed as per day-time VFR flight recommendations.

The approach surface is divided in 3 sections while the take-off surface is divided in 2. This applies to both infrastructures.

The approach surface for the Airship port surface-level starts at the inner edge. The latter effectively occupies the diameter of the FATO which measures 75 m. The surface dimensions are present on Table 3 and Figure 27. For the Airship port upper deck, the inner edge has 33 m and its dimensions are present on Table 3 and Figure 28.

The take-off surface of the Airship port surface-level starts at the inner edge. The latter effectively occupies the diameter of the FATO which measures 75 m. The surface dimensions are present on

Table 4 and Figure 29. For the Airship port upper deck, the inner edge has 33 m and its dimensions are present on Table 4 and Figure 30.

Table 3 - Dimensions and Slopes of Obstacle Limitation Surface for Approach Surface.

Non-instrument (Visual) FATO - Approach Surface - Day Option - Adapted Hybrid Airship Class		
Surface and Dimensions	Airship Port Surface-Level	Airship Port Upper Deck
First Section		
Divergence	10%	18,45%
Length	245 m	245 m
Outer Width	124 m	124 m
Slope	8%	8%
Second Section		
Divergence	10%	10%
Length	1.200 m	1.200 m
Outer Width	315 m	315 m
Slope	9,72%	9,72%
Third Section		
Divergence	Parallel	Parallel
Length	87 m	87 m
Outer Width	315 m	315 m
Slope	15%	15%

Table 4 - Dimensions and Slopes of Obstacle Limitation Surface for Straight Take-off.

Non-instrument (Visual) - Straight Take-off - Day Option - Adapted Hybrid Airship Class		
Surface and Dimensions	Airship Port Surface-level	Airship Port Upper Deck
First Section		
Divergence	10%	44,76%
Length	315 m	315 m
Outer Width	315 m	315 m
Slope	4,5%	4,5%
Second Section		
Divergence	Parallel	Parallel
Length	3.018 m	3.018 m
Outer Width	280 m	280 m
Slope	4,5%	4,5%

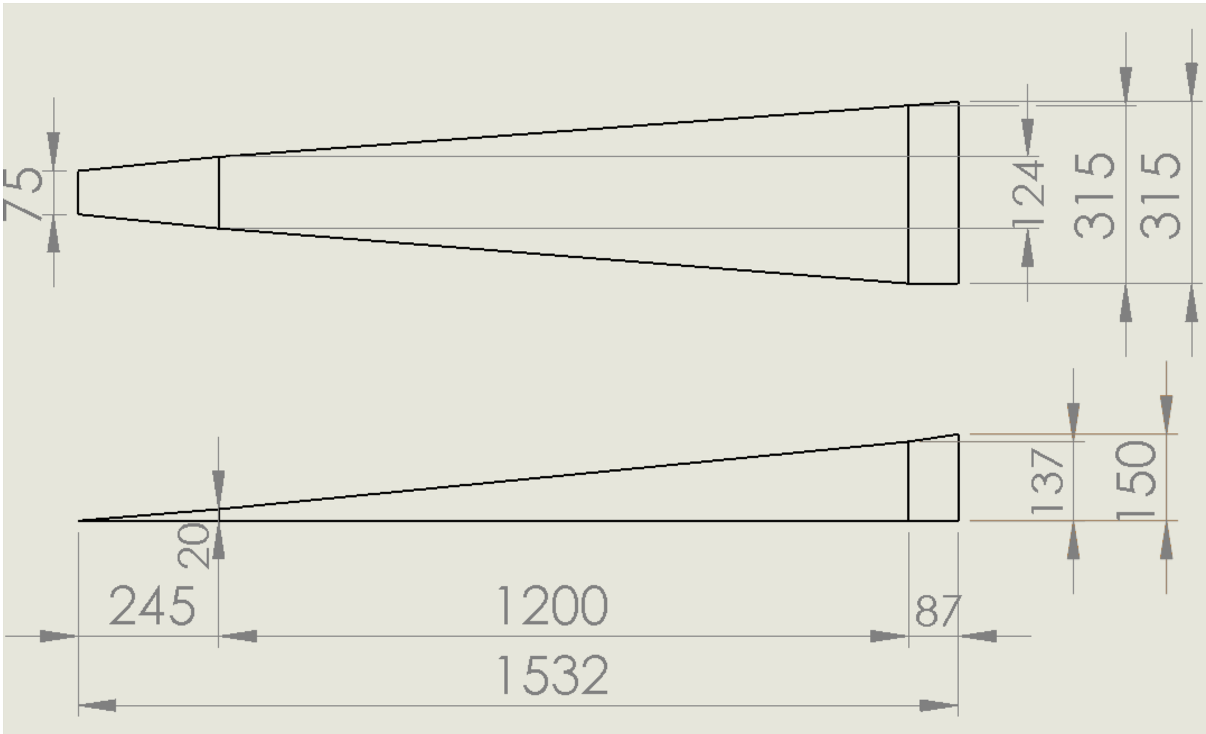


Figure 27 - Approach Surface Dimensions to Airship Port Surface-level, (SolidWorks).

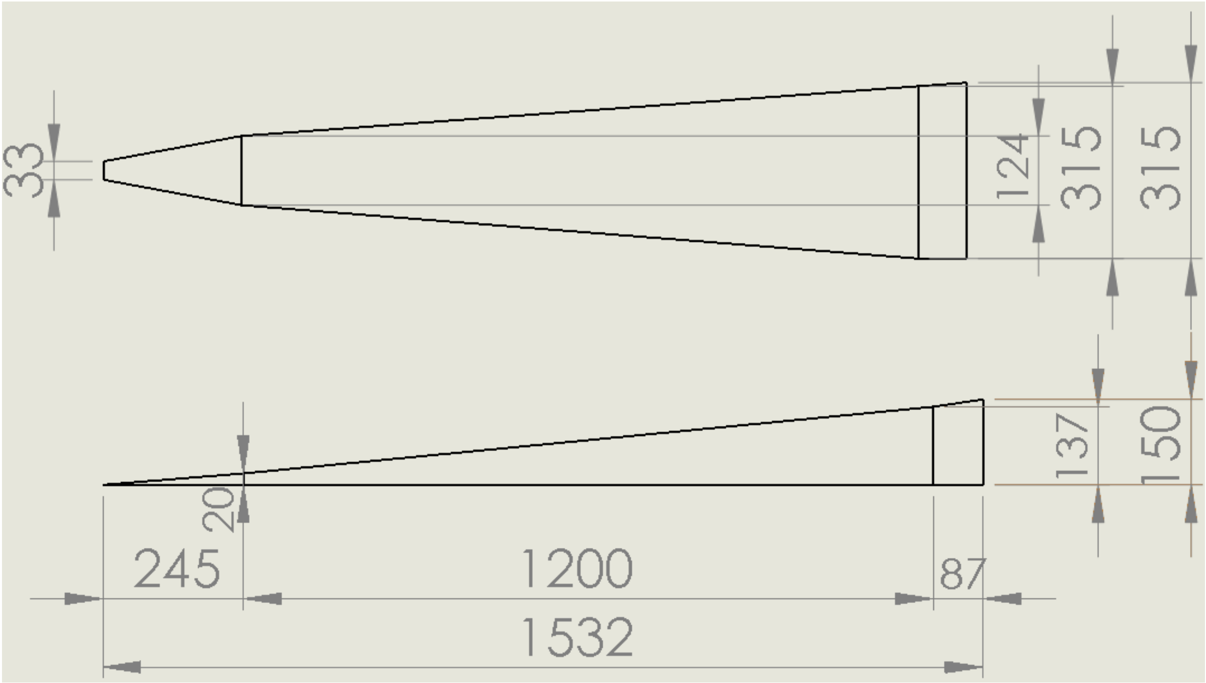


Figure 28 - Approach Surface Dimensions to Airship Port Upper Deck, (SolidWorks).

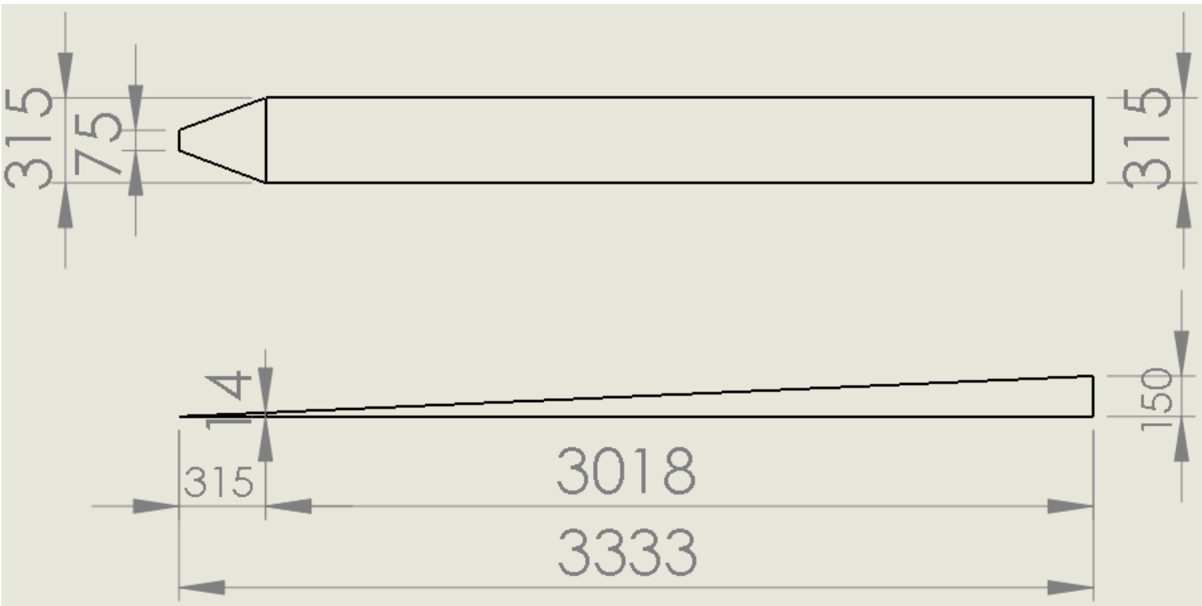


Figure 29 - Take-off Climb Surface Dimensions to Airship Port Surface-level, (SolidWorks).

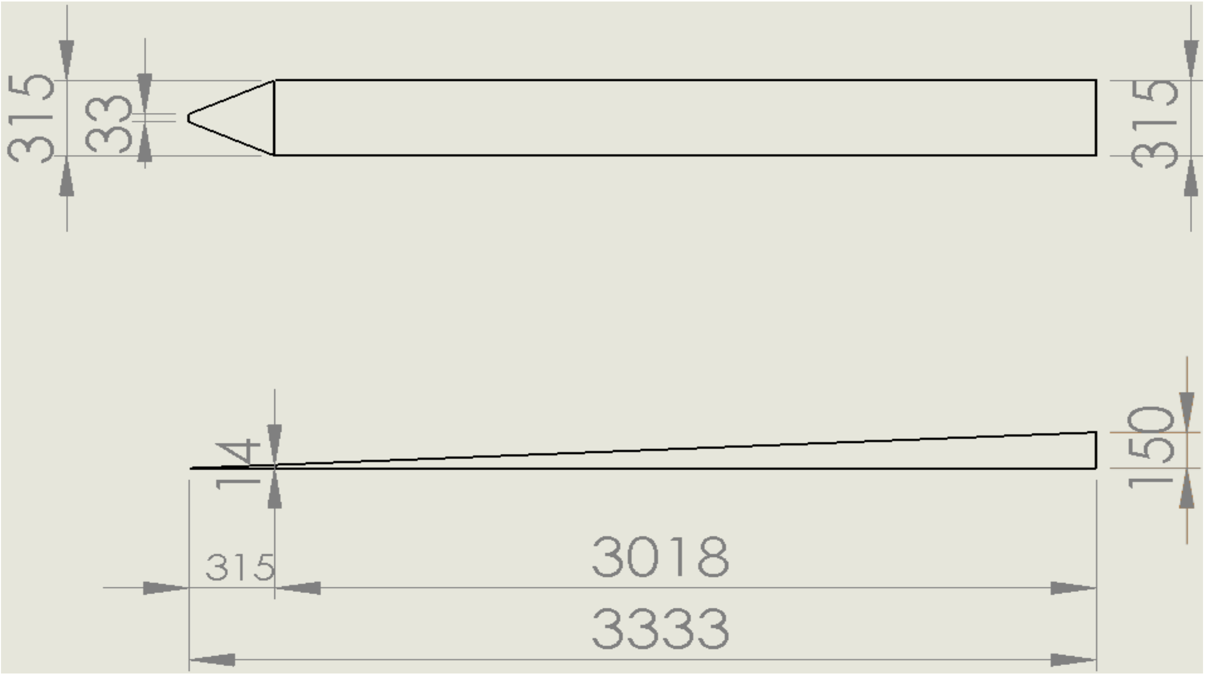


Figure 30 - Take-off Climb Surface Dimensions to Airship Port Upper Deck, (SolidWorks).

3.4 Visual Aids to Navigation

3.4.1 Wind Direction Indicators

The Airship ports are equipped with one wind direction indicator, located outside the safety area and visible from a height of at least 200 m above de Airship port. This allows the approaching airship to observe the direction and velocity of the wind.

The dimensions of the wind cone are stipulated in Table 5 and the colors of the wind cone are white and orange (Figure 31) to bestow better visibility to the pilot.

Table 5 - Wind Direction Indicators Dimensions

	Airship Port Surface-level	Airship Port Upper Deck
Lenght	2,4 m	1,2 m
Diameter (Larger End)	0,6 m	0,3 m
Diameter (Smaller End)	0,3 m	0,15 m

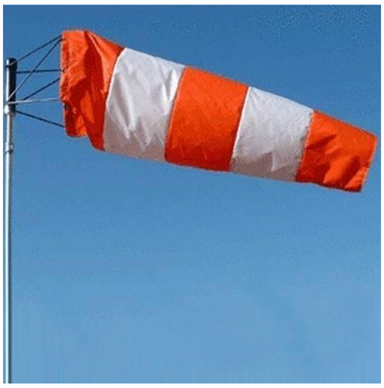
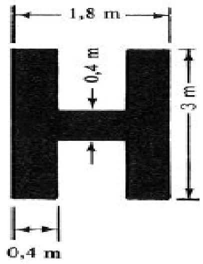
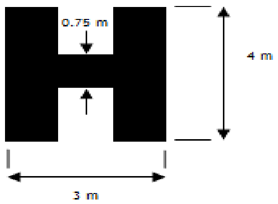
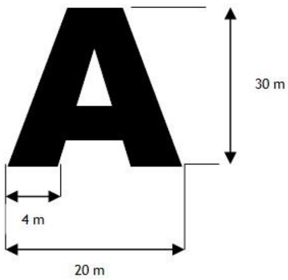
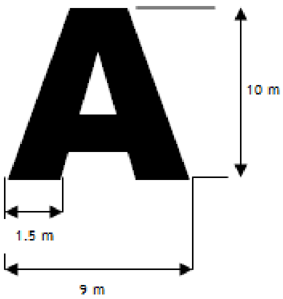


Figure 31 - Wind Indicator, [32].

3.4.2 Identification Marking

The purpose of the identification marking (Table 6, Figure 32 and Figure 33) is to provide the location of the Airship port and provide visual aids to the airship pilot by signaling the safety area, FATO, TLOF and Touchdown/positioning areas. The structure identification letter for airship operations is the letter “A” for "Airships", in order to differentiate it from similar structures such as heliports which adopted the letter “H”. The size of the letter "A" at the two Airship ports were changed due to the large size of the TLOF, thus making it easier for the pilot to identify this area.

Table 6 - Identification Markings, Dimensions and Colours.

	Letter	Touchdown/positioning	FATO	TLOF
ICAO Marking Rules and Measurements for Surface -level Heliports [8:5:1-9]		Circular line 0,5D, with width of 0,5 m to surface level heliports	Minimum of five spaced rectangular stripe with a length of 9 m and width of 1 m	Continuous line with a width of at least 0,3 m
ICAO Marking Rules and Measurements for Helidecks [8:5:1-9]		Circular line 0,5D, with width of 1 m to helideck	Continuous line with a width of at least 0,3 m	
Airship Port Surface-level		Circular line with 37,5 m of diameter and width of 0,5 m	Circular line of 75 m whit five rectangular stripe spaced by 6 m with a length of 9 m and width of 1 m	Circular line with a length of 62,25 m and width of 0,3 m
Airship Port Upper Deck		Circular line with 16,5 m of diameter and width of 1 m	Circular line with 33 m of diameter and width of 0,3 m	
ICAO Surface- level Heliports Color [8:5:1-9]	White	Yellow	White	White
ICAO Helidecks Color [8:5:1-9]	White	Yellow	Dark color	
Airship Port Surface-level Color	White	Yellow	White	White
Airship Port Upper Deck	White	Yellow	Dark color	

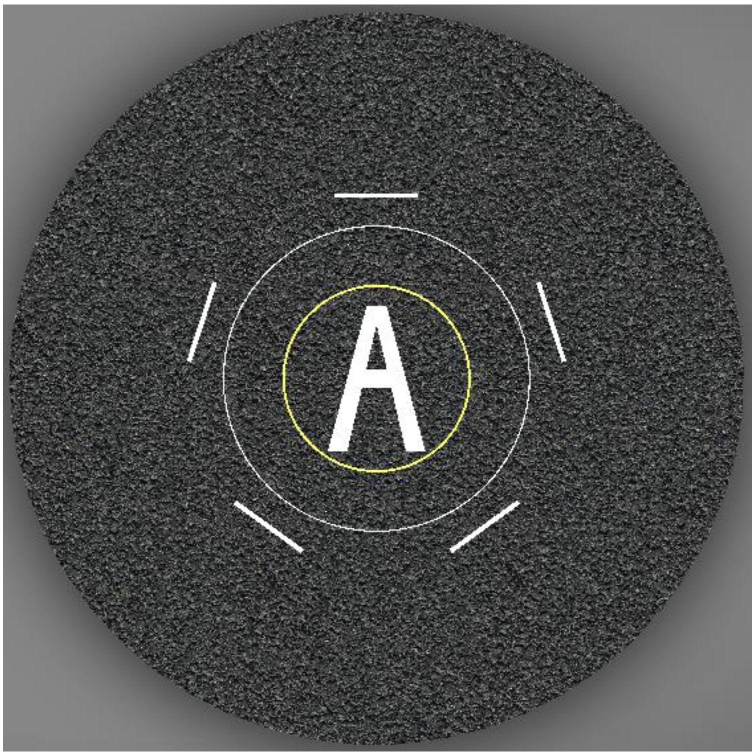


Figure 32 - Airship Port Surface-level Layout, (SolidWorks).

Figure 33 - Airship Port Upper Deck Layout, (SolidWorks).

3.4.3 Lights

Owing to the characteristics of the operation (VRF, daytime) all that is needed is the approach lighting system to the Airship port surface-level. The application follows ICAO recommendation, but the Airship port upper deck doesn't require any lighting system.

The approach lighting system (Figure 34) shall be located in a straight line along the preferred direction of approach. The system consists of a row of three lights spaced by 30 m intervals and a crossbar 18 m in length at a distance of 90 m from the perimeter of the FATO. The crossbar lights are five and spaced by intervals of 4,5 m. The lights beyond the crossbar are four sequenced flashing lights with a flash frequency of one per second, the flash sequence commences from the outermost light and progresses towards the crossbar. All the lights are colored white [8:5:15].

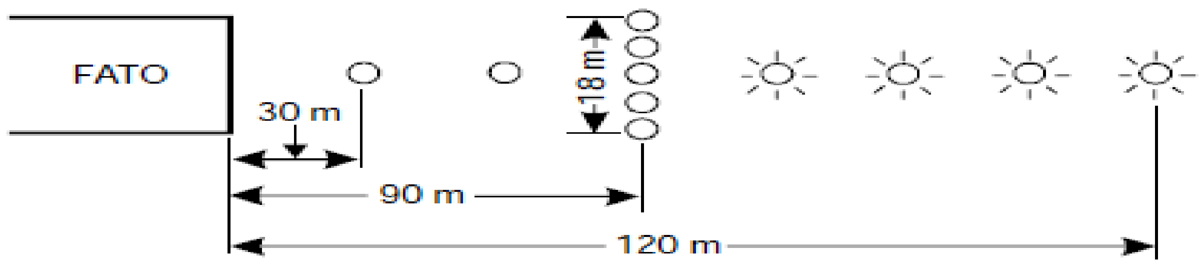


Figure 34 - Approach Lights, [8:5:15].

3.5 Airship Port Services

From the ICAO Annex 14, Vol. II "The level of protection to be provided for rescue and fire fighting should be based on the overall length of the longest helicopter normally using the heliport" [8:6:1].

The maximum airship length is 100 m. This is quite remarkable when compared with H3 helicopter class, the longest in existence, which is limited to 35 m.

A linear calculation was made in order to extrapolate plausible values for extinguishing agents (Tables 7 and 8) and Rescue equipment (Table 9).

Table 7 - Extinguishing Agents Airship Port Surface-level.

Category	Water	Discharge Rate Foam Solution (L/min)	Dry Chemical Powders (kg)	Halons (kg)	CO_2 (kg)
Airship Categorie (100 m)	3.430	1.720	225	225	450

Table 8 - Extinguishing Agents Airship Port Upper Deck

Category	Water	Discharge Rate Foam Solution (L/min)	Dry Chemical Powders (kg)	Halons (kg)	CO_2 (kg)
Airship Categorie (100 m)	17.143	1.715	97	97	194

Table 9 - Rescue Equipment List.

Equipment	Number
Equipment Adjustable Wrench	1
Axe, Rescue, Aircraft Type	1
Bolt Cutters, 0,6 m	1
Crowbar, 1,05 m	1
Grab Hook Heavy Duty	1
Hacksaw with 6 Spare Blades	1
Fire Resistant Blanket	1
Ladder 15 m x 0,05 m Lifeline	1
Side Cutting Pliers	1
Set of Assorted Screw Drivers	1
Harness Knife & Sheath	1
Fire Resistant Gloves	6
Power Cutting Tool	2
Containment Locker - Height 0,60 m x Width 0,94 m x Depth 0,48 m	1

3.6 Conclusion

From the review of the "Annex 14, Volume II Heliports" [8], some changes were made to accommodate the characteristics and dimensions of the hybrid airship.

The surface area of the airship upper deck was modified, from the length of an helicopter, to the size of the gondola. There is a foundation, in this particular case, that this kind of surface would support, theoretically, the loads imposed by the hybrid airship during the landing maneuver. As it was already referred in this work, the aircraft distributes the dynamic load of landing by the docking on the upper deck. The combination of the flight envelope and the aircraft's rotors allow for a soft docking.

The structure's identification letter was changed from an "H" to an "A", so this type of structure won't get confused for an helipad, thus having a unique mark for the operation of hybrid airships.

The clearance areas where developed having as a reference the length of the airship and the length between rotors.

The length between rotors was obtained, taking into account the diameter of the blades from the rotor of an helicopter, which is in general bigger than two thirds of the length of an helicopter. But the length between rotors regarding the length of the hybrid airship is three fifths, which is up to 60 m.

The emergency services that these infrastructures must have, were totally based on the document and the specifications for the h3 class of helicopters, in which, through a linear proportion for the size of the airship, the adequate quantity of extinguishing agents and the rescue equipment were obtained.

Chapter 4. Case Study

4.1 Introduction

A circuit was made for the aircraft among an airship port surface level and two airship port upper decks, all located inside the urban center of Lisbon, Portugal.

The goal of this case study is the implementation of the infrastructures developed in the previous chapter, analyzing the feasibility of their construction on the suggested grounds, presenting the strengths of their location, inherent problems and specific solutions for each infrastructure.

The hybrid airship's flight plan is developed taking into account the current legislation on overflying of congested areas. The interaction with existing air traffic is analyzed, together with the restrictions that may come from the proximity to other airport infrastructures present in the area, exposing the problems that may come from that proximity. The operational viability depends on this analysis.

4.2 Hybrid Airship Features (Example), Location of the Infrastructures and Route

4.2.1 Hybrid Airship[4]

The hybrid airship that will serve as a model to operate in congested areas, like Lisbon, has a set of features; however, as we shall prove with this case study, current legislation is focused on conventional aircraft operations, which do not include this type of more versatile aircraft.

It is noteworthy to say that this hybrid airship does not exist physically, only in theory. Its features and performance are the result of conceptual studies that permit an operational study of the aircraft.

The hybrid airship has for example the characteristics and performance of those of Table 10 and the design as for example in Figure 35.

[4] *Parte da dissertação relevante para efeitos do processo de proteção da invenção referido no Aviso no início deste documento.*

Table 10 - General Characteristics and Performance of a Hybrid Airship (Example).

General Characteristics	
Crew	2
Cargo weight	up to 2.000 kg
Length	up to 100 m
Length of gondola	up to 30 m
Volume	up to 35.000 m^3
Gross weight	up to 30.000 kg
Performance	
Cruise speed	100 km/h
Range	1.200 km
Endurance	12 h
Service ceiling	up to 2.000 m

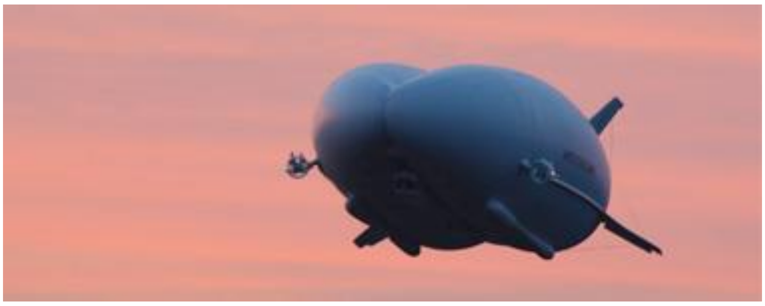


Figure 35 - Hybrid Airship Design (Example), (http://www.ecnmag.com/news/2014/03/photos-day-hav-304-hybrid-airship).

4.2.2 Location of the Infrastructures and Route

Location of the infrastructures in GPS coordinates are those of Table 11 and satellite images of the locations are as in Figures 36, 37 and 38.

Table11 - Infrastructures GPS Coordinates.

	Latitude	Longitude	Altitude
Airship Port Surface-level	38°42'18.62"N	9°11'51.30"W	65 m
Airship Port Upper Deck 1	38°44'40.11"N	9° 8'37.26"W	82 m
Airship Port Upper Deck 2	38°42'36.84"N	9° 7'39.57"W	6 m

Figure 36 - Airship Port Surface-level, "Rua Bica do Marquês 21, Lisboa", (Google Earth).

Figure 37 - Airship Port Upper Deck 1 "Travessa Henrique Cardoso 107, Lisboa", (Google Earth).

Figure 38 - Airship Port Upper Deck 2, " Avenida Infante Dom Henrique 38D, Lisboa", (Google Earth).

Distances among infrastructures are those of Table 12 and respective Routes are as in Figure 39.

Table 12 - Distances Between the Infrastructures "Routes".

	Distance
Airship Port Surface-level to Airship Port Upper Deck 1	6.439 km
Airship Port Surface-level to Airship Port Upper Deck 2	6.09 km
Airship Port Upper Deck 1 to Airship Port Upper Deck 2	3.949 km

Figure 39 - Route Up View, APSF "Airship Port Surface-level", APUD 1 "Airship Port Upper Deck 1", APUD 2 "Airship Port Upper Deck 2", (Google Earth).

4.3 Implementation of the Infrastructures

In terms of functionality, the Airship port surface-level aims to handle the occidental area of the city; the Airship upper deck 1, the central city area and the Airship upper deck 2 the city's downtown.

The approval to this sort of infrastructure is provided by ANAC, pending on construction, certification and heliport exploration as stipulated in "Decreto-Lei n. º 55/2010, de 31 de maio" [10]. ANAC redirects to ICAO recommendations in this document.

8 factors must be studied when setting up the aerodrome location [33:578]:

1) Class and layout of aerodrome;
2) Convenience for users;
3) Airspace obstructions;

4) Coordination with other aircraft movements;
5) Prevailing Winds;
6) Social and environmental factors;
7) Turbulence;
8) Visibility.

The approximation zones layout depends on the combination of all these factors which result in the best possible solution. Hence, those present in this thesis are merely representative, having only attributed to them defined characteristics such as minimized terrain navigation conflict (by setting up these zones perpendicularly to the Tejo river), minimizing obstacle interaction and spacing, as further apart as possible, the approximation areas from conventional air traffic from the Lisbon international airport.

4.3.1 Airship Port Surface-level

Concerning the implementation of the Airship port surface level, the following conclusions can be drawn, regarding the viability of the initial space occupied for this location, by visualizing Figures 40, 41 and 42.

This infrastructure's operation collides with a few buildings already present in the area. That is to say that the approximation and lift-off zones intercept surrounding buildings.

For the construction, amplification or modification of the heliport surface-level infrastructures, cultural, health, learning and worship establishments/centers must be carefully observed. Pyrotechnic, cattle breeding and fishing centers must also be carefully contemplated. The concerning radius affects the locations distancing less than 300 m from the center of the infrastructure [10]. The Palácio da Ajuda is certified as a national monument ("Monumento Nacional, Estabelecimento de Cultura") and distances less than 200 m from the center of the infrastructure.

The studied location is then rendered unsuitable for this kind of operation.

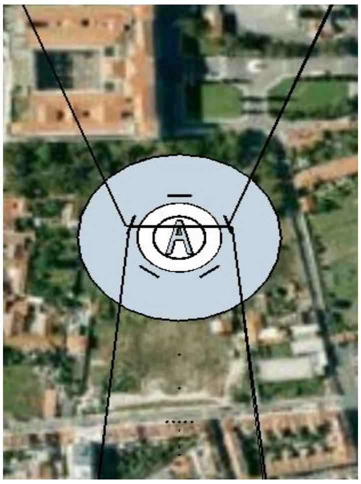


Figure 40 - Airship Port Surface-level, (SketchUp).

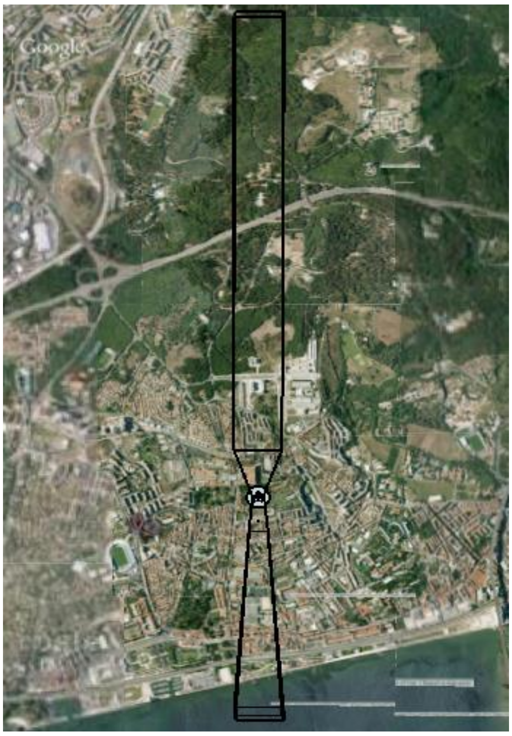


Figure 41 - Airship Surface-level and Obstacle Limitations Surfaces, Top View, (SketchUp)

Figure 42 - Airship Surface-level and Obstacle Limitations Surfaces, Isometric View, (SketchUp).

4.3.2 Airship Port Upper Deck 1

In respect to the implementation of the Airship port upper deck 1 in the location indicated by Figures 37 and 43, there are no initial physical drawbacks to its construction on ground level or in the approximation/take-off zones.

The problem concerning this location arises both from the fact that it is located at the end of the approximation area of the Lisbon international airport, which can possibly generate operational conflicts between the activities regarding both airport infrastructures, as well as from the evidenced fact that the take-off zone is situated above the 03 runway of the Lisbon international airport (Figure 44).

Concerning viability, it is pertinent to re-iterate the saturation of constant air traffic regarding the use of runway 03 of Lisbon's international airport. Apropos, any task in that area must first be proposed to ANAC, which then defers for NAV's, the Portuguese Air Navigation Service Provider (ANSP), professional opinion. NAV studies the viability of said operation, pending on a preceding approval to affect the air-traffic already present in the area. By reason of an international airport being the generator of all this air traffic, it can then be surmised that a negative answer will always follow from ANAC itself. This is due to the comparative character of "Cargo Hybrid Airship vs International Airport" operations, and the inherent prevalence of the strongest economic power.

Figure 43 - Airship Port Upper Deck 1, (SketchUp).

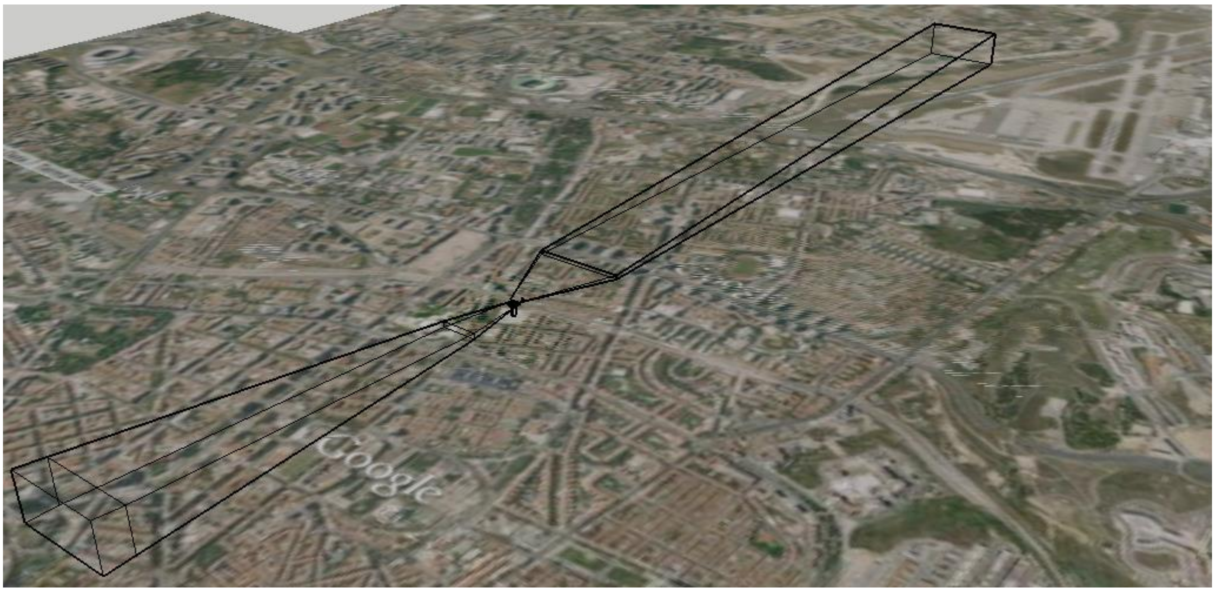


Figure 44 - Airship Port Upper Deck 1 and Obstacle Limitations Surfaces, Isometric View, (SketchUp)

4.3.3 Airship Port Upper Deck 2

This location (Figures 45 and 46) has the same inherent problem as the previous, being that the IFR (Instrument Flight Rules) approximation corridors from runway 03 of Lisbon's international airport, conflict with the Airship port upper deck's traffic (Figure 47). Being that international airports are always used to full operational capacity, it is then impractical to construct the infrastructure in this location.

Figure 45 - Airship Port Upper Deck 2, (SketchUp).

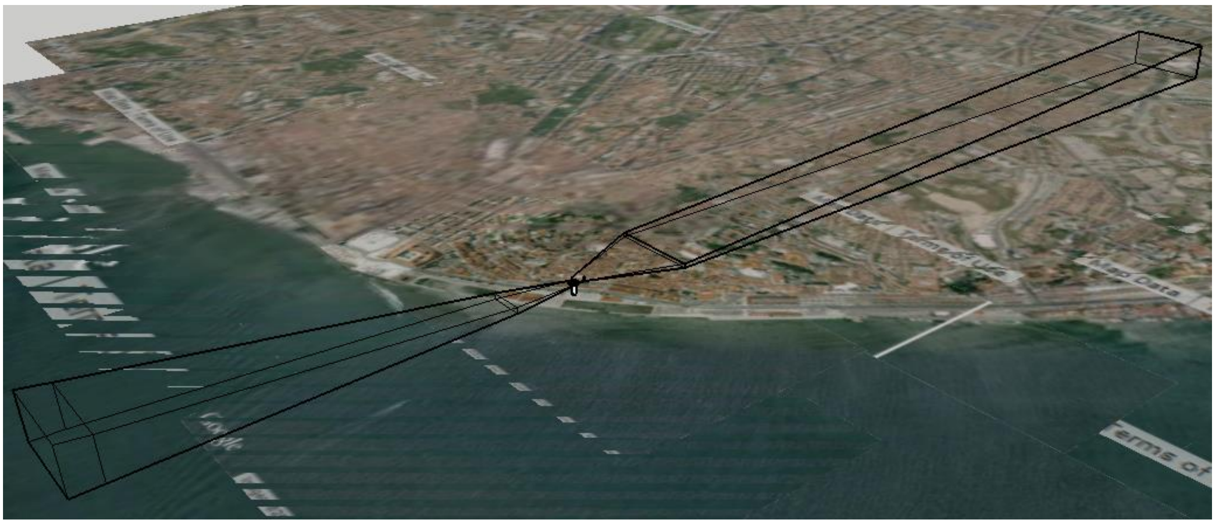


Figure 46 - Airship Port Upper Deck 2 and Obstacle Limitations Surfaces, Isometric View, (SketchUp).

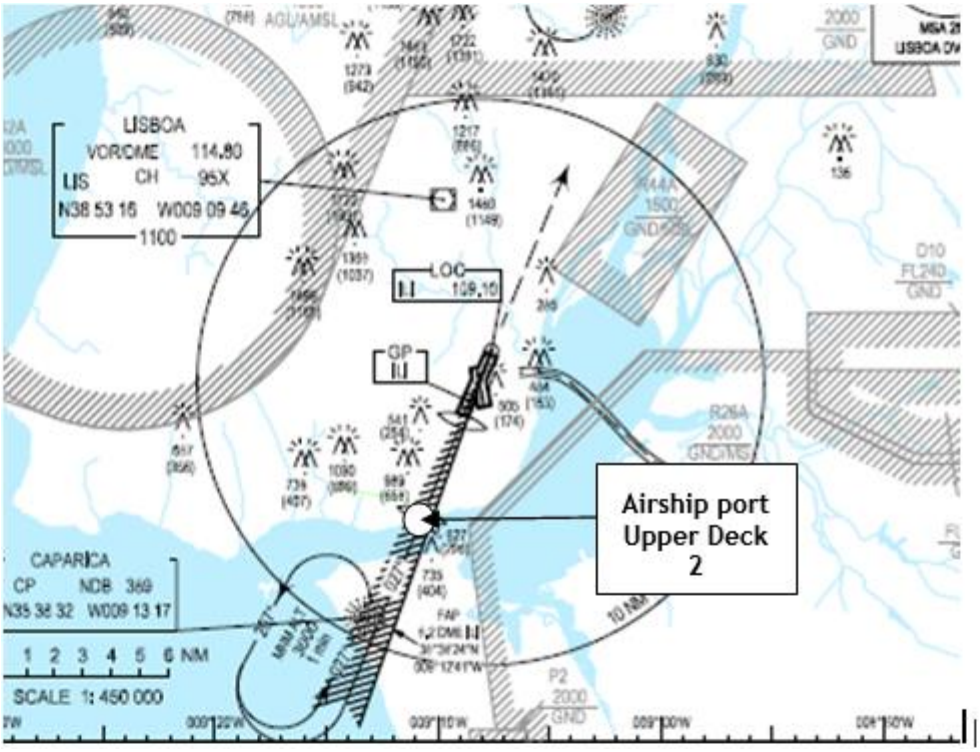


Figure 47 - Lisbon IFR Approach Chart, (Adapted from [34]).

4.4 Flight Plan and Rules of the Air

Hybrid airships, when flying in VFR routes (Figure 48), must always utilize a transponder and communicate bilaterally with an ATC (Air Traffic Control) unit such as the Lisbon airport control tower. All aircraft that wish to fly in controlled airspace must submit their flight plan and obtain ATC approval, such as in the case of a controlled CLASS C airspace zone “IFR and VFR flights are permitted, all flights are provided with air traffic control service and IFR flights are separated from other IFR flights and from VFR flights. VFR flights are separated from IFR flights and receive traffic information in respect to other VFR flights” [35:1].

This activity requires ANAC authorization. When granted, a NOTAM is issued. “A notice to airmen (NOTAM) is a notice containing information concerning the establishment, condition or change in any aeronautical facility, service, procedure or hazard, the timely knowledge of which is essential to personnel concerned with flight operations” [36:1].

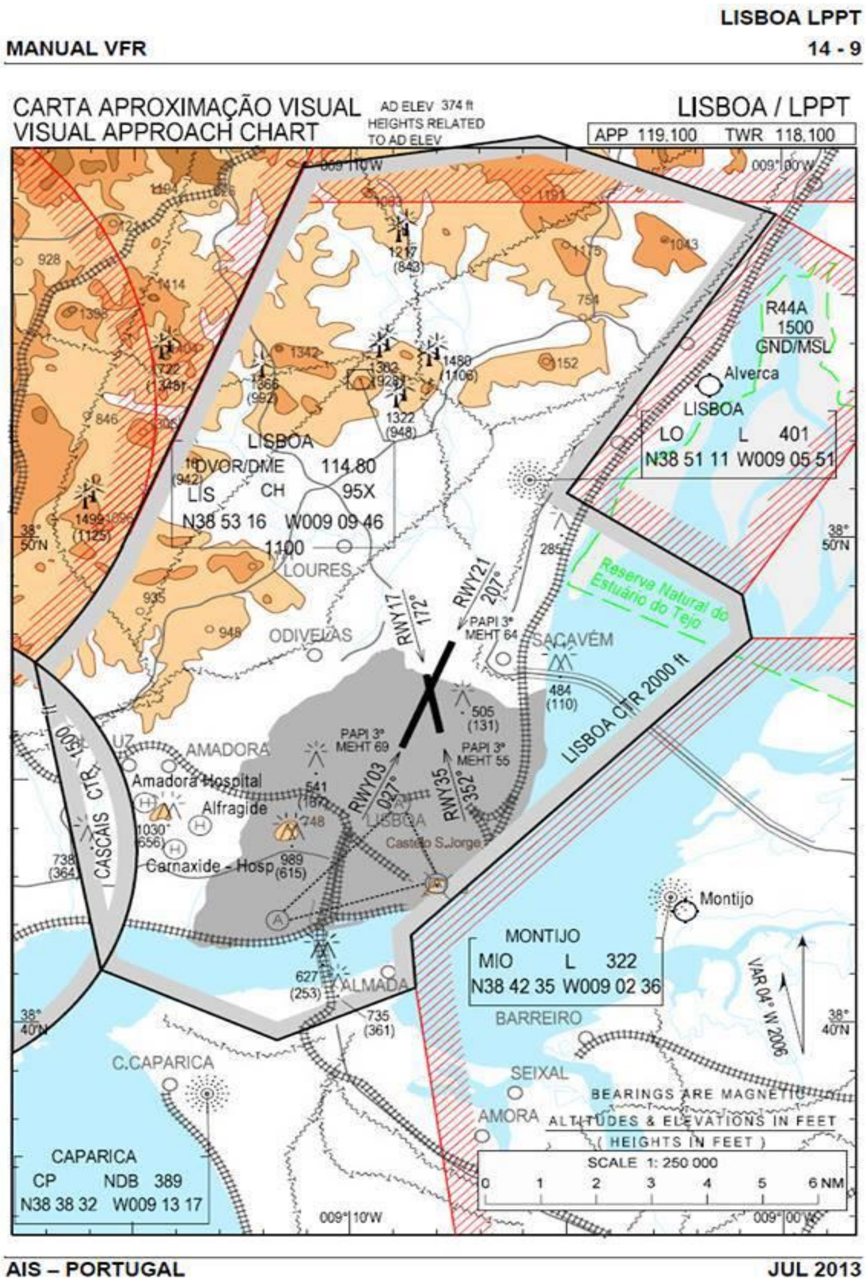


Figure 48 - Lisbon Approach Chart with Hybrid Airship Routes, (Adapted from [37]).

The desired airspace is a saturated air-traffic zone, with several heliports and five aerodromes, including two international airports. Any and all studies for procedures for utilizing the airspace must firstly be concerned with soliciting ANAC which will then defer for NAV for a professional opinion. NAV is tasked with verifying the aptitude for SPECIAL VFR FLIGHTS: "These are controlled VFR flights cleared by ATC to operate within a CTR in meteorological conditions bellow VMC (if the ground visibility is not lower than 1.500 m). Permission for conducting this type of flight shall be subject to traffic conditions" [38:2].

The minimum operation altitude for this kind of flight is 300 m above congested areas. It is noteworthy that studies for authorizing congested traffic operation are prolonged and complex.

According to the Portuguese AIP where Helicopter routes in Lisbon's CTR are present (Figure 49), VFR tunnels only function in exceptional cases, requiring previous ANAC authorization. This prevents such use from becoming occasional, as VFR tunnels are often closed given the air traffic presented by airport infrastructures surrounding the VFR tunnels.

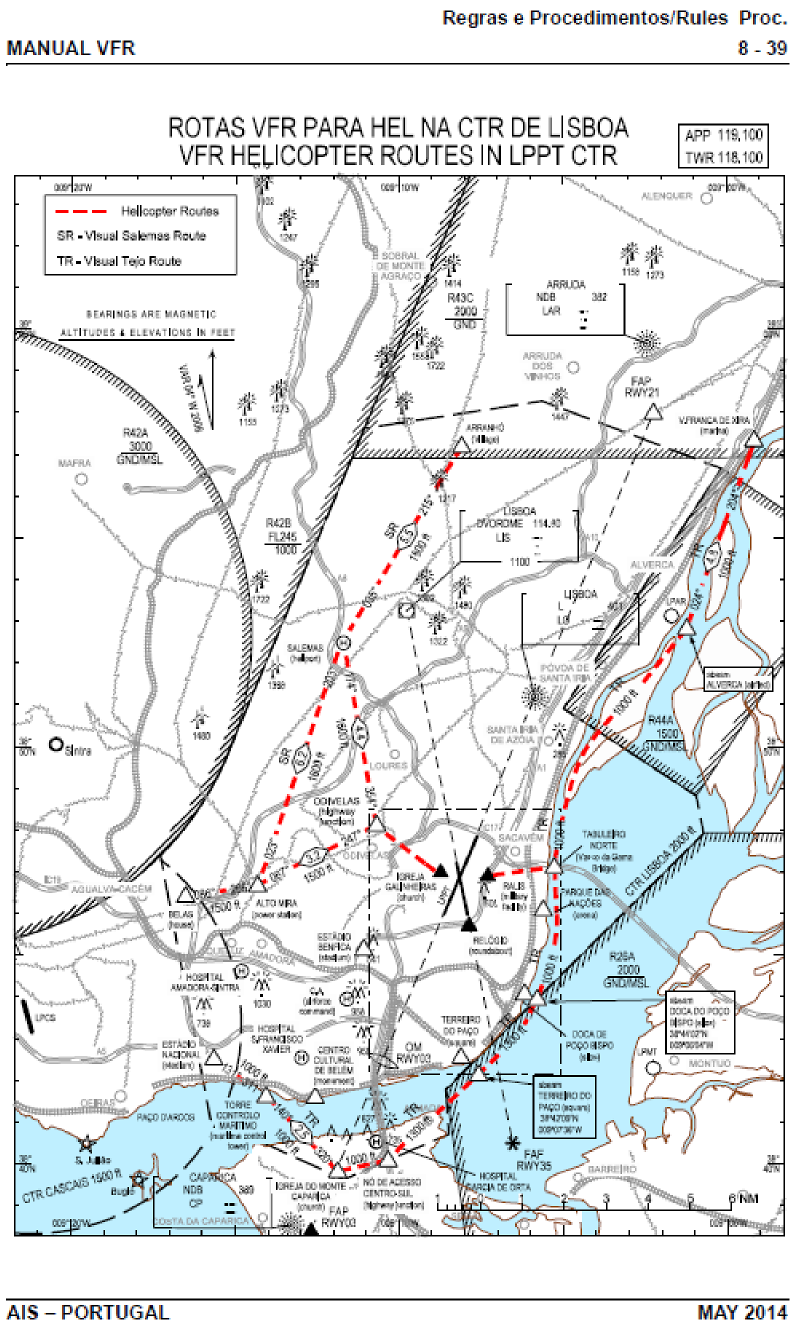


Figure 49 - VFR Helicopter Routes in Lisbon CTR, [39:39].

The unavailability arises from the fact that the operation takes place in a zone saturated by traffic, which immediately bars it from any sort of exceptional flight permits from ANAC. This is the case because the operation would collide with the operational domains of an international airport, namely the approaching maneuvers of imminent incoming aircraft. The VFR tunnels above Lisbon are completely out of reach for the desired routes for the case study (Figure 50), which once again demonstrates the impracticality of operating the airport infrastructure as well as the need to measure and counterbalance many factors, out of which the existing air traffic in the zone being the most impervious to solutions.

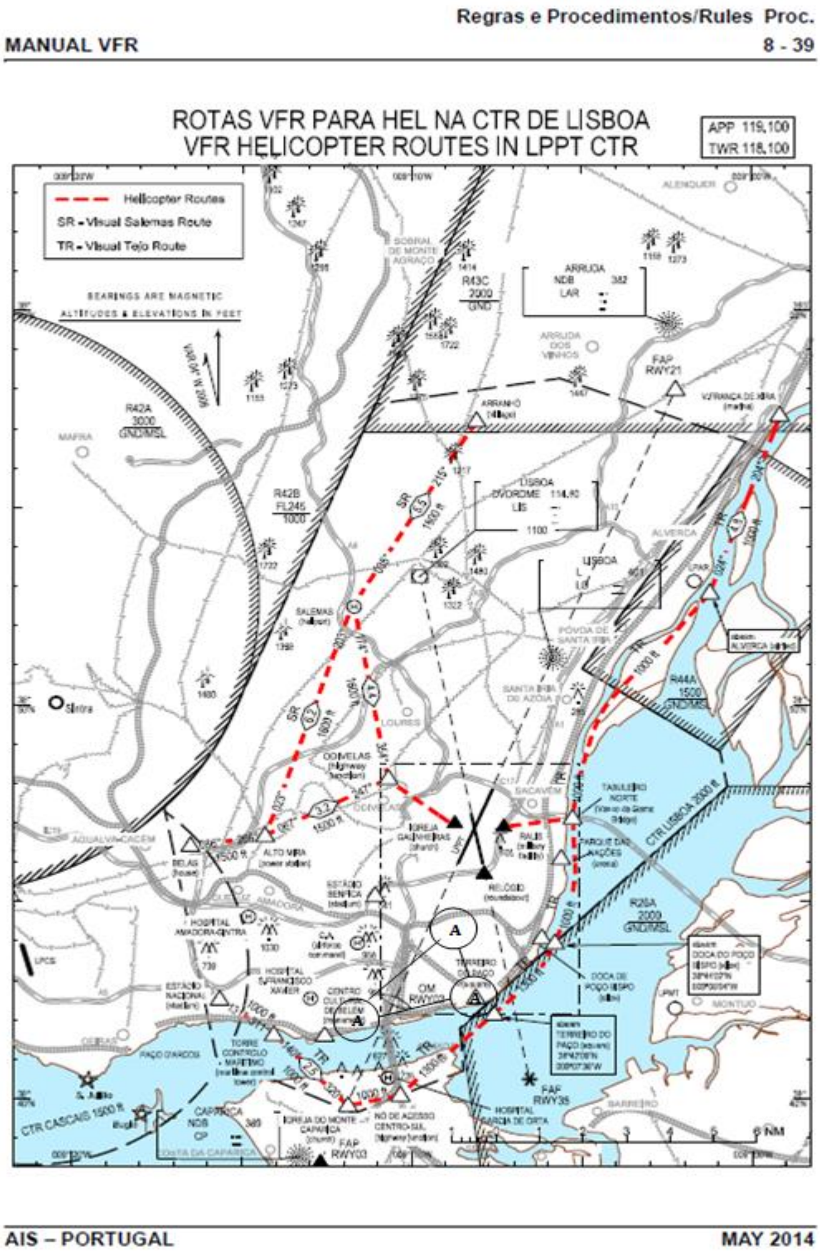


Figure 50 - VFR Helicopter Routes in Lisbon CTR with Hybrid Airship Routes, (Adapted from [39:39]).

4.5 Conclusion

The infrastructure location was not the best-suited, chiefly the prior given knowledge that the area is prone to be heavily saturated by traffic. This arises from the fact that the implementation of any airport infrastructure is concerned with conjugating a number of variables, by means of extensive and exhausting studies so as to ascertain the viability of the project, prior to construction. It is important to measure all pertinent parameters inherent to the location being studied, because ample ground space to build the aerodrome on is not the most important parameter. Nor its inherent capability to provide and comply with the services pretended out of the operation of airships. It is essential to make the location adequate to the restrictions already present in the area.

Chapter 5. Conclusion

5.1 Dissertation Resume

Airships have remained, ever since their conception, an open question in the worldwide aviation framework. They surged as the reference aircraft in the 1920's, but following tragedies and the appearance of the common aircraft have since led to their disappearance. Airships are currently reserved for tourism and publicity purposes. In consequence of such diminutive operation, there's a lack of specific regulation and documentation for this kind of aircraft, on behalf of the international civil aviation regulatory entities, as well as by FAA, EASA and ANAC.

The new generation of hybrid airships eliminates previous flaws concerning maneuverability and operation. They are then an upgrade, for the transport of heavy loads into areas which make other means of transport impractical, enabling landing in small areas and on all sorts of terrain.

As a means of developing this sort of operation, being as there are no base legislation specific to airships, it was pertinent to adopt and then adapt helicopter legislation, seeing as they both possess similar operation capabilities. The framework for this was the Annex 14 Vol. II Heliports of ICAO for the idealization of support infrastructures and the Annex 2 Rules of the Air, also of ICAO, which concerned the movement of the aircraft in the air, allowing it to be implemented in the case study.

Infrastructures meant to accommodate hybrid airships were designed, taking chiefly into account the existing helicopter specific document previously mentioned for that effect. It was adapted to the hybrid airship dimensions in a fashion that allowed it to comply with all safety requisites. It is notable the particularity of operation in docking upper decks, as this resulted in defining dimensions not stipulated in the base document, as the need to reference the size of the gondola became apparent towards dimensioning the Airship port upper deck surface areas. These infrastructures contain markings, visual aids as well as clearance services meant to facilitate lift-off and landing maneuvers.

The implementation of these infrastructures was done in a case study inside Lisbon's urban center, so as to study and evaluate the feasibility of such an operation. Given the technical impossibility of operating Hybrid Airships in the case study, we then conclude that it is futile to bring forward solutions for the implementation of said operation in Lisbon.

5.2 Final Considerations

This dissertation raised pertinent questions related to hybrid airships operation. It then presented proposals for the resolution of a problem which will certainly surface when these airships are ready for generalized use.

Nevertheless, we conclude that the case study is completely unviable due to its proximity to the international airport of Lisbon and other airport infra-structure present in the zone, which occupy a great volume of air traffic over the urban area.

The process for selecting and locating infrastructures is, in fact, very important and encompasses multiple variables which must be equated. The location would not enable these infrastructures to operate upon any airship, as the traffic in the zone does not allow for said operation to occur.

According to ANAC, no airship has even been operated in Portuguese territory. It was then impossible to obtain information or professional opinions for the development of infrastructures for this kind of aircraft operation.

NAV, however, immediately provided based responses. When questioned about the feasibility of operating this special kind of aircraft in the Lisbon area, it promptly answered that the unique characteristic of an operation over such a congested area, with defined routes, immediately precludes its execution. It is their professional opinion that no matter how lengthy and complex the studies applied to that area, the only possible outcome for those studies is to conclude the impossibility of operating any aircraft over the intended zone.

5.3 Future Perspectives

The adaptation of helicopter legislation to suit hybrid airships would fill in the gaps in its legislation. It is then presented as an inexpensive way to quickly regulate the airships and its operations, once experimental stages are complete and they become more commonly used.

The operation developed in this thesis can be applied to other cities outside the case study. Namely, urban areas which do not contain high air traffic or airport infrastructures which would conflict with said operation in the same airspace. It also stands as a means to facilitate operations between cities by increasing capabilities and posing as a competitive means of transport.

The frame developed for the dimensioning of infrastructures can be applied for dimensioning other airships areas. Sketch tools such as SolidWorks, when used for the development of infrastructures and obstruction limiting surfaces and then further combined with SketchUp, allow us to visualize in a greater scope the occupied area. This constitutes an innovation.

Future computing advances will allow us to visualize city structures in 3D, which will expedite easier obstacle identification. This will save resources and surely become an asset for this kind of operation.

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Annex 1. Scientific Paper Accepted for Publication at the 18th ATRS Conference

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^2 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.

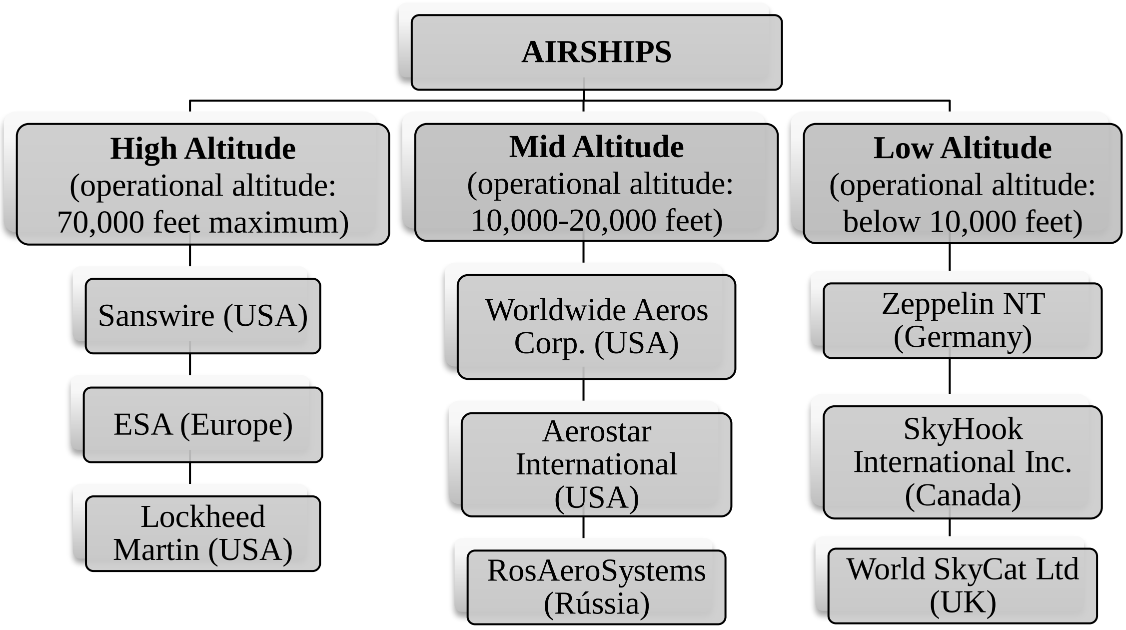


Figure 1. Airships Operational Altitude and Related Investment Companies

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.

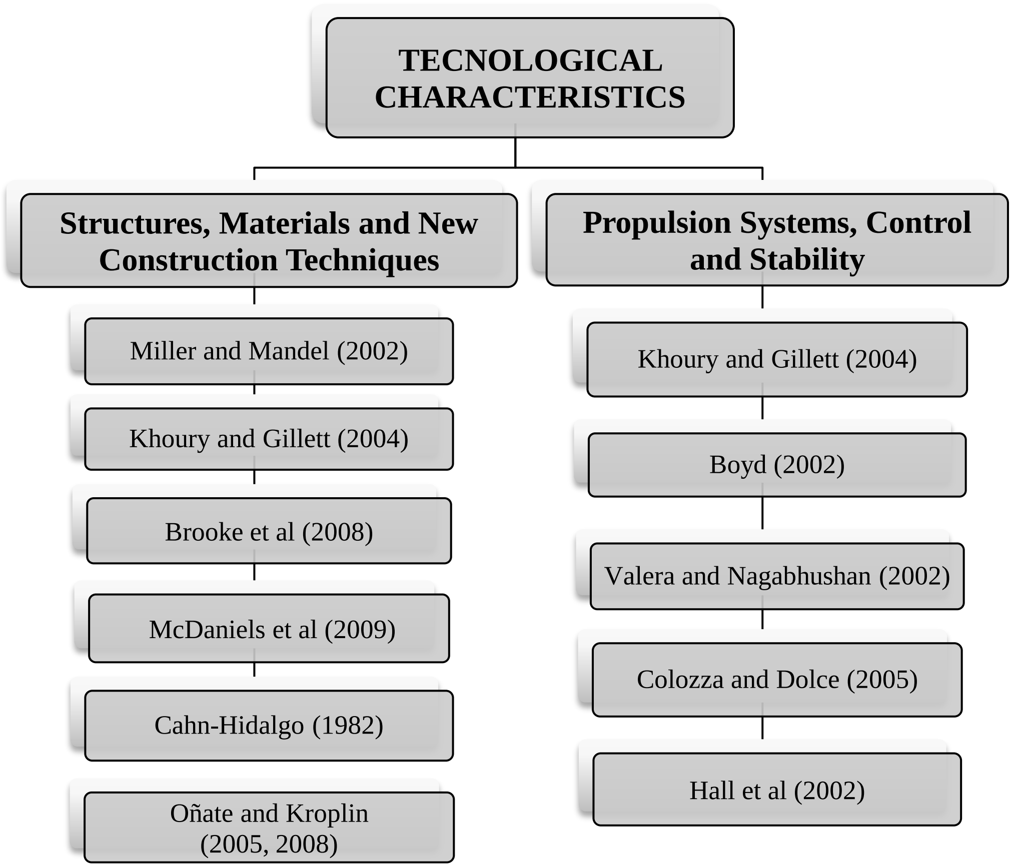


Figure 2. State of Art Review Related to Some Technological Characteristics

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

	Transportations Modes				
Climatic Factors	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**

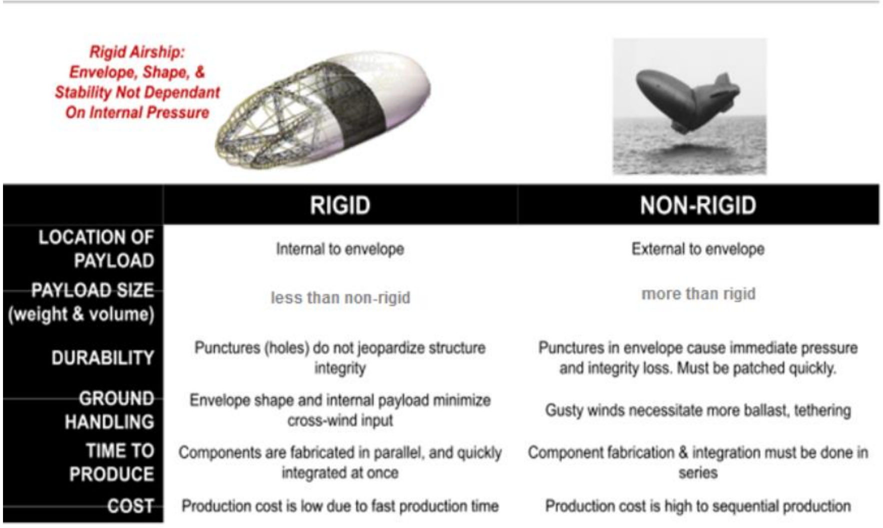
3. TECHNOLOGICAL PROBLEMS AND SOLUTIONS

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	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)

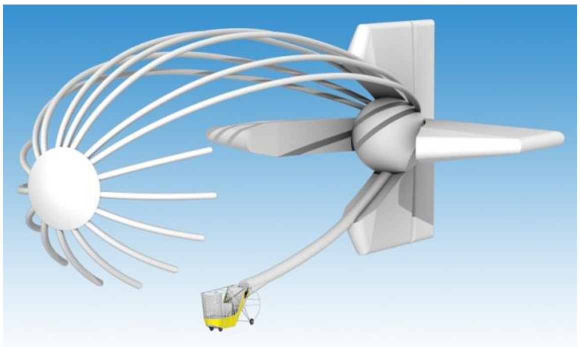


Figure 4. Semi-Rigid Airships (Apexballoons, 2013)

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).

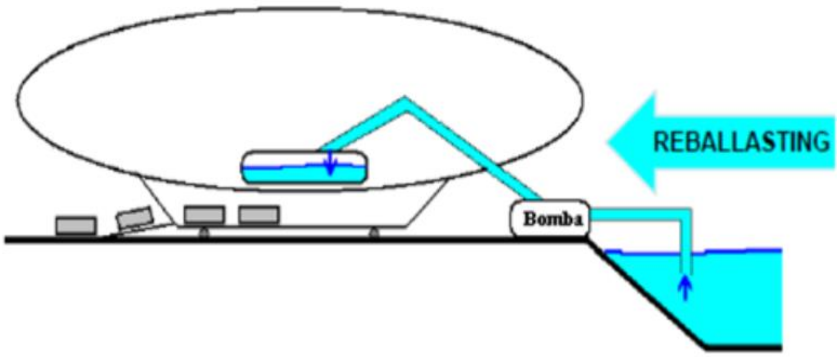


Figure 5. Refilling System of the Ballast Water (Pevzner, 2009)

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^3)	Lifting Force (N/m^3)	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).

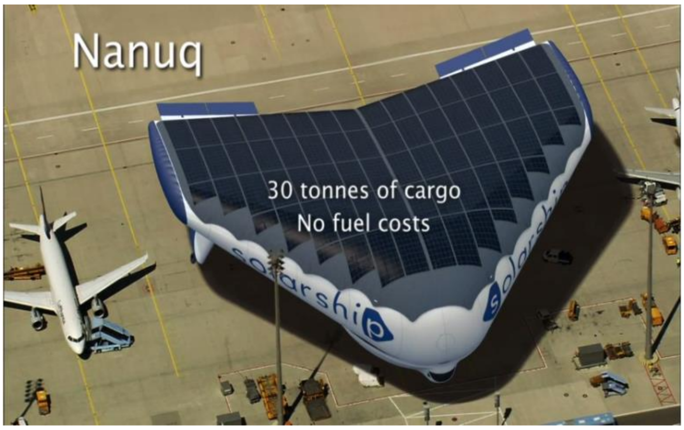


Figure 8. Nanuq Airship (Technewsdaily, 2013)

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 naviogation 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 tourits 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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