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FlyWin, a H_2-lifting gas airship demonstrator

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Abstract

This paper gives an overview of the project FlyWin that intends to develop an airship using hydrogen as a lifting gas. The paper briefly discusses milestones in the design process and gives more details on the work package for which Université Libre de Bruxelles is responsible. All steps of gas containing bags manufacturing are explained and the tests that are involved in the process, as well as the pressure relief system.

1 Introduction

The FlyWin project was founded by Belgian engineer and entrepreneur Laurent Minguet, and supported by Walloon region. The goal of the project is to develop an airship for cargo transport, specifically a universal container (20 tons). It should be economical and ecological.
An airship is a type of aerostat or lighter-than-air aircraft that is able to navigate through air by means of a propulsion system.

Figure 1: FlyWin Airship

1.1 Motivation

According to the prognosis of the Boing forecast [1] the air cargo traffic is going to keep growing over the next couple of decades (See Figure 2). At the same time there is more and more rising issue of climate change and interest in alternative sources of energy that could substitute fossil fuels and could decrease the effects of the climate change.

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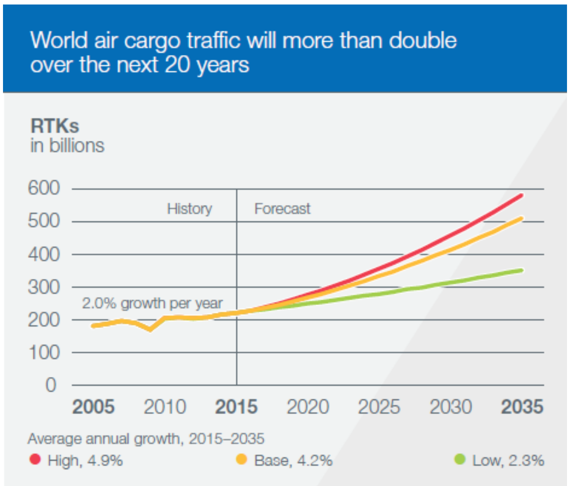

Figure 2: Air cargo traffic forecast by Boing

These trends led to the motivation of the project of developing a cargo airship: lifted by hydrogen, unmanned, using electrical propulsion, and capable of transporting a universal container (20 ton).
The main requirement of the project is to consider using hydrogen as a lifting gas, and not helium. The first reason of the choice is the cost and availability of hydrogen. In comparison to helium it's cheap and is produced in big quantities all over the world [2]. Although the mixture of hydrogen and air is easily flammable and requires a little amount of energy to ignite [3], it's believed that with necessary precautions and new kind of materials available nowadays it's feasible to safely operate a hydrogen-filled airship. Indeed, as history shows, there was a huge industry and use of hydrogen rigid airships in Germany. Zeppelin built and operated a number of hydrogen lighter-than-air aircrafts. For instance, Graf Zeppelin LZ 127 (1928) successfully made 590 flights covering more than a million of miles (more than 1.7 million km) [4]; Graf Zeppelin LZ 130 (1938) made 30 flights in 11 months in 1938–39 before being scrapped in 1940 [5].
The biggest accident that remains unrevealed is the Hindenburg disaster. All other airships that were destroyed, were either shot down during war, or exploded when accidentally hit the electrical power transmission lines (Roma [6]) or because of the envelope damage (for example, when exploring the North Pole because of icing, Norge [7]) and extensive hydrogen leak. Over the past 100 years the technologies advanced significantly in such areas as gas tight materials, light-weight constructions, electric propulsion, and safety and handling of hydrogen.
The transportation by airship technology would be significantly cheaper than by airplanes and faster than by ships (See Table 1).

Table 1: Comparison of transportation by airships vs aircrafts and ships

	Cost (FlyWin estimation), € ton/kilometer	**Average speed, kph**	**Propulsion**
Aircraft	0.40	875	Internal Combustion Engines
Ship	NA	35 [8]	Internal Combustion Engines
Airship (H_2)	0.10	125 [9]	Electric Motors

1.2 Approach

Scale up approach was chosen for the project (See Table 2). Prior to the final version of the airship capable of 20 ton cargo transport, it was decided to design, build and test a demonstrator. This is going to be done via industrial-academic collaboration within two years framework (2016-2017).

The consortium consists of 5 partners – 3 commercial companies and 2 academic institutions:

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- FlyWin
- GDTech
- Deltatec
- Université catholique de Louvain - UCL
- Université Libre de Bruxelles – ULB-ATM

Table 2: Scale up approach

Small-scale	Demonstrator	15 m long
Medium-scale	Prototype	40 m long
Full-scale	Operational Cargo Airship	100 m long

2 Design of the Demonstrator

Several principal design decisions had to be made in the beginning of 2016. After some time of studying of the airship technology and considering the whole system and interactions between the subsystems the consortium fixed the design keeping in mind several aspects.

- Feasibility of the implementation on the small scale demonstrator
- Keeping in mind the bigger goal (full-scale airship) - the choices must represent as much as possible those that would be later used on the full-scale airship

For example, a logic realization of a small scale airship would be in a blimp construction, a co-called “soft” aerostat that doesn’t employ any kind of structure. But a blimp isn’t capable of transporting tons of cargo, thus it doesn’t really represent the technology that is more likely to be used for the full-scale FlyWin airship. It’s most likely that a rigid structure has to be used. But now, building a small-scale airship with a rigid structure isn’t a trivial task, because the lifting force available in a smaller volume might not be enough to lift the rigid structure.

2.1 Requirements

Requirements were the starting point for the design (see Table 3).

Table 3 : Demonstrator design requirements

Volume	+/- 150 m^3
Dimensions	15x4x4 m
Lifting gas	hydrogen
Propulsion	electric motors (batteries)
Control	RPAS (Remotely Piloted Aircraft System)
Operations required	Vertical take-off and landing, stationary flight, cruising

2.2 Structure

One of the crucial design decisions that had to be made was about the structure of the airship. It’s one of the most important because it affects the internal organization of the airship, the realization and the materials required for the gas containing bags (ULB-ATM Work package, see Chapter 3).
There are three principal design options with regard to structure (Figure 3)

1. No structure
2. Rigid structure
3. Semi-rigid structure

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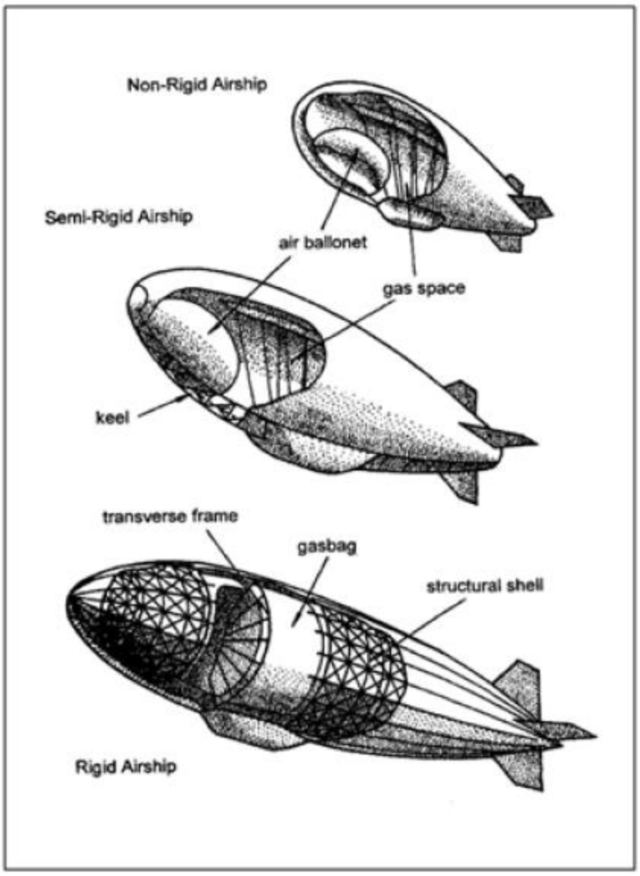

Figure 3: Structure design options for airships [10]

No structure [10] **– Blimp.** A blimp is a kind of aerostat that uses no structure. The aerodynamic shape is maintained through slightly overpressurized envelope, therefore the envelope is required to be strong and thick enough. It also requires having ballonets [11] filled with air in order to allow the expansion of the lifting gas and to keep the same overpressure over changing ambient temperatures and altitude.
Rigid structure [10] **– Rigid Airship.** A Rigid airship is an airship that uses full rigid structure in order to maintain the aerodynamic shape. The gas cells are stored inside of the structure, and the structure is covered with another kind of material, which means that there are two different types of material: gas containing cells and other skin. In this case there is no need for the air ballonets, because the structure keeps the shape. It also offers multiple points of attachment for motors and cargo, and allows carrying heavier loads.
Semi-rigid structure [10] **– Semi-rigid Airship.** A Semi-rigid airship is a half way from a blimp to a rigid airship. It still uses ovepressurized envelope and air ballonets, it has a keel structure but on the bottom only.

As a conclusion of the preliminary studies phase of the project the rigid structure was chosen for several reasons. First of all, foreseeing 20 ton cargo the rigid airship seems to be the obvious choice. Second, from the safety point of view it’s better to avoid any pockets of hydrogen and air mixture, so it’s unfavorable to have air ballonets inside of an envelope filled with hydrogen.

The structure of the FlyWin Demonstrator is going to be made out of carbon tubes, supported by wires and connected with 3D-printed connectors (Figure 4). And thus, consequently it means that the lifting gas is stored in gas cells (see Chapter 3 for more details).

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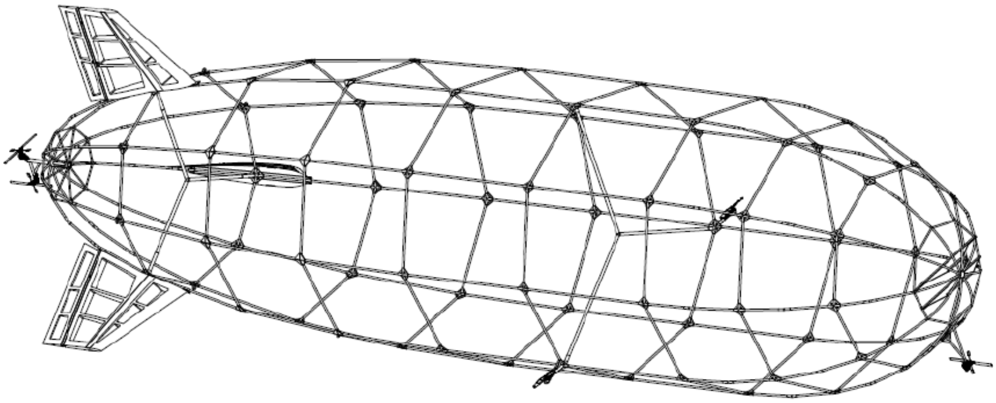

Figure 4: FlyWin Demonstrator rigid structure

3 ULB-ATM work package

Aero-Thermo-Mechanics (Universite Libre de Bruxelles) work package includes development and manufacturing of gas containing cells, its materials, pressure relief system, handling and safety of the lifting gas.

3.1 Envelope, gas cells and materials

Due to the fact that the rigid structure was chosen there are two types of materials that need to be used: internal gas containing cells (see Figure 5) and external skin that covers the structure. The external skin is of a lower priority at the step of the Demonstrator, so main attention was paid to the internal gas cells.
Because the carbon tubes structure is supported by cross-sectional wires and it makes three volume compartments, there are three gas cells of different shapes (See Figure 6) and volumes (See Table 4). They have to fit the internal volume provided by the structure as close as possible.

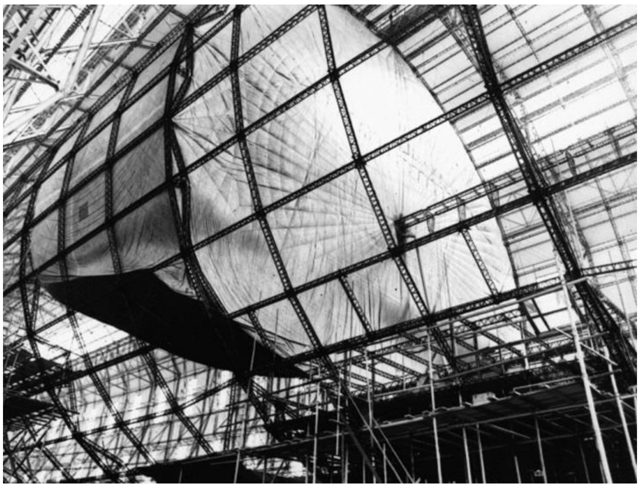

Figure 5: A partially inflated gas containing cell inside of the airship’s structure [12]

Table 4: Gas cells

	Volume, m^3	Surface Area, m^2
Front Gas cell	26.03	46.8
Middle Gas cell	91.17	119.1
Rear Gas cell	6.32	21.0

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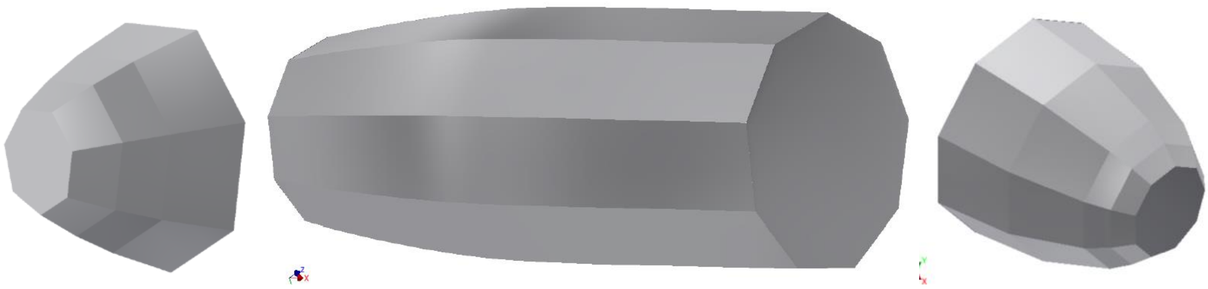

Figure 6 : Shapes of the gas cells: Rear, Middle, Front gas cell (from left to right)

A. Requirements for the gas cells material. A combination of requirements was set to a pretty much high level of challenge: available on the market, the lighter and the tighter the possible, electrically conductive. From the point of view of the strength the requirement was relaxed due to the non-overpressurized configuration of the gas cells. After a market research, a packaging film was chosen - an aluminized film EVAL. The requirements and the properties are listed in the Table 5.

Table 5: The requirements vs properties of the gas cells material

Requirements	EVAL technical specifications
Ready to use	Yes
Gas tight	Oxygen transmission rate < 0.05 $cm^3/m^2 \cdot day \cdot atm$
Light	20 g/m^2
Electrically conductive layer	Contains an aluminum layer
Able to sustain overpressure of 0.5 mbar	Tensile strength at break = 200 MPa
High flex resistance	Yes

B. Internal gas cells manufacturing & Tensile tests. The tensile strength that is indicated by the manufacturer is sufficient for the loads expected, although the weaker points of the gas cells are going to be seams of the material when joining two pieces of the film together. On the other hand, it’s important to keep in mind how easy (or difficult) one or another joining technique is to work with. Therefore the options of seams were investigated and tested, and tensile strength was measured in different combinations.

The three joining techniques have been considered: Lap seam, Butt seam, Side seam (see Figure 7). Side seam is the easiest to handle especially where the access is limited (side walls or the final closing seams). Butt seam is probably the most difficult to manufacture and a double width of the adhesive should be used in order to have seam surface equivalent to the lap seam, but it may have better gas tightness.

The tensile tests were performed by means of an equipment Zwick/Roell with a rate 10 mm/min (see Figure 8). It was impossible to use an extensometer for such thin and soft material, so the tensile strength was of the main interest for these tests.

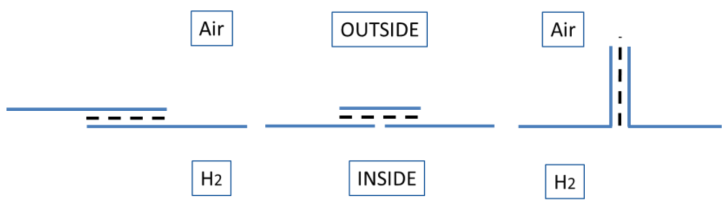

Figure 7: Joining techniques. Lap seam, Butt seam, Side seam (from left to right)

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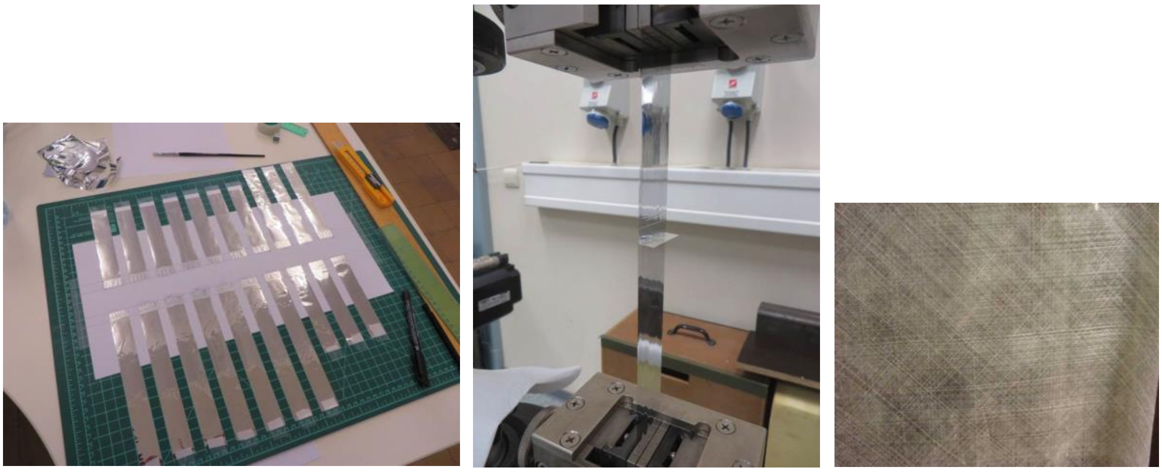

Figure 8: Samples cut for the tests (left), test of a side seam sample (middle), EVAL/Composite (right)

The Figure 9 shows typical curves of the EVAL strength tests. The loads for the Demonstrator were approximated as following:
Limit load strength: 1.1 N/25mm (the fabric must be able to support limit loads without permanent deformation);
Ultimate load strength: 5.5 N/25mm (the fabric must be able to withstand ultimate loads for at least 3 seconds without failure).
According to the results of the tests the Side seam was eliminated from consideration as being too weak, and too easy to start peeling off.

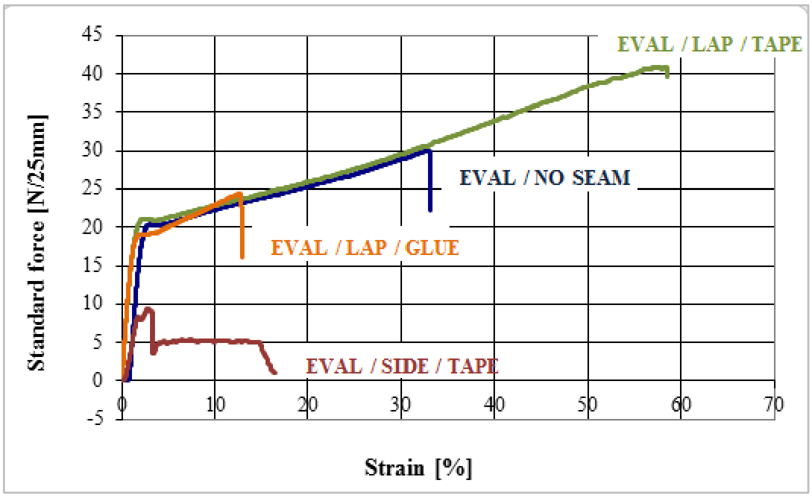

Figure 9: Typical curves of EVAL strength tests

The lifting forces for the full scale (80 000 m3), not the demonstrator, are estimated as following:
Limit load strength: 18 N/25mm (the fabric must be able to support limit loads without permanent deformation);
Ultimate load strength: 87 N/25mm (the fabric must be able to withstand ultimate loads for at least 3 seconds without failure);
Apparently the simple EVAL film wouldn’t satisfy the requirements for the case of the full-scale airship, therefore a step further has been done, and a composite material was manufactured and tested - EVAL/Composite (Figure 8). The performance of this material was definitely much better. All the samples broke at the joint. The maximum force withstood was 180 N/25mm versus 40 N/25mm for simple EVAL while the same joining technique was used - Lap seam (Table 6).

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Table 6: EVAL vs EVAL/Composite comparison

	EVAL	**EVAL/Composite**
Joining technique	Lap seam	Tape
Adhesive	Lap seam	Tape
Force, N/25mm	180	40
Strain,%	5	60
Place of rupture	The film	The seam

C. Leakage rate tests. As well as the tensile strength at break the transmission rate through the material doesn't take into account the leakage rate through the seams of an assembled gas cell made of several parts. Therefore, a small balloon of 1 m^3 was built (using lap seam as joining technique), inflated with hydrogen and the lift losses were measured over time. A heavy object was attached to the balloon (see Figure 10), and a balance was used to measure the lifting force and its loss. For a 1 m^3 balloon it took almost exactly two weeks before it lost enough lifting gas to descend. The plot (Figure 11) shows the curve of the cumulative lift loss over time. It can be seen that the lift loss rate, and thus hydrogen leakage rate, was higher in the first hours and slowed down later on. This is believed is due to the fact that the balloon was slightly overpressurized at the very beginning, and there is physically less and less volume of the gas that can permeate through the film over time.

Figure 10 : Small balloon using lap seam. Leakage rate test

This data is important and is going to serve as a baseline for estimation of the lift losses for the small-scale Demonstrator, and for the further comparison with another leakage test balloon that will be made using a different joining technique (butt seam).

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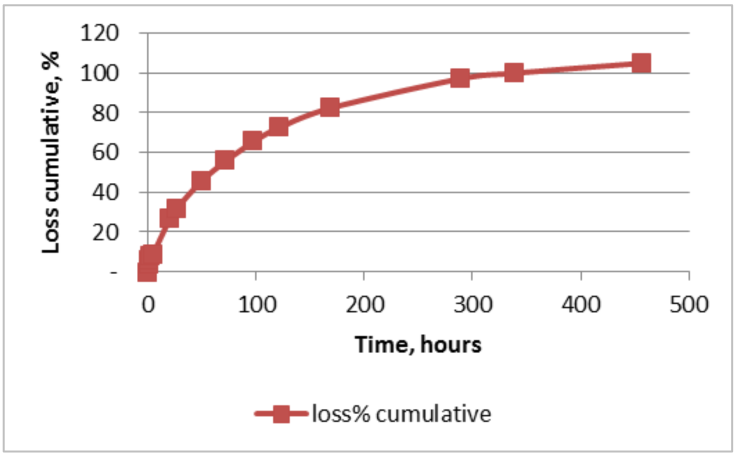

Figure 11: The cumulative loss of lift as a function of time

3.2 Safety Subsystem

The safety subsystem is a pressure relief system that includes a controlled pressure relief valve (PRV), an automatic/controlled emergency pressure relief valve (EPV), and an overpressure sensor.
During the airship operation the lifting gas can expand and may cause rupture of the gas cells or even the structure, but also some amount of gas needs to be ventilated to control the altitude. For this reason valves need to be used.
Because of the flammability of the lifting gas (H_2) with air, the possibilities of mixtures should be avoided as much as possible; therefore it's required to place any kind of sensor or equipment outside of the gas cells. Looking at the past [12] there is a simple solution for controlling the gas cells expansion. An overpressure sensor is placed right under the gas cell (see Figure 12, left), it doesn't measure the exact pressure, but acts as an ON/OFF sensor. In case the lifting gas expands and for as long as there is the ON position the emergency pressure relief valve (EPV) will be open (see Figure 13). As soon as enough gas is relieved the sensor switches to the position OFF and the valve is closed. The EPV should allow for high mass flow rate. Figure 12 (right) shows a valve that was used on Zeppelin LZ-129 (Hindenburg), its diameter is about 50 cm.
In order to control the altitude and to land there is another, more precise, pressure relief valve (PRV) – it's a remotely controlled valve that should allow for smaller mass flow rate.
To minimize the failure of the safety subsystem the two valves are controlled through separate channels.
It was decided to use additive manufacturing for producing the safety subsystem components – PRV, ERV, and overpressure sensor – in order to make it as light as possible. The overpressure sensor has been already manufactured using PLA, 80% filling; its total weight is approximately 25gram (Figure 14).

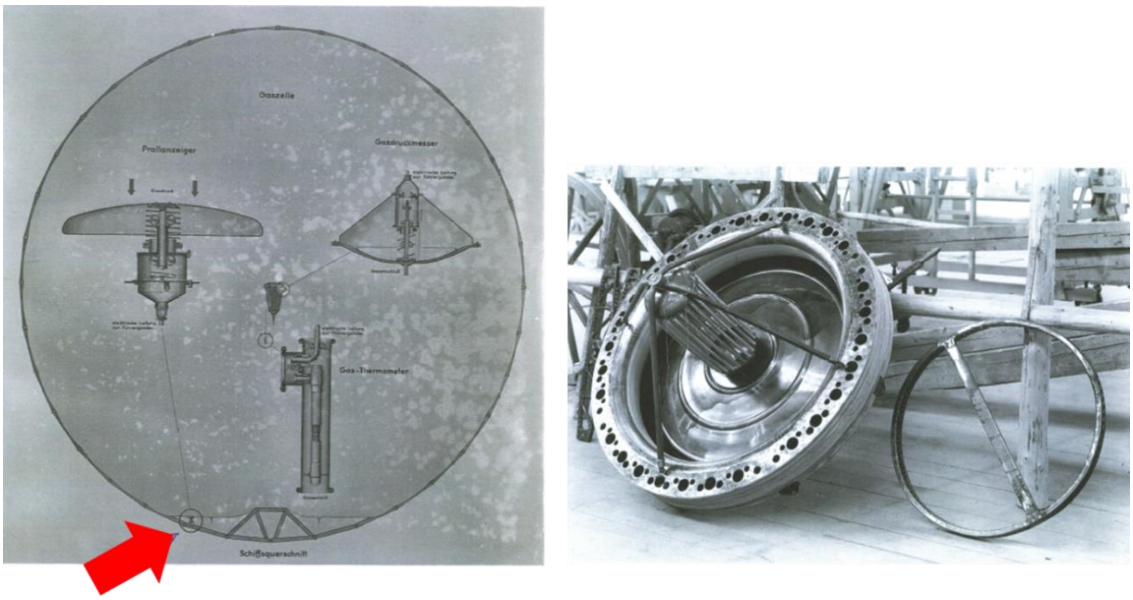

Figure 12: Zeppelin LZ-129 (Hindenburg). Overpressure sensor (left), Overpressure valve (right)

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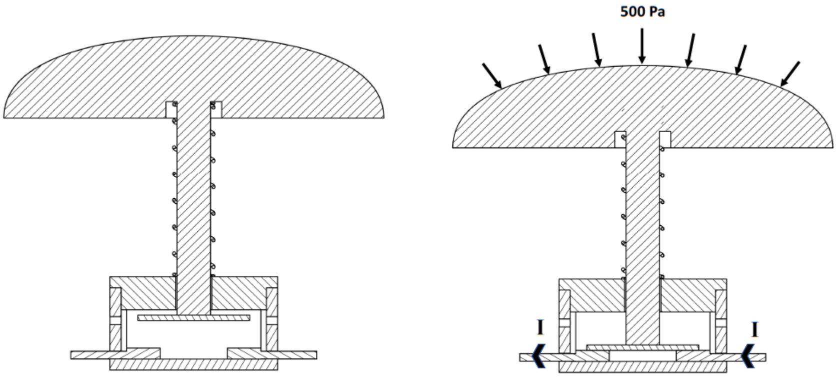

Figure 13: Working principle of the overpressure sensor

Figure 14: Overpressure sensor. Additive manufacturing

4 Conclusions

The FlyWin project of development of an airship is an ongoing project, in which most of the development of Demonstrator phase has been already achieved, such as main design decisions, structure design and materials, gas containing cells design and materials, safety subsystem design, controls, motors, and power supply network. The main further steps include:

Production and purchase of all necessary components	July/August 2017
Integration of all subsystems	August/September 2017
Flying tests	**October 2017**
EASA certification	ongoing

The FlyWin project has been a challenging and exciting research project under leadership of Laurent Minguet, and supported by Walloon region of Belgium.

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