Design of different elements of a pressurized capsule for stratospheric balloons

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MEMORY

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Purpose

The project consists in solve specific technical problems and design different structural subsystems such as windows, a proper entry and the pressurization system for a semi-built manned stratospheric balloon capsule. It has also been designed a test experiment to verify the security and technical feasibility of the main elements.

Dealing with suppliers and designing pre-launch procedures will be also studied in order to ease the implementation stage. This is a real project carried out by Zero2infinity SL, a private company that develops Near-Space technologies.

Scope

The main points to be addressed are:

- Study the state of the art.
- Design the capsule's windows.
- Design the crew's entry and access system.
- Design a pressure test.
- Define and study all the requirements for the electronics firmwares.
- Study of the pre-launch procedures.

In this project won't be addressed the electronic subsystem or the building process.

Justification

This is a real project that takes part on the framework of an aerospace company submitted to economically and time limitations. Moreover, this is a necessary and important part of the work plan because allows pressurization and perform the different test to verify the capsule's habitability during the whole flight cycle.

This project contributes to develop technologies on a raising sector which looks for an environmentally friendly and sustainable business model. Furthermore, I am contributing to make possible the dream of providing the world a true vision of the beauty and fragileness of the Earth through a high technological mission.

Requirements

- All the chosen solutions shall be economically feasible and in the technological framework of the company. Furthermore, all the operations not practicable for Zero2infinity SL should be justified for the appropriate company.
- Security is the main factor to consider so that the security factor to be applied in the windows and pressurization system shall be 2.5.
- Weight is one of the most significant factors so all the solutions should be studied to be minimized it, but without compromising security.
- Although this project doesn't emphasize in electronics, we have to study the necessary inputs to provide the electronics department with all the necessary information to design a proper control system.

Acknowledgement

To my project directors Mr. Rafael Weyler and Mrs. Montserrat Sanchez for guiding me thought out the development of this project.

To all the zero2infinity members for trusting in my personal and engineer aptitudes, specially: Mr. Daniel Romero, Mr. José Miguel Bermudez, Mr. Jorge Salas, Mr. David Ferrer and José Mariano Lopez.

To my family and friends who supported me and gave me strength along the whole project.

CHAPTER 1:
OVERVIEW OF HIGH-ALTITUDE BALLOONING

1.1. Background

Stratospheric balloons are aerostatic platforms filled of gas (normally helium or hydrogen) that rises among the stratosphere located between 11 and 50 Km height. Its singularity as a scientific tool is based on its capacity to perform stable and long term flights.

A stratospheric balloon is not just classifiable as a vehicle of instrumental transport it is also a conjunct of several subsystems which work together to perform correct flight cycle.

Based on the Archimedes principle and through ascension push they rise from light weights to heavy payloads about 3500 Kg up to 40 Km.

This platform can be divided into two main systems: the balloon and the flight chain where are located all the necessary subsystems for its operation such as a parachute to recover the instrumentation, a communication system to send and receive commands, a telemetric system of pressure, height, temperature and position of the conjunct, a radar reflector, a ballast ejector, a separation mechanism of the payload and a supply to provide power to all the electronics. The structure that contents and protects the payload is denominated the gondola which can be a pressurized volume.

1.2. Historical outline

The first gas aerostatic launch was made by Jacques Charles the 27th august, 1783 in the *Champ de Mars* and In the same year was performed the first manned hot air balloon flight reaching a height of 152 meters and travelling 9 Km. The same year Nicholas Robert and Jacques Charles made the first lighter- than-air based balloon by using hydrogen and raised about 610 meters and travelled 43 Km. After that, in the XVIII century balloons were applied to perform scientific test. Robertson in 1803 and Gay-Lussac and Biot in 1804 demonstrated that temperature pressure and moisture decreased as the altitude rises. In the XIX century gas aerostats were used during the US civilian war and during the Napoleonic wars and by acrobats such as Blanchard.

1.3. A near space platform

A near space platform (NSP) based on the high-altitude balloon technology enable access to near space to a series of customers distributed among different markets. These markets include scientific research, technology development and demonstrators, sponsorship and, as a last step, space tourism.

Any of the NSP consists of three parts:

- The gondola: Responsible for accommodating the payload. They include from non-pressurized structures to hold scientific experiments to pressurized capsules equipped to comfortably sustain life.
- The sail: Responsible for holding the helium gas and providing buoyant lift.
- The chain: Makes the connection between the sail and the gondola. It includes communications equipment as well as part of the descent and landing systems.

1.4. Flight cycle

The NSP flight cycle is made up of three phases, which can be tuned to fit with the customer's requirements:

- Launch and ascent phase: Ascent up to the desired float altitude at an average ascent rate of 5 m/s. The float altitude can reach up to 45 km. It is usually between 25 km and 40 km.
- Cruise phase: At roughly constant altitude once the ceiling altitude is reached. It can last from a few minutes to several days. It usually ranges from a few hours to 3-4 days. Some polar campaigns can last up to 45 days.
- Descent phase: The envelope is detached and the gondola descends with a round parachute. It is intended to offer a final descent phase with an autonomously guided ram-air parachute.

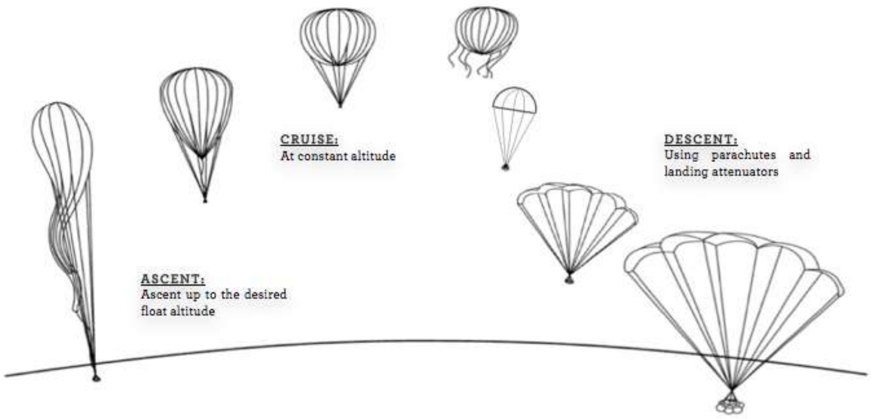


Figure 1 : Balloon flight cycle.

1.5. Balloon types

Balloons can be divided into two general categories: opened or closed. The first ones are also commonly known as zero pressure balloons because in the lower part are opened so that when altitude rises and pressure decrease the interior gas expands to achieve equilibrium between the inner and the outer side of the balloon. Any pressure rising produced for example by the greenhouse effect inside the balloon volume is instantaneously compensated by the gas flow through the lower opened section. The other typologies are called superpressure balloons because are totally closed and doesn't allow gas flow. When the inner pressure rises the shell wrap holds the pressure and expands until it achieves equilibrium.

Usually, zero pressure balloons are used for high payloads, above 3 tons, and 7 days to 3 weeks depending on the climate conditions and location. On the other hand, super pressure balloons can fly along months but can carry a limited payload. They are particulary good for survey missions because maintain a constant altitude.

Figure 2: Zero pressure and super pressure balloons

1.6. Gases

The most common gases used in the aerospace ballooning technologies are:

• Hydrogen: historically one of the most used in the industry, easy to obtain and the most common in the earth and cheap. Moreover, it is the lighter known gas in the world very important for this application. On the other hand, it is a dangerous gas to handle due to its flammability.

• Helium: It is a noble gas and one of the most abundant in the universe. More difficult to obtain and weight more than hydrogen. Even though, it is more stable and secure.

1.7. Main applications

Along history science has used balloons to perform experiments in almost space conditions with a good stability, long term and relatively low cost. Moreover, in the pre-satellite period this was the only way to perform many astronomic and astrophysics experiments.

Nowadays stratospheric balloons are used in many scientific and general technological disciplines as science of the atmosphere by the remote and in situ observation of portions of the atmosphere with radiometry or chromatography, studying the present particles of the atmosphere and its chemical interaction with the environment. Earth sciences thrive on that technology thanks to aerial photography and the study of the geomagnetism phenomena. Otherwise, this kind of flights allows companies to test the future satellites instruments, calibrate solar cells and test different systems applicable to aeronautics such as parachutes, capsules, probes, avionics systems and all kind of electronics.

Many countries are carrying out scientific balloons active programs such as the Swedish stratospherical balloon program which among other studies the different atmospheric and physical phenomena in the artic area.

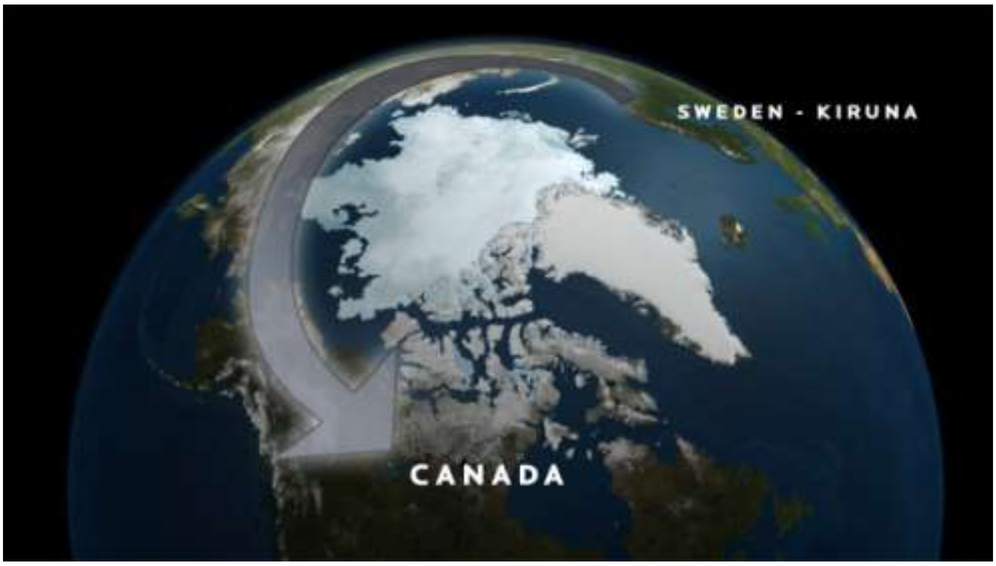


Figure 3: Swedish balloon trajectory

To allow the missions development Sweden had to sign accords with other countries such as Finland, Norway Russia and even Canada to permit flying over and recover the equipment.

There are other countries such as Canada, China, Brazil, Australia, United States, France, India, Italy, Japan or Norway that also perform this kind of scientific flights.

CHAPTER 2: ENVIRONMENTAL CONDITIONS IN NEAR-SPACE

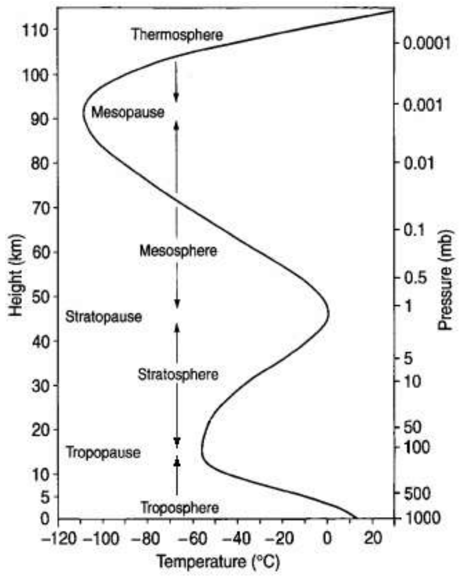
The different designed elements in this project will face different and variable conditions in each of the three phases described above. These conditions shall be estimated according to the International Standard Atmosphere (ISA) as derived below:

- Temperature
  - Troposphere: constant descent of 6.5 K/km until 11km reaching 216.5 K.
  - Low stratosphere: constant temperature at 216.5 K from 11 km until 20 km.
  - High stratosphere: a first rise of 1 K/km until 32 km reaching a temperature of 228.65 K and a second rise of 2.8 K/km until 36 km where bloon will set the cruise mode at a temperature of 239.85 K.
- Density
  - 99% of the mass of the atmosphere is below bloon at cruise altitude with a density of 0.006 kg/m^3.
- Pressure
  - Follows an exponential decrease as altitude increases arriving at pressures of nearly vacuum at cruise level.

This data is represented numerically in the table below:

Height Above Sea Level		Static Pressure		Standard Temperature	Temperature Lapse Rate	
(m)	(ft)	(Pa)	(inHg)	(K)	(K/m)	(K/ft)
0	0	101,325	29.921	288.15	-0.0065	-0.0019812
11,000	36,089	22,633	6.683	216.65	0	0
20,000	65,617	5,475.2	1.617	216.65	0.0010	0.0003048
32,000	104,987	868.1	0.256	228.65	0.0028	0.0008534
47,000	154,199	110.9	0.033	270.65	0	0

Table 1: ISA altitude pressure and temperature



Stratospheric conditions in terms of heat transfer are similar to space conditions:

- Radiation is the most relevant heat transfer mechanism since the outside air density is not enough to entail convection.
- Great thermal input differences exist between the sides facing towards and away from the sun.
- UV energy is high at cruise altitude as bloon goes above the ozone layer. The maximum UV intensity is 78 W/m^2 (±15 W/m^2), which is about 3 times the intensity at Sea Level (SL) exposure.

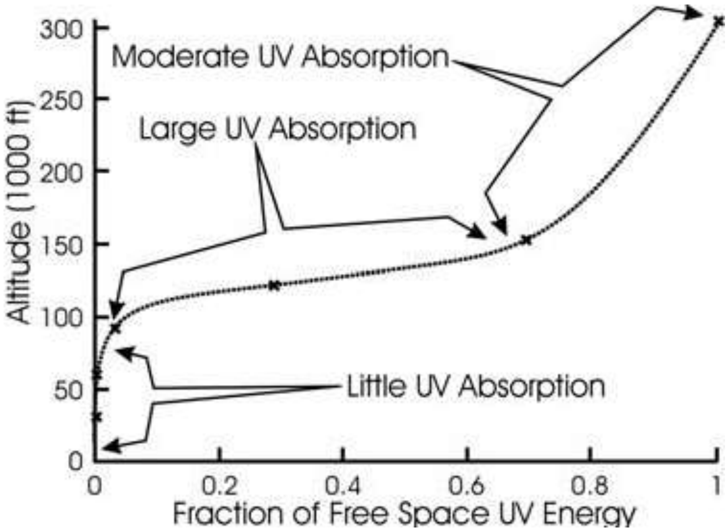


Figure 4: UV atmospheric absorption vs. altitude

- Radiation exposure is higher than at SL. This radiation environment is made up of radiation trapped in the Earth's magnetic field, galactic cosmic rays (GCR) and solar particle events (SPEs). This radiation is highly dependent on the latitude, the solar cycle and the solar activity (solar storms). However, the dose received during a standard flight of bloon remains at the same level of the ones of a transoceanic flight (~50 µSV).

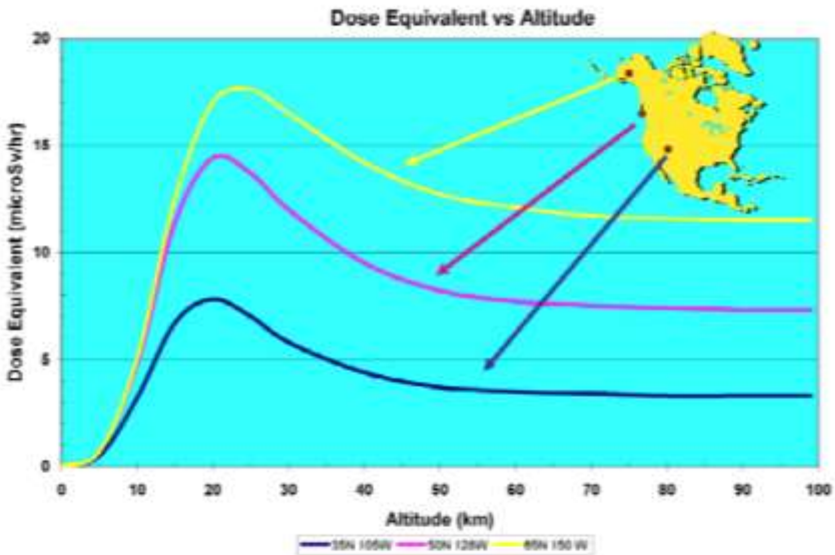


Figure 5: QARM Dose Equivalent (in tissue, no additional shielding) vs. Altitude for solar minimum (max GCR) under geomagnetically quiet condition (Kp~2)

There is a strong existence of corrosive gases:

- Ozone (O_3): The ozone layer is a range of altitudes in which the partial pressure of ozone reaches 20 mPa at about 20 km. The mixing ratio gets to 10^{-5} at 30 km.
- Atomic oxygen (O): Monatomic oxygen can reach mixing ratios of 10^{-10} at cruise altitude.

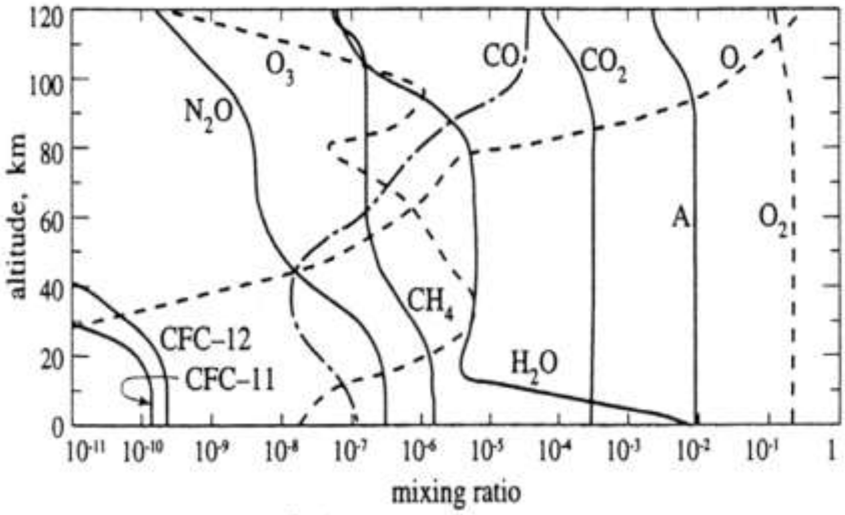


Figure 6: Corrosive gas vs. Altitude

2.1. Loss consciousness

Exposure to oxygen-poor environment causes hypoxia and reduces the efficiency of the pulmonary system. Effective performance time is defined as the time in which a person is able to perform work duties in an inadequate oxygen supply. This time depends on each person and its susceptibility but according to height this time is reduced drastically. Otherwise, explosive decompression on an aircraft or space capsule can cause death specially if the subject is holding its breath in the right moment but in case of slow decompression this will become critical from 5500 m height.

The table and figure above resumes loss consciousness according to each height level.

Altitude in Flight level	Time of Useful Consciousness	Altitude in meters	Altitude in feet
FL 150	30 min or more	4,572 m	15
FL 180	20 to 30 min	5,486 m	18
FL 220	5-10 min	6,705 m	22
FL 250	3 to 6 min	7,620 m	25
FL 280	2.5 to 3 mins	8,534 m	28
FL 300	1 to 3 mins	9,144 m	30
FL 350	30 sec to 60 sec	10,668 m	35
FL 400	15 to 20 sec	12,192 m	40
FL 430	9 to 15 sec	13,106 m	43
FL 500 and above	6 to 9 sec	15,240 m	50

Table 2: Time of useful consciousness (TUC)

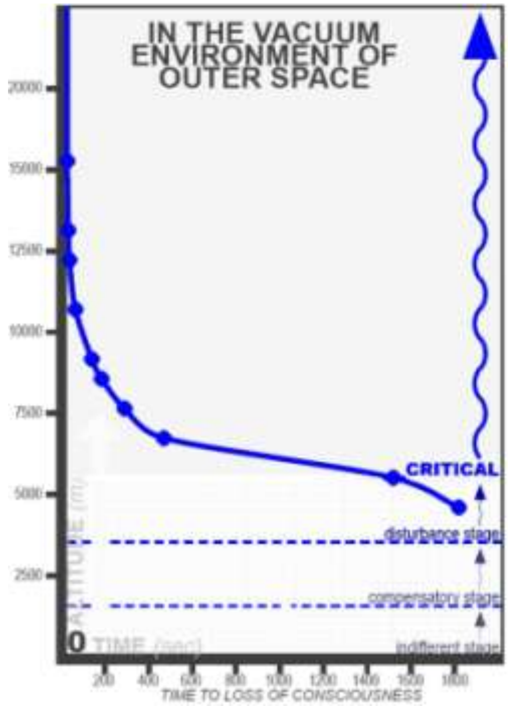


Figure 7: TUC plot [meters vs seconds]

CHAPTER 3:
WORKFRAME OF THE PROJECT

The development of the overall project follows four phases. Each phase is used to improve the capabilities and know-how of the capsule, offering additional possibilities and services to the different customers. Each phase has also an associated gondola.

3.1. Nanobloon.

nanobloon has been the initial development phase. Its purpose concerning bloon's technical development has been to test conditions and obtain images. Several flights have been successfully performed.

nanobloon is now a ready-to-fly vehicle able to perform uninhabited scientific and commercial flights for unpressurized payloads up to 3 kg at altitudes of 30 km.

3.2. Microbloon

microbloon is the second phase of development. Three different vehicles have been designed, built and tested.

Its first version, microbloon 1.0, is a $1/10^{th}$ scaled prototype designed to analyze the behavior of pressurized capsules during a near space flight. microbloon 1.0 first flight took place in October 2010.

Figure 8: Microbloon 1.0 flight test

microbloon 2.0 is a $1/3^{rd}$ scaled version of bloon. It was developed and tested during 2011 and 2012. This phase has been used to test flight equipment and systems that will be the starting point for minibloon. The result is a family of pressurized capsules of about 1.5 m^3 volume capable to offer preselected environmental conditions for unmanned payloads. The first flight of microbloon 2.0 occurred in November 2012.

Figure 9: microbloon 2.0 flight test

Microbloon 3.0 flew the 6th of October of 2013. The pod consisted in a light inflatable structure builded by Thin Red Line Aerospace. His objective was verifying some specific electronics technologies.

Figure 10: microbloon 3.0 flight test

This second phase has also entailed the development of the capabilities and equipment to perform mid-heavy payload high altitude balloon launches (up to 1,000 kg)

Figure 11: microbloon 2.0 November 2012 launch

3.3. Minibloon

Minibloon is the third phase of the spiral development of *bloon*. minibloon will be used to test and validate not only all the subsystems that will be mounted on the commercial version of bloon but also the launch of the balloon. It can host up to 2 people in a breathable environment and will be our first inhabited vehicle.

Nonetheless, the scope of minibloon is not only within the engineering field. Its inhabited flight will be a proof of concept of bloon for prospective customers. Whereas the first uninhabited flight of minibloon will take place by mid2016, its first inhabited flight will occur in Q4 2016 or Q1 2017.

minibloon is also intended to be the vehicle to beat the balloon altitude world record. Although *minibloon* is not meant to obtain certification to host customers, it will ride it on a regular basis to conduct scientific experiments and PR & media events in near-space

Figure 12: minibloon structure at Scaled Composites

3.4. Bloon

bloon is the final development phase. Once the initial test flights with the 100% operative version of bloon have been performed under a special flight regime, bloon will proceed to the certification process. The culmination of the development process, once the EASA/FAA certifications and licenses are acquired, will enable the beginning of commercial activity of bloon in near space tourism.

bloon will accommodate passengers (4) and crew (2) as well as scientific payloads if required, during a 5-hour flight: 2h ascent, 2hfloat at 30 km – 36 km, 1h descent.

CHAPTER 4:

OVERVIEW OF MINIBLOON

In this chapter is explained a general review of the main features about the platform in which will be based the whole design of this project.

4.1. General configuration

The capsule is made up of three parts:

- Pressurized module: 2.4 m diameter spherical cabin of carbon fiber. It was designed and built by Scaled Composites. It is intended to accommodate the crew (up to 2) and equipment.
- Non-pressurized module: Equipment can also be fitted at the top crown.
- Impact attenuation: A crushable system is fitted at the bottom of the capsule to reduce the impact forces at landing.

Figure 13: minibloon structure CAD and transport to z2i workshop

4.2. Carbon fiber frames

The capsule presents five holes dimensioned to support the windows and distributed around the sphere. The following table/picture describes the position of all the windows and the corresponding diameters.

Figure 14: Top view

Hole	Diameter (mm)
1	355
2	355
3	406
4	358
5	620

Table 3: Hole diameter

Each hole has a carbon fiber frame laminated around the window surface. The holes number 1, 2 and 4 can share the same window type and dimensions due to its dimensional similarity.

Figure 15*: Structural frame section diagram*

4.3. Crushable

The crushable is the lower structure which absorbs the impact during the descent. Initially it was designed by dick Rutan's, an aerospace engineer that pretended to go around the world with our capsule. The main problem is that it was thought to fight with a hot air balloon so he could control the descent speed and minimize the shock. In our case, the shock would be conditioned by the parachute's drag and is estimated to be a 5-6 m/s speed. The global project requires to design a new crushable and a structural system to support it but won't be included in the scope of this project.

4.4. Structure

The structure is composed by a 2mm thickness carbon fiber sphere that absorbs the pressure differential and two Kevlar structural wires that surrounds and secure the sphere to the flight chain. This surrounding system is very useful to isolate the capsule to the rest of stresses such as the landing impact or the shock produced when the parachute is opened.

4.5. The standard flight cycle

Since minibloon has to be representative of the final vehicle, it has to be designed to perform a similar flight cycle as the one to be performed by *bloon*. However its capabilities shall be extended to adapt to the requirements of the investigators that will be mounting their experiments on minibloon. The flight cycle, then, is:

- Ascent up to 30 km – 45 km. The average ascent velocity is 5 m/s. This value is dependent on external conditions and altitude.
- Cruise at an altitude between 30 km and 45 km during 2 hours (capable of increasing up to 10 hours).
- Descent (guided and/or unguided) and landing. The descent velocity is dependent upon the size of the parachute and the altitude. Peak descent velocities of 60 m/s can be achieved during the initial descent if the parachute is not reefed. If it is reefed, this velocity can be increase up to 200 m/s. It is expected to land at 5-6 m/s (vertical velocity). After the release of the balloon, a few seconds of reduced gravity values are expected.

4.6. External cover

Space conditions require a special foam seal in order to control the inner conditions. In this project we won't perform an exhaustive study but we will propose a possible exterior design.

Figure 16: Outer design

CHAPTER 5:

DESCRIPTION OF THE PROPOSED DESIGN FOR THE WINDOWS

As explained on previous sections, minibloon's structure was designed and built by Dick Rutan, an American Aeronautic engineer which pretended to fly around the world with a hot air balloon. All the holes were designed according to its needs so our intention is to finish its design and adapt them to our necessities.

5.1. Requirements

The windows are used to control the situation from inside to outside and vice versa and, of course, enjoy the view. It will be a fix element and the only part that could be useful to be dismounted is plastic the dome. The whole design has to be planned in a way that dilatations affect as the fewer is better. Once more, all the used materials have to endure to several flight cycles without losing their mechanical properties.

5.2. Constructive design description

The main constructive goal is to avoid drilling the structural frames of the capsule and ensure sealing during the whole flight cycle. To achieve this aim it is proposed to use adhesive between the carbon fiber surface and the internal frames. This system is composed by a metallic frame (Blue) adhered to the capsule and the rest of the window set consisting in two polycarbonate windows (Green&Purple) joint by a spacer (Orange) whose function is to create an offset between both windows. The union between the internal frame and the rest of the set is made using screws and a plate to protect the polycarbonate window and to distribute the stress. This design allows disassembling and replacing the windows easily. Finally, the conjunct is sealed with a silicon seal (yellow).

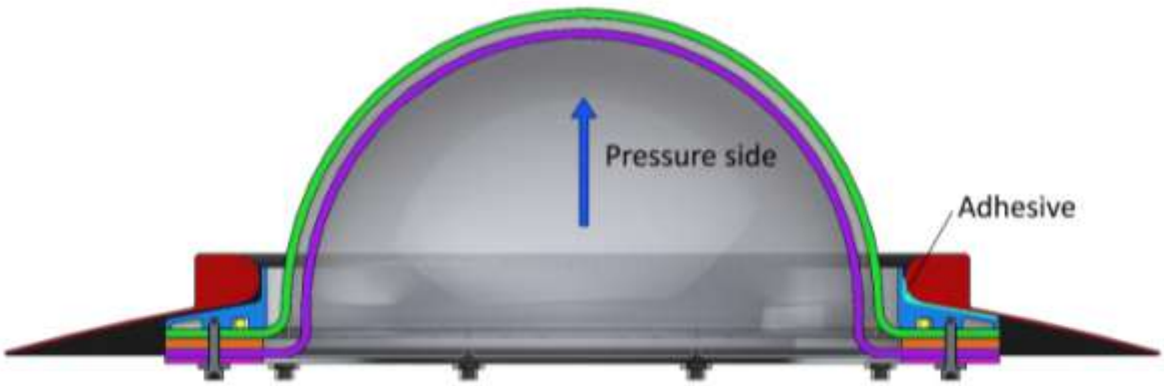


Figure 17: Window scheme

Part Number	Description
1	Structural capsule frame
2	Internal frame
3	Outer polycarbonate window
4	Inner polycarbonate window
5	Polycarbonate spacer
6	Protection plate
7	Washer
8	Screw
9	Seal

Table 4: BOM

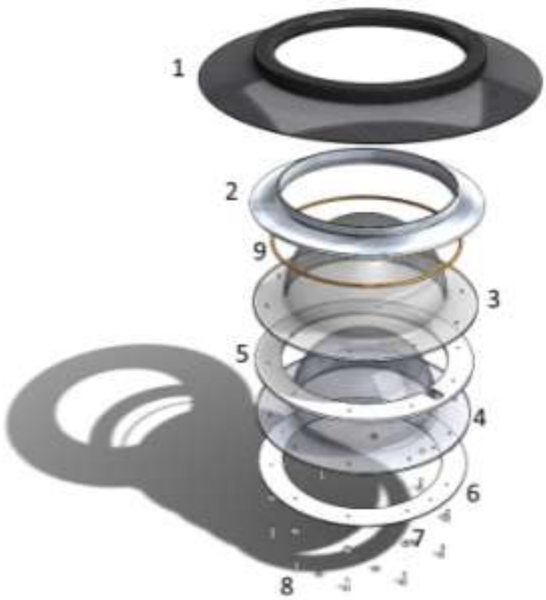


Figure 18: Explosion view

A possible solution could be a double layer window with Argon in the middle (good for radiation filtration, it is an ideal gas, so we have no humidity and no condensation). Each layer should be capable of withstanding the whole pressure drop (1 bar) with a N=2 safety factor by itself ensuring the pressurization in case of collapse of one of the glass layers meeting the fail-safe requirements. A possible approach to increase the reliability of the system would be ensuring that they would not work at more than 0.5 bar (N=4). This would be possible if the inner air layer was kept at a pressure of around 0.5 bar so the pressure drop between it and both the interior and exterior would always be 0.5 bar. This would be a security factor that should not under any circumstances substitute the resistance of each glass layer to 1 bar with the corresponding safety factor (N=2). Actually, the case mentioned before corresponds to the cruise phase case (1 bar of differential pressure), but the idea is to have a pressure regulation system that ensures that we always have the average pressure (between capsule int. and external atmosphere) in the inner layer. For example, during the ascent phase, if we have 1 bar inside the capsule and 0.4 bar outside, the internal Argon pressure must be 0.7 bar.

Argon intake could be made drilling a hole through the protection plate (6) and the inner window (4). There is a special cut in the spacer to introduce the argon from the racor hole.

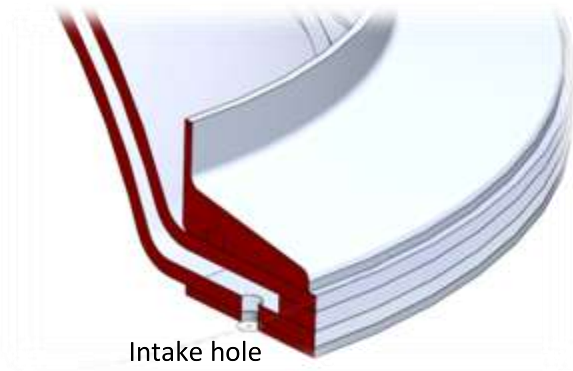


Figure 19: Argon intake scheme

5.3. Sealing joint

Due to the position of the window's frame we can afford that the joint works on a compression position so that the more pressure the better. Although the frame is on the inner side of the capsule we have to afford that our joint can endure the outer conditions. For that reason I have selected a silicone material so that its work rank is between -70ºC and 200ºC.

Otherwise, the screwery ring is placed near the joint to afford that is compressed during the whole flight cycle, even at the sea level.

5.4. Adhesive justification

It is important to have into account that space conditions provoke a contraction of the metallic elements such as the inner frame so we have to select an adhesive which possess an elastic behaviour under extreme cold conditions. In that way, conventional structural adhesives are discarded due to their elongation at break (around 2-3%).

Loctite 5399 is a silicon sealer that provides endurance in the hardest condition with a rank of use from -70ºC to 275ºC and elongation at break about 500% so will be the best option for our application.

5.5. Dilatation analysis

In order to obtain the dimensional contraction of the material we will make a simulation analysis. An outstanding fact is that, in this case, all the frames are partially inside the capsule so the only part almost entirely affected by the outer conditions is the polycarbonate window. Aware of this we shall consider that the contraction between the frame + screwery and the polycarbonate will be different.

In order to avoid stresses produced by any contact between the window and the through bolts we will provide an extra diameter to the window and plates so as to absorb any reduction from the polycarbonate.

5.6. Windows typology

According to the different holes we can sort the windows into 3 types; 355 358 406 mm and the entry.

Figure 20: Top view

Hole	Diameter (mm)
1	355
2	355
3	406
4	358
5	620

Table 5: Hole diameter

In order to reduce operating costs we will unify both 355mm and the 358mm window into the same type. Otherwise, the polycarbonate dome thickness will by calculated for the window number four and applied in all the cases as this is the diameter subjected to most mechanical solicitations. In this way we will reduce significantly costs.

5.7. Argon introducing protocol

As mentioned, the argon system avoids the windows fogging and helps to protect the crew against UV rays. It is important to get a full argon atmosphere in the mid-layer in order to maximize its properties and to achieve that it is necessary to make the argon flow and be extracted several times.

In order to make this process handy we will use the electro valve to make the argon flow through and electronic protocol at the sea level.

Under these conditions the signal that arrives to the electro-valve should make the inner layer pressure grow so that argon flows to the exterior.

5.8. Materials justification

In the case of frames, lightweight and machinability are one of the main inputs to take into account. It is true that as temperature decrease dilatation will affect the capsule's carbon fiber frame much less than aluminum but this design has been planned in a way that silicon adhesive absorbs all the possible deformations preventing from stress concentrations. So the selected materials for the frames will be aluminium 6082 T6 and will be manufactured by *Grumeber SL*.

Regarding domes both layers will be built in polycarbonate due to its mechanical properties and easy thermo conformation. *FPS Ferplast* offers manufacture and transformation of different plastic types. They will mechanize the necessary molds and perform the different sticking stages.

According to the provider recommendations silicone is the best choice for the joints due to its good thermal properties from -70 ºC to 200ºC.

The rest of elements, plate and screws will be made of aluminum because of its lightweight properties and to avoid any galvanic corrosion.

See the annexes to find all the simulation information.

The following table resumes the different materials and providers.

Code	Description	Material	Provider
0002-P-0041	External window layer	Polycarbonate makrolon UV	FPS Ferplast
0002-P-0040	Internal window layer	Polycarbonate makrolon UV	FPS Ferplast
0002-P-0004	Internal frame	Aluminium 6082 T6	Grumeber SL
0002-P-0006	Protection plate	Aluminium 6082 T6	Grumeber SL
0002-P-0024	Sealing joint	Sillicon	Epidor S.A.
0002-P-0021	Spacer	Polycarbonate makrolon UV	FPS Ferplast
-	Screws	Aluminium	Aubert SL

Table 6: Materials and providers

CHAPTER 6:
DESCRIPTION OF THE PROPOSED DESIGN FOR THE ENTRY

6.1. Requirements

The functional requirements can be separated in two typologies: Launch/recovery and cruise.

Cruise requirements are very similar to the windows although, in addition, the entry frame has to pass throw the 620mm diameter hole of the capsule. Moreover, the system has to be designed to endure the toughest conditions and allow easy mounting and dismounting on an emergency situation.

Otherwise, the main complexity of the access and exit point is focused not only on the nominal usage but in the emergency situations. In the normal situation the fixation and sealing during the launch and the capsule opening will be performed by the appropriate company personnel but in an exceptional case the inner crew should be able to open the hatch by its own from the from inside and without outer help. That makes it an additional ravel because the system has to be blocked during the cruise ergo the unlock system shall be shared by the inner and outer side. In the emergency cases it will be analyzed case by case.

6.2. Emergency cases

In emergency situations we shall take into account four variables:

- Independent entry and exit from the inside/outside.
- Quick unlock.
- Crew's health.
- Outer assistance

Conventional lock systems are sealed with screws but the problem is that the study concludes that at least are necessary 18 screws to support the hatch. In an exceptional situation you can take more than 15 seconds per each screw and so let's suppose that we need 4 minutes and 30 seconds to unscrew the hole set. This is completely unacceptable in case of fire or any healthy problem.

Another special case to have into account is that the entry is in the upper zone of the capsule and that means that you need any element such as a ladder to reach it with independence. So it will be special situation to study.

6.3. Constructive design description

The window's design allows that the main frame remains in the inner side of the capsule so that the pressure differential helps and works on the same direction of the sealing. It was possible because the frame was smaller than the entry hole. In this case, the frame has to be outer the capsule because if it is bigger it will not pass through the capsule hole. We will avoid double layering because the hatch has to be a removable part and it could be a problem to remove the set with the argon tube connected or the routing sytem.

The picture bellow represents the proposed option:

Figure 21: Part scheme

It is composed by an outer frame (4) screwed to the capsule structure through inserts (10) specially designed for carbon applications. This frame holds the entry's pressure and avoids the ejection of the subsystem thanks to inserts specially designed for carbon fiber applications.

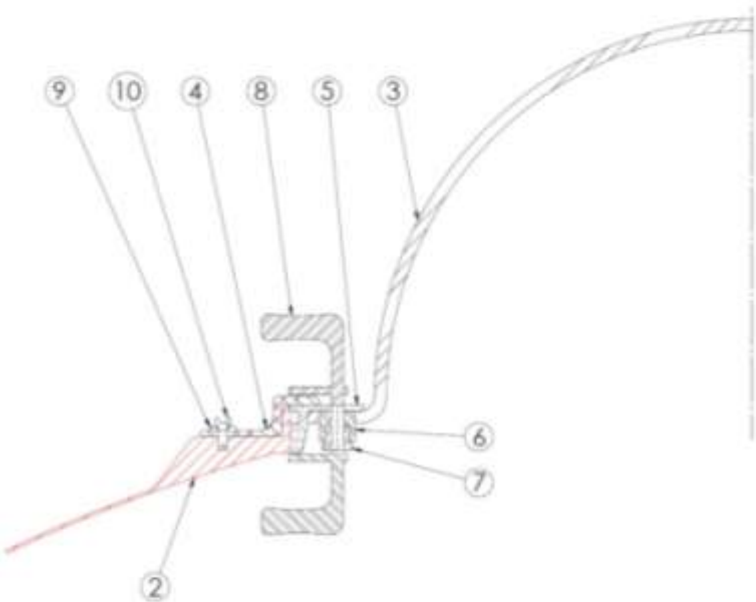


Figure 22: Entry section

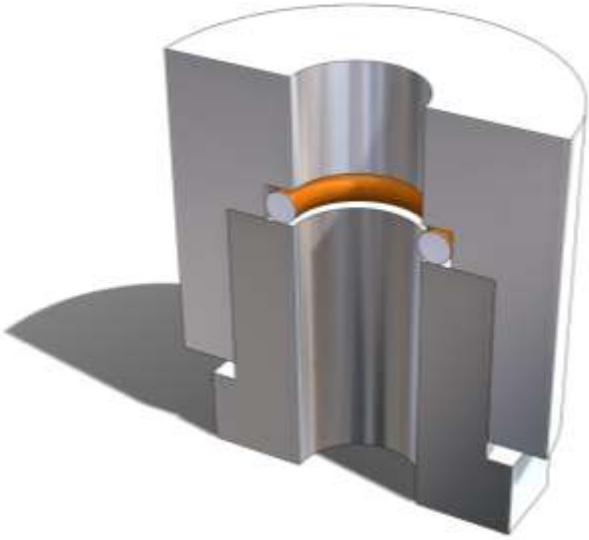
Otherwise, the polycarbonate window (3) and the inner frame (5) are glued by structural adhesive along the contact region between both parts. That makes it an inseparable set that allows to be removed inwards and outwards the capsule.

6.3.1. Entry handle and sealing

Opening is performed by a handle and an axis that pass-through the polycarbonate hatch and the inner frame. Two plates allow to blocks the vertical movement between the handle and the capsule frame so, in that way, the hatch remains in its nominal position.

The handling has been splitted in two parts for constructive reasons. A rivet will perform the binding between both components.

Otherwise, the sealing is done through two threaded inserts that shapes the housing of the joint. It could be designed with only one insert and the internal integrated but it is also hard to mechanize and for that reason it has been detached in two different elements. Moreover, it is easier to collocate it in its working position.



It is important to have into account that when the pressure differential is high no lock system is required due to the projected force around the polycarbonate area but, in the sea level that force doesn't exit so we need a system that locks the handle in its closed position.

The proposed solution is a torsion spring welded between the handle and the inner frame that provides a double redundancy to ensure that the hatch is no affected by any shock or aggressive g-force during launch stage. This system will be added at most 2 handles. Furthermore rotation will be limited by two plates that will prevent from the overdraft.

6.4. Inserts and structural adhesive

The total number of screws/inserts has to be calculated taking into account the pressure differential force. Each insert works with a maximum traction force of 3000 N and with a safety factor of 2.5.

Figure 23: Insert for carbon fiber applications.

The equivalent force is calculated multiplying the projected area of the hatch and the pressure differential.

$$p = \frac{dFa}{dA} \cdot n$$

P=pressure; Fa=Equivalent force; A=area; n = direction vector

Projected area: 264207.942mm ^2 ; Pressure differential: 1 bar

F= 26420N

Total inserts:

$$N = \frac{F}{F_{insert}} * SF = \frac{26420}{3000} \cdot 2 = 17.61 \approx 18\, inserts$$

At least we will need 18 inserts for around the periphery of the outer frame.

6.1. Insulation joints

The windows sealing was made thanks to adhesive along the contact region between the inner frame and the capsule but in this case the frame is not completely inside so the options are: designing a joint outside the capsule or a lateral joint between the inner frame and the capsule's frame. In the first case the problem is that dilatation and the few deformations due to differential pressure could provoke that the separation in the seal housing is enough to break the insulation. The second option allows that even if there are lot of deformations in the vertical direction the seal will stand doing its job.

Silicon (OR FEP+SI) is the chosen material due to its good behavior under extremely cold conditions and its adaptability to different insulation pressures. Its housing is designed under the manufacturer's recommendations. In this case, it is very important to establish a quality control of all the measures according to an h9 for the inner wall of the shaft and H8 for the hole.

During the design process we have to adapt to the capsule geometry and, as a consequence, we need a very specific sealing geometry which is not included in the standard catalogues so we will have to order this item in advance so the manufacturer can produce and provide us before our deadlines.

6.2. Materials Justification

Once more, low weigh is one the main input besides security. In this case for the outer frames we will use aluminum 7075-T6 due to its high yield strength and lightness. This is not weldable aluminum alloy but, in this case, we only need good machinability properties so that unions are performed by adhesives and screws. Results from the simulations shows that the inner frame doesn't suffer in the same way so I chose a cheaper aluminum but with good mechanizing and mechanical properties. The dome is built in polycarbonate due to its visual and mechanical properties

6.3. Entry platform and protocol

The travellers will flight with a spacesuit and that means difficulties to move around. It is important to establish an entry protocol and all the necessary tools to allow entry easily and under secure conditions.

The entry begins in ground when the travellers are aside the capsule. It is required a special platform or a ladder shape in the capsule to reach the upper zone of the capsule so that travelers could step its feet and hold their hands on a special railing. The second option is a smart option but also adds weight to the conjunct so a peripheral structure shall be contemplated. The best option will be a multi-personnel elevator that allows transportation of, at least, 4 people at the same time.

The image above describes an example of an elevating platform

The whole operation is performed by 3 operators that assist the two travelers and prepares all the tools to the launch. The list below describes the operating protocol:

- Three operators get into the elevator while one of them controls it. They will bring with them a ladder to allow travelers go downstairs and ship the pod.
- One of them will open the hatch while the other holds it to prevent it from falling.
- Once the hatch is opened the ladder shall be placed in the floor of the capsule.
- The upper operator will introduce the ladder inside the capsule while the lower one holds it with his hands and blocking it with his feet.
- After the ladder is placed correctly the upper operator will help the traveler in all his movements holding his bag and arm.
- Once the first traveler is inside the capsule the lower operator will help him to seat and fasten the four point seat belt.
- The same sequence is repeated with the second traveler.
- When both travelers are secured to each seat the lower operator will give the hatch to the upper one and will raise the ladder and remove it from the inside.
- Finally the second operator will block the entry and ensure that the hatch and is perfectly sealed.

All the operators shall wear gloves and bracelets, rings or necklaces are forbidden intended to prevent the structure, wires or tubing from damage.

6.4. Dilatations study

During the flight cycle a big temperature gradient is produced and this is an important fact to consider because our sealing joint is placed around the inner frame. In case of the dilatation is big enough to break the contact between the pod's frame and the inner frame a spontaneous decompression would be produced.

These dilatations will affect, as noted ahead, to the insulation joint and the different parts due to their different coefficient of thermal expansion.

For the analysis we will quantify the dilatations that could be produced by applying a temperature differential from 297K to 203K.

The results show that the maximum dilatations between the external-lateral walls of the frame are about 0.63mm.

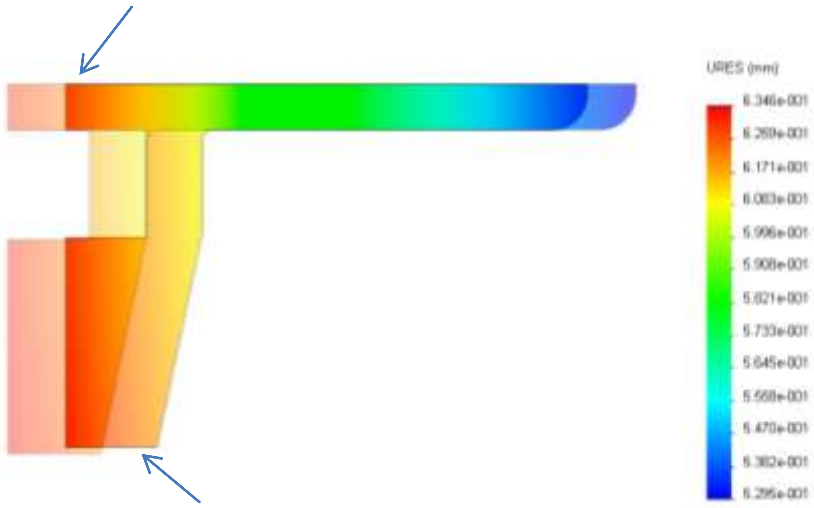


Figure 24: Inner frame dilatation study

This contraction produces a gap enough to compromise the pod's security so we will dimension the joint's housing to provide a pre-compression. The inner area of the pod's frame is built with an aluminum alloy so, as we know, this part will also produce a contraction and as a result the relative cavity between both frames will be less than 0.63mm but, for security reasons, we will give an extra pre-compression to afford that this case is never produced.

Otherwise, the different coefficients of thermal expansion produces dissimilar dilatations that could introduce internal stresses in our model. So it is important to dimension a gap between the inner frame and the polycarbonate window (see image below/red arrow) so that can absorb a possible contact between both parts.

Furthermore, the upper wall will be assembled with a silicon based adhesive (see image below/green arrow) which elongation at break (503%) can afford the shear stress.

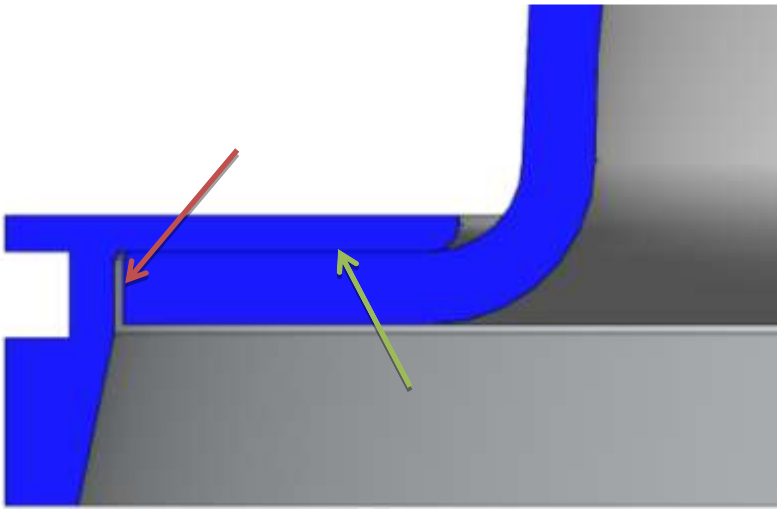


Figure 25: inner frame/polycarbonate hatch scheme

This study has given us an idea about the dilatations that could be produced but it is important to note that the best way to verify its behavior is performing a real conditions test.

See the annex for more info about the study.

CHAPTER 7:

WINDOWS AND ENTRY TESTING

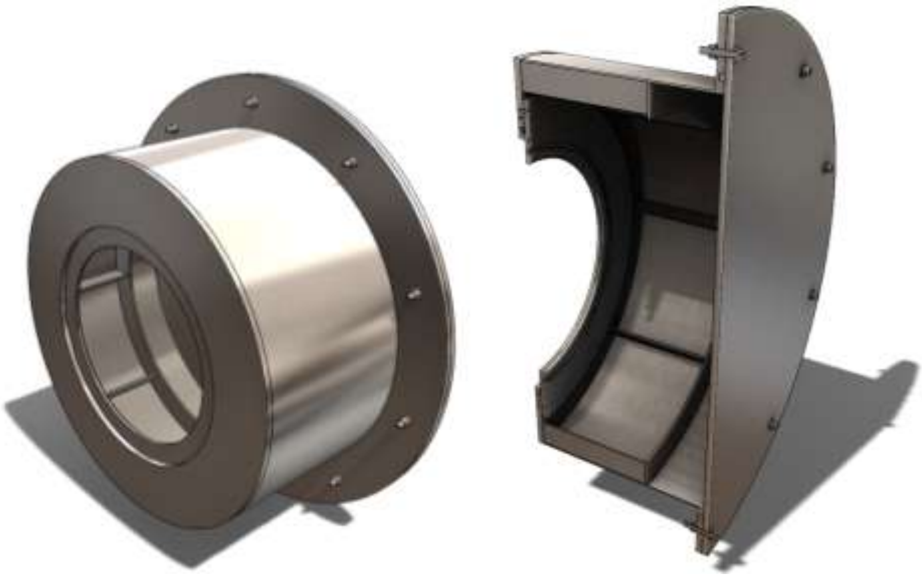
Minibloon's testing will pass through different stages. The first one will be a test of each window and entry with a water pressure boil as explained bellow. The second one will be flooding the whole capsule underwater and applying pressure from the inside. The third one will be introducing the capsule in a void and cold chamber to analyze the behavior and reaction of the different elements under almost real conditions and cyclic loads.

If the capsule passes the entire test adequately the last test will be performed in real space condition operating a non-manned flight.

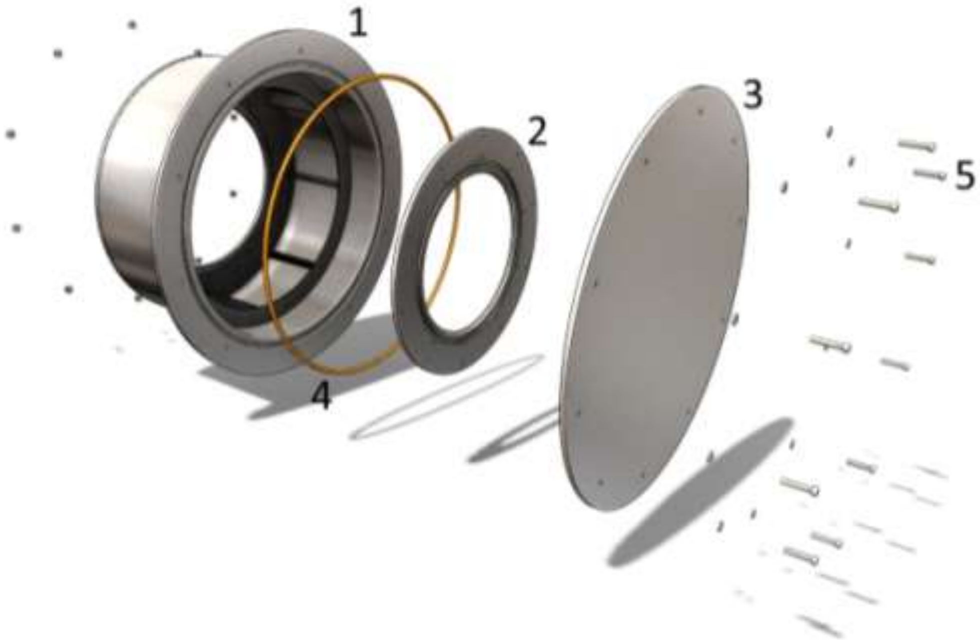
Our goal is to address the first test and verify independently each window to ensure that the polycarbonate thickness reacts properly to the pressure conditions.

7.1. Testing structure

For that test we will resort to a structure that allows testing three different windows leveraging its geometry. Pressure testing can become dangerous if we inject air under 1 differential bar so, Instead of that, we will use water as it is not a compressible fluid and in case of breach it won't explode. In real conditions the capsule will be under 0.8 bar pressure and outside nearly 0 but in our case we will suppose a 1 bar pressure differential in order to increase the security factor of the test.



In order to reduce costs we will build a single support to perform three tests. This structure is composed by five different parts: (1) The main body, (2) a removable adaptor, (3) the back cover, (4) a silicone joint and (5) screws. The images bellow resumes how are assembled these different parts.



The rear part of the main body wears a silicon joint that works with the back cover to isolate water from the outside.

The following table resumes the amount of water that we will need to perform the test:

Window	Water volume [liters]
Average size	101
Small size	90.7
Entry	58.9

Table 7: Testing water volume

Following we will explain how is accommodated the different tests and the different details of the structure.

7.1.1. Average size window test

To perform the average windows test we will only need to use the main body, the back cover and the window polycarbonate window.

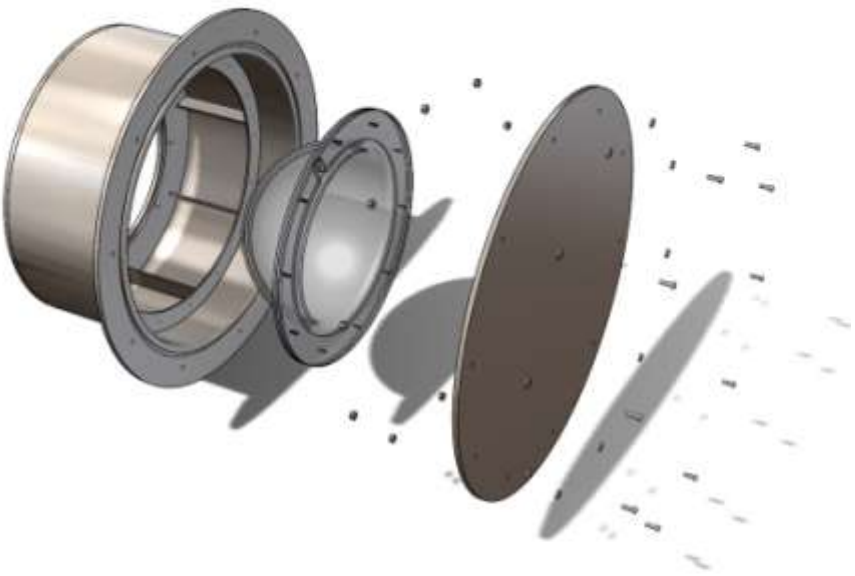


Figure 26: Average window mounting

When the polycarbonate dome is introduced into the main body the flat surface is sealed by a silicone joint that seals the test from the outside. This contact region reproduces the union between the window aluminium frame and the polycarbonate dome. The seal housing is dimensioned with the same size and sealing housing. To fix the polycarbonate we will also reproduce the same screws into the main body with no trespassing holes.

In this test we will also reproduce a breakage situation of the internal and external layer by plugging a screw in the mid layer intake. So if we cover the intake we will be assuming that the inner layer is holding the 1 bar pressure differential and if we open that intake the outer layer will be holding the entire pressure. This allows validating not only the whole polycarbonate assembly but each part individually.

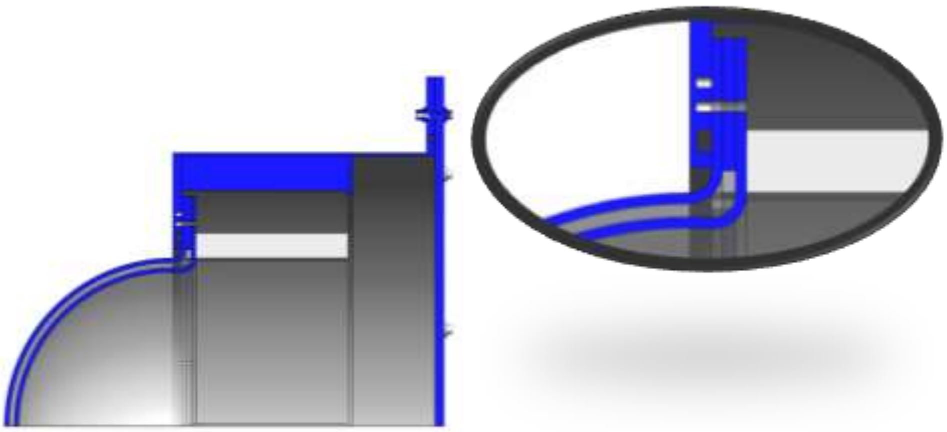


Figure 27: Average window test section

7.1.2. Small window test

The small window requires the intervention of the removable adaptor in order to allow a correct contact between the polycarbonate and the steel. In this case we need to keep the sealing between the adaptor and the main body through the silicon joint (see image bellow) used to insulate the window explained above.

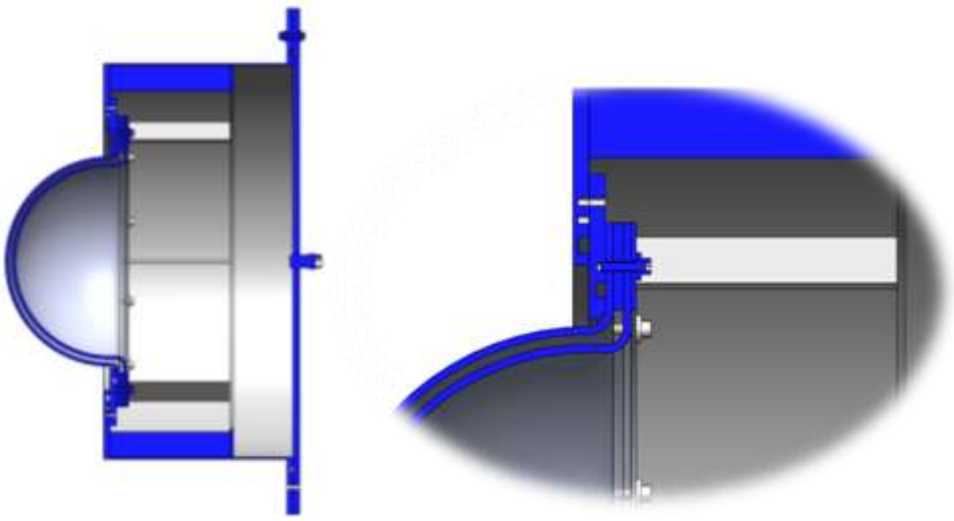


Figure 28: Small window mounting

The rest of the test is performed in the same way; Blocking or not the argon intake with the aim of testing both windows separately and consequently testing both windows on a failure situation.

7.1.3. Entry test

The entry sealing is made thanks to the lateral silicon joint so we need to afford that the contact surface has a good circular shape because if not a pressure loss will appear. Otherwise, we will fix the polycarbonate dome with a flat surface (enseñar) with the aim of prevent moving through the boil main body.

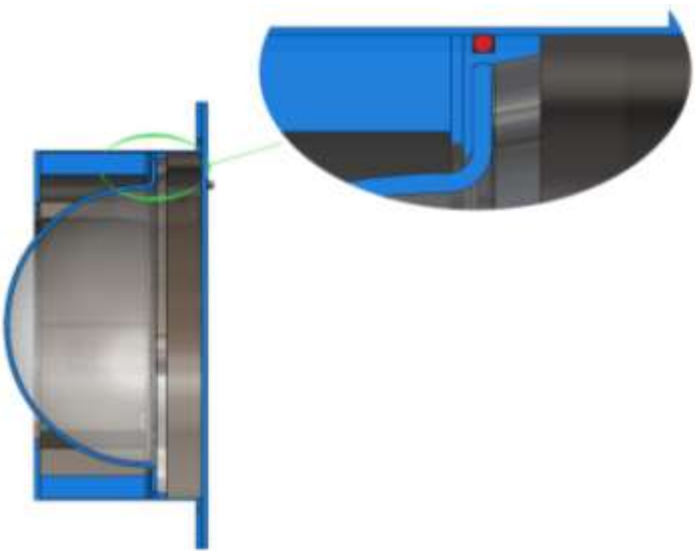


Figure 29: Joint detail

Pressure differential will cause a severe force against the flat surface (Red) and it is important to reinforce (Blue) the boil in order to prevent from significant deformations. The detailed image shows special drills designed to avoid that the frame plays the role of sealing element and mislead if the joint is working properly

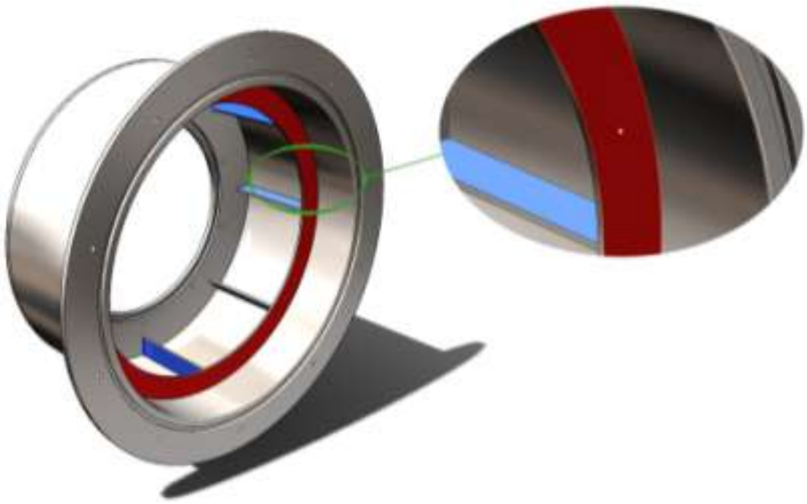


Figure 30: Main body parts

7.2. Hydraulic elements

Water introduction will be performed through a hydraulic racor in the rear side of the back cover with the aim of introducing water without any pressure loss. Next to the racor we will insert a non-return unit and a manometer to control the introduced water pressure inside the water boil. Water pressure generated by a hydraulic pump connected to an accumulator.

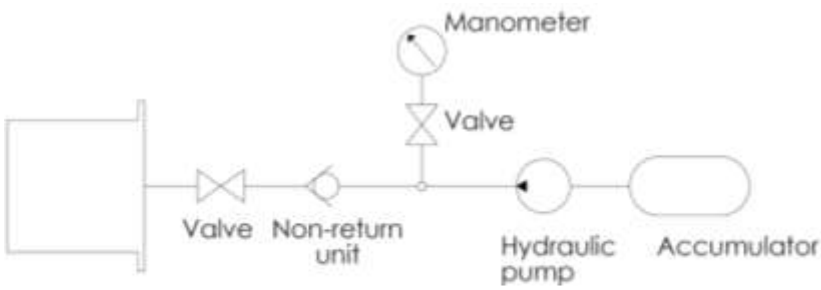


Figure 31: Hydraulic scheme

7.3. Insulation joints

The joints housing will be designed according to manufacturer's recommendations simulating the same position than in the real frame.

CHAPTER 8: ARGON SYSTEM DESIGN

8.1. Introduction

The argon system pretends to reduce the pressures that stands each layer of the windows and eliminates any fogging and condensation effect. Besides that, it provides ultraviolet protection for the inner crew.

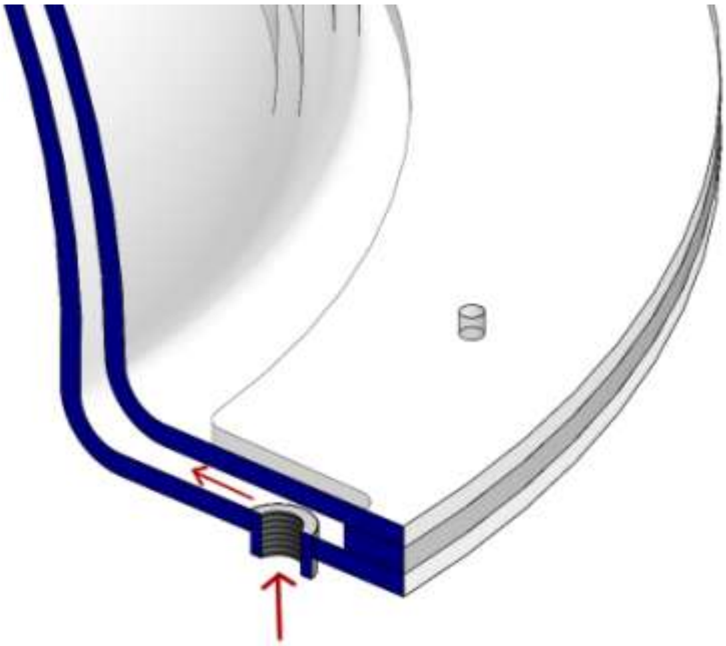


Figure 32: Argon intake

As the capsule rises the internal layer has to vary its pressure according to the pressure differential between the inside and the outside the capsule. This pressure differential will be controlled by an electro valve which according to different sensors will introduce the proper quantity of argon.

8.2. Preliminary aspects

The following table shows the pressure state the two most critical situations during the flight:

	Sea Level		Maximum altitude	
	Absolute Pressure	Relative Pressure	Absolute Pressure	Relative Pressure
Atmospheric pressure	1 bar	0 bar	0 bar	-1 bar
minibloon internal pressure	1 bar	0 bar	1 bar	0 bar
Windows internal layer	1 bar	0 bar	0.5 bar	-0.5 bar
Argon tank	12 bar	11 bar	-	-

Table 8: Pressure values for several minibloon items

Although minibloon internal pressure remains constant all along the flight, the atmospheric pressure decreases as the altitude increases. Hence, window internal layer pressure must be properly controlled in order to equally distribute the window stress due to the pressure differential:

$$window\ internal\ layer\ pressure = \frac{atmospheric\ pressure + minibloon\ internal\ pressure}{2}$$

The window internal layer control is carried out by a vacuum proportional valve which provides pressurized argon gas into windows internal layer. The main goal of using argon is to ensure non-tarnished windows all along the trip.

8.3. Flight cycle pressure and temperature variation

The flight cycle pressure will be modelled according to the ISA (International Standard Atmosphere) formulation. This model is separated into three part sections from 0 to 11000m, from 11000m to 20000, from 20000 to 32000 and from 32000 to 47000.

$$P = Po \cdot (1 - \frac{b \cdot h}{a})^{g \cdot po \cdot \frac{To}{Po \cdot b}}$$

Where:

T0 =Temperature at 0 m (288.15°K) ; T0=Temperature at 0 m (288.15°K) ;
T11=Temperature at 11000 m ; T20= Temperature at 20000 m ; T32=Temperature at 32000 m ;

A=Temperature at sea level

B=Temperature decrease per m altitude:

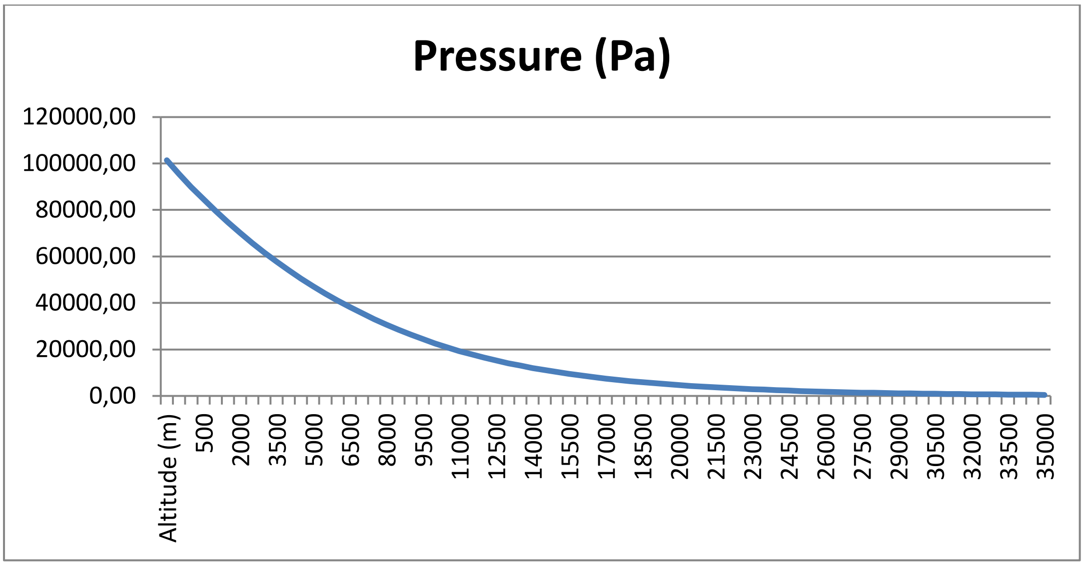
0 - 11000m -0.0065°K/m

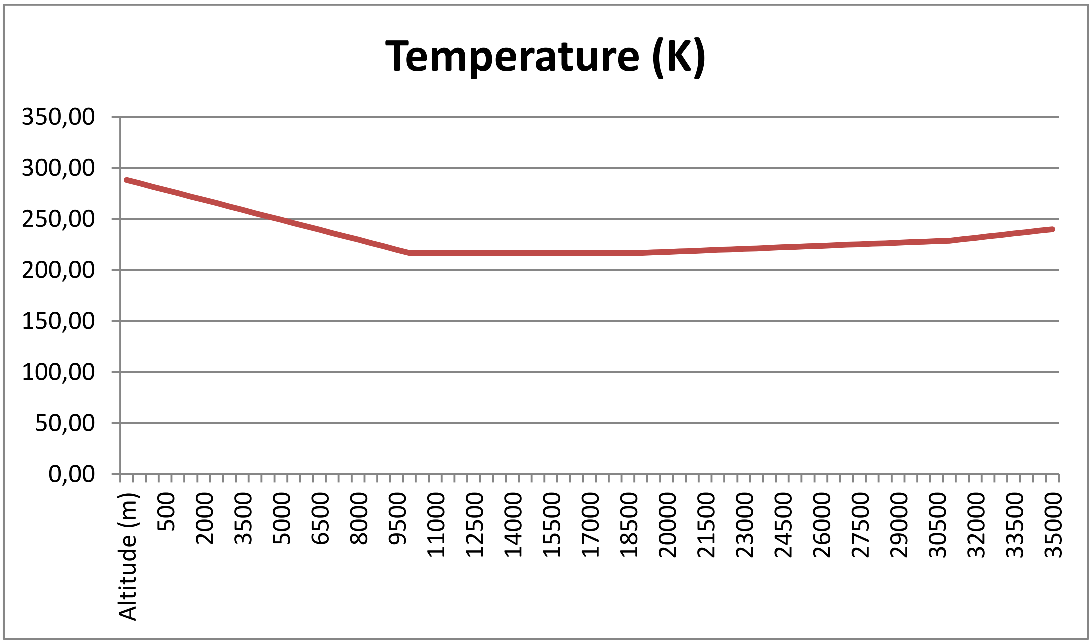
11000 - 20000m Stable

20000 - 32000m +0.001°K/m

32000 - 47000m +0.0028°K/m

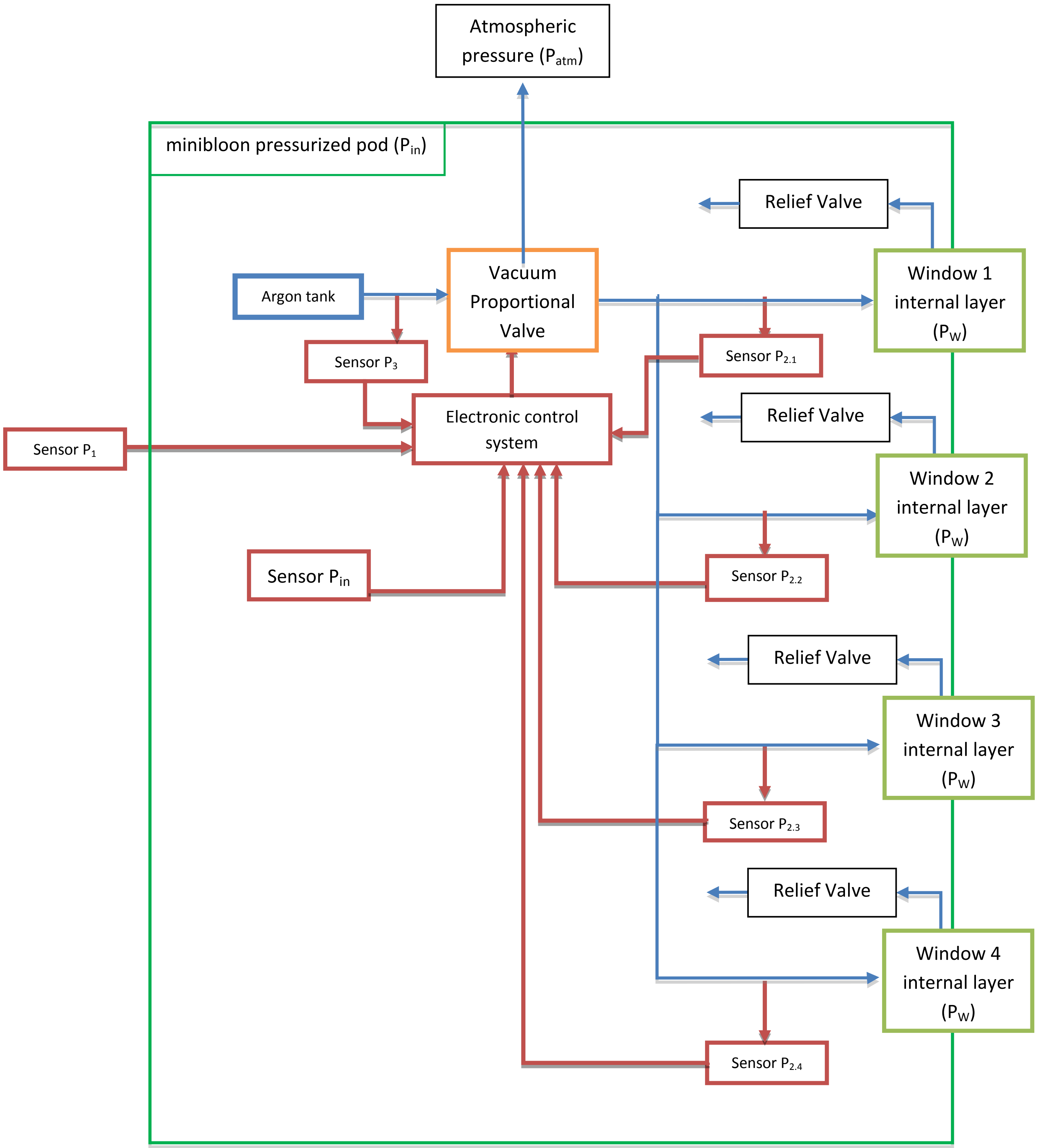
G=9.80665 m/s² ; rho0=Air density at 0 m (1.225 kg/m3) ; P0=Pressure at 0 m (1013.25 hPa)





8.4. Pressurization system layout

The following scheme resumes de different active and passive parts of the system.


Atmospheric pressure (P_{atm})
minibloon pressurized pod (P_{in})
Relief Valve
Argon tank
Vacuum Proportional Valve
Window 1 internal layer (P_W)
Sensor P_3
Sensor $P_{2.1}$
Electronic control system
Sensor P_1
Relief Valve
Window 2 internal layer (P_W)
Sensor P_{in}
Sensor $P_{2.2}$
Relief Valve
Window 3 internal layer (P_W)
Sensor $P_{2.3}$
Relief Valve
Window 4 internal layer (P_W)
Sensor $P_{2.4}$

The whole system is controlled by only one proportional vacuum valve because variations in each internal window layer are produced with similar pressure values. The electronic system control the vacuum proportional valve and acquires data from 7 sensors distributed in each window, at the exit of the argon tank and inside/outside the capsule. Those sensors will be used to analyze if the whole system is running in a normal situation or if an anomalous behavior has appeared.

8.5. Argon volume calculation

The available argon volume is supplied by:

Linde MINICAN® Argon 5.0 - 12 Liter

The total available argon volume depends on the number of argon tanks.

Figure 33: minibloon window distribution

Item		Description/Notes	Volume (L)
Window nº:	1	Volume taken from window design	1.2011
	2		1.2011
	3		1.2011
	4		1.5840
Tubing and pneumatic devices		1.5 security factor applied on windows volume	2.5937
Total Volume Estimated			7.7810

Table 9: minibloon's items volume calculations

8.6. Vacuum Proportional Pressure Control Valve

The main goal of the Vacuum Proportional Valve is to keep the pressure equally distributed between the internal capsule pressure, the windows internal layer and the atmospheric pressure. The windows internal layer pressure is reached thanks to a pressurized argon gas tank. Although the argon gas tank pressure is much higher than the pressure needed for the windows internal layer, the proportional valve's mission is to keep the pressure under control.

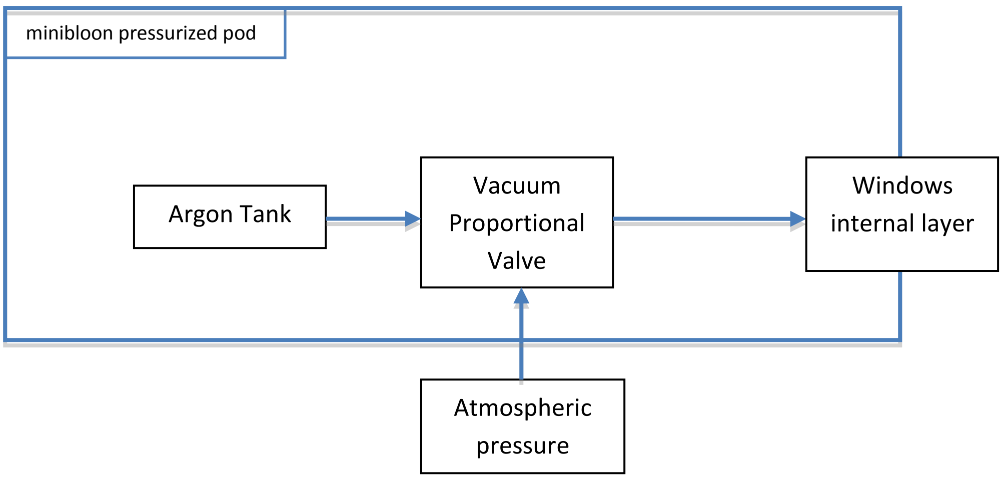


Figure 34 : Windows pressurization system layout

8.7. Relief valve

Windows internal layer are connected to an argon tank through a proportional valve. Since a valve malfunction shall be considered, a relief valve is needed for windows internal layer overpressure. The reason is that argon tank pressure is much higher than atmospheric pressure at sea level, what could overcome the window's maximum allowable pressure differential.

Each polycarbonate window layer has been designed to endure a pressure differential of 1 bar. Hence, the maximum internal layer pressure ought to be 1 bar even if minibloon is on sea level or at its maximum altitude.

Two relief valve configurations are possible:

a) Between windows internal layer and minibloon pressurized capsule

Firstly, windows internal layer pressure (varies with altitude) is connected with minibloon internal pressure (what remains constant). If an overpressure happened the valve would release the extra **argon inside the minibloon pod**. Hence, the **oxygen percentage would decrease**.

minibloon internal pressure is meant to be slightly below 1 bar. Given that, both minibloon internal pressure and window internal layer maximum pressure are close to 1 bar, the **relief valve should be calibrated to a pressure differential near to 0,1 bar**. Now the air relief condition is:

$$P_W - P_{in} < 0.1\ bar \rightarrow valve\ Closed$$
$$P_W - P_{in} > 0.1\ bar \rightarrow valve\ Opened$$

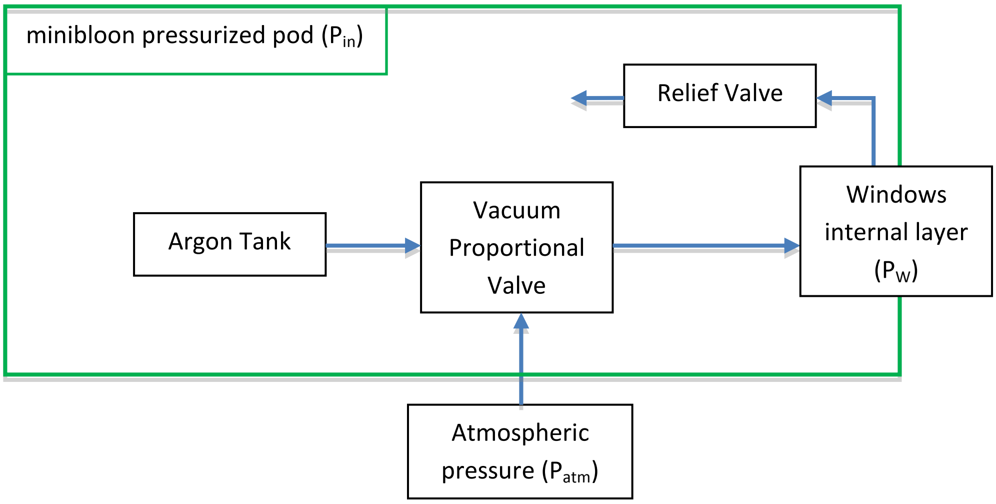


Figure 35: Relief valve diagram; configuration a)

Altitude (m)	minibloon internal pressure (P_{in}, bar)	Windows internal layer pressure (P_W, bar)	Atmospheric pressure (P_{atm}, bar)	$P_W - P_{in}$	Relief valve
0	1	1	1	0	Closed
5,000	1	0.7701	0.5402	-0.2299	Closed
11,500	1	0.60455	0.2091	-0.39545	Closed
30,000	1	0.50585	0.0117	-0.49415	Closed
In case of proportional valve malfunction:					
0	1	1.1	1	0.1	Opened
30,000	1	1.1	0.117	0.1	Opened

Table 10. Relief valve operation in configuration a), for several scenarios.

b) Between windows internal layer and atmosphere

Secondly, the relief valve can connect windows internal layer to atmospheric pressure instead of minibloon internal pressure. Now, both windows internal layer pressure and atmospheric pressure varies with altitude.

The relief valve will be calibrated at 0.5 bar instead of 0.1 bar. Then the air relief condition is:

$$P_W - P_{atm} < 0.5\ bar \rightarrow valve\ Closed$$
$$P_W - P_{atm} > 0.5\ bar \rightarrow valve\ Opened$$

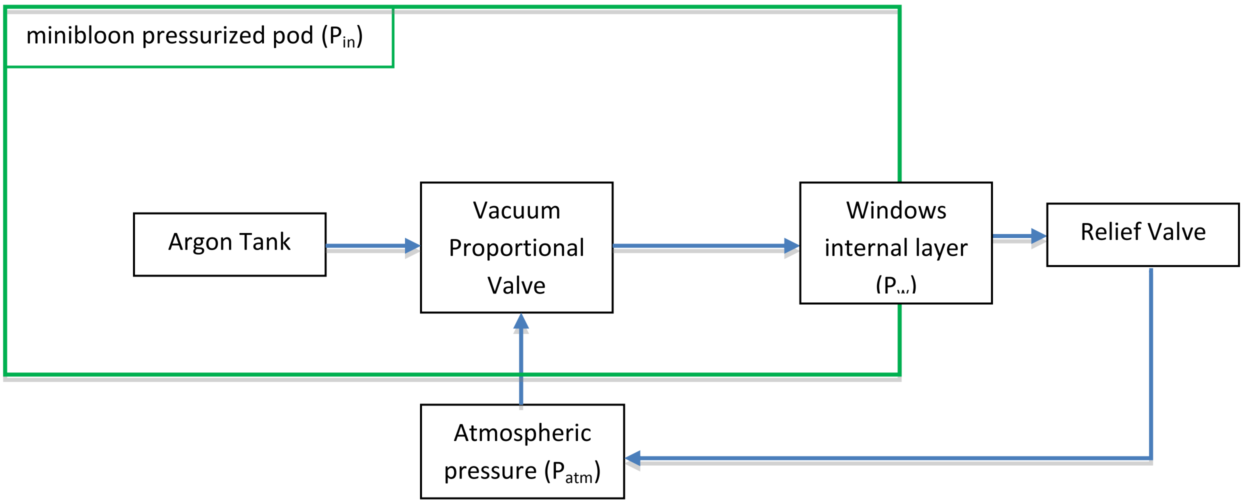


Figure 36: Relief valve diagram; configuration b)

Several stages have been worked out to check whether the relief valve would work properly:

Altitude (m)	minibloon internal pressure (bar)	Windows internal layer pressure (P_W, bar)	Atmospheric pressure (P_{atm}, bar)	$P_W - P_{atm}$	Relief valve
0	1	1	1	0	Closed
5,000	1	0.7701	0.5402	0.2299	Closed
11,500	1	0.60455	0.2091	0.39634	Closed
30,000	1	0.50585	0.0117	0.49415	Closed
In case of proportional valve malfunction:					
0	1	1.5	1	0.5	Opened
30,000	1	0.617	0.117	0.5	Opened

Table 11. Relief valve operation in configuration b), for several scenarios.

In spite of the apparently viability of this configuration, relief valve performance in vacuum conditions is not as good as expected (Valve tested: NORGREN V07-100-NNLG).

As far as relief valve models are concerned, two possible NORGREN relief valve models have been considered:

Figure 37: Relief valve models: NORGREN V07-100-NNLG (left) and NORGREN 1002/BM000 (right)

On the one hand, the NORGREN V07-100-NNLG relief valve allows a pressure differential range from 0.3 to 9 bar. Its configuration enables the user to adjust comfortably the relief pressure value, and both input and output can be ducted as showed in the figure. However, its lowest sensitivity (0.3 bar pressure differential) is still too high, what makes it available not for the first relief valve configuration (Figure 35) but for the second one (Figure 36).

On the other hand, the NORGREN 1002/BM000 relief valve presents a narrower pressure range (from 0 to 1.6 bar), also adjustable. Accordingly, this valve is adequate for being used in configuration "a)" (Figure 35). Moreover, 1002 model not only is lighter and smaller than V07 but also manually operable. However, the outlet cannot be ducted.

Finally, notice that minibloon pod shall be provided with a relief valve as well, due to not only argon tanks but oxygen pressured tanks.

If an internal window break down occurs, the vacuum proportional valve would detect an outlet (2) pressure equal to its surrounding pressure (1 bar, internal minibloon pressure). Therefore, the valve would keep on releasing the supposed extra argon. However, minibloon internal air would be released too and the internal pressure would decrease until it reached 0.5 bar.

CHAPTER 9:

FAILURE SITUATIONS

In the scope of this project we won't study the electronic system that controls the vacuum differential valve, but, in the other hand, we will focus our study on how the pressures vary depending on the height in each failure situation. This information will be used by the electronics engineer to configure our system.

9.1. Behavior conditions

In order to understand how the system should behave we will plan conditional premises that will help us to recognize what elements are failing on an anomalous situation.

We can separate our condition into two typologies: static pressure values and variation gradients.

		Nominal Condition	Conclusion if not accomplished	Situation
Pressure values	Invariant conditions	$P_1 \geq 0.001\ bar = 1\ mbar$	The pressure sensor is broken	1
		$P_3 \leq 12\ bar$	The pressure sensor is broken	2
		$P_3 \geq 7\ bar$	Outer window loss	3
	Normal performance	$P_2 = \frac{1}{2}(P_1 + P_{in})$	Anomaly to be analysed	4
		$P_{in} = 1\ bar$	Anomaly to be analysed	5
Pressure gradient	Ascending	$\Delta P_2 = \frac{1}{2}\Delta P_1 < 0$	Anomaly to be analysed	6
		$\Delta P_3 = 0$	Anomaly to be analysed	7
	Descending	$\Delta P_2 = \frac{1}{2}\Delta P_3 > 0$	Anomaly to be analysed	8
		$\Delta P_1 > 0$	Pressure sensor is broken	9
	Cruise	$\Delta P_2 = 0$	Pressure loss	10

In the following points we will explain the different failures situations:

9.1.1. Nominal conditions

1. The first situation responds to a sensor anomaly so that we won't arrive to such a low pressure. At 36000m we are around 400 Pa, 4 times more pressure that the minimum admitted.
2. The second case represents that the pressure measured at the end of the bottle has to be less than 12 bar. In case of default we are assuming that the pressure increases as the altitude rises.

3. We have calculated the lower pressure value for one argon bottle and conclusions shows that we will descent around 10 bar. In order to give to the system a margin we will allow 7 bar as a minimum limit.
4. In this case we are controlling that the pressure differential is accomplished between the internal and external pressure.
5. In point number 5 we are just controlling that there is no anomaly with the ECLSS and the inner pressure is in a normal range. The maximum and the minimum normal values will be defined according to the Environmental Control and Life Support System.

The next cases respond to dynamic pressure variations. These situations are useful to detect pressure loss in each system and to afford that everything is running well during the ascending and descending.

Ascent:

6. The following graph resumes how the pressure varies according to altitude

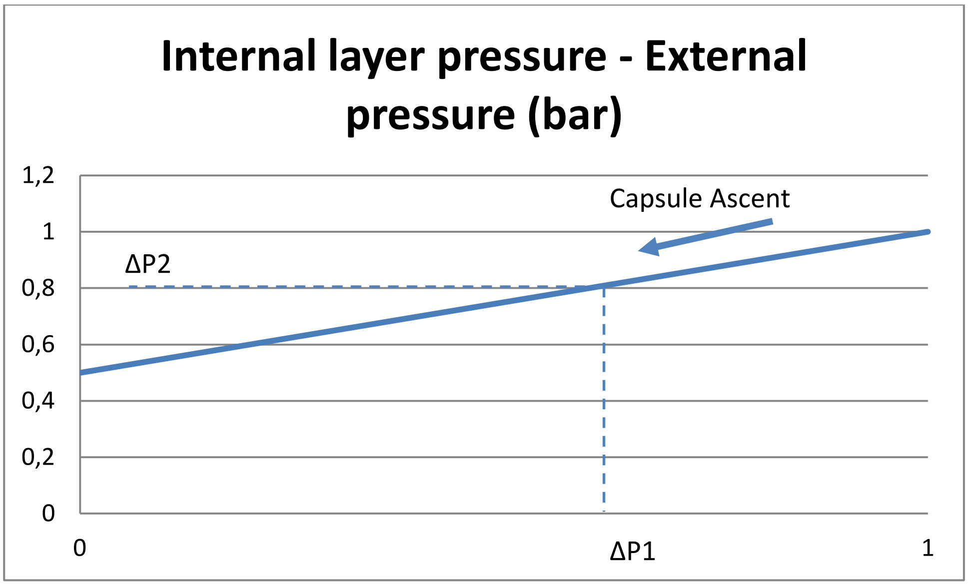
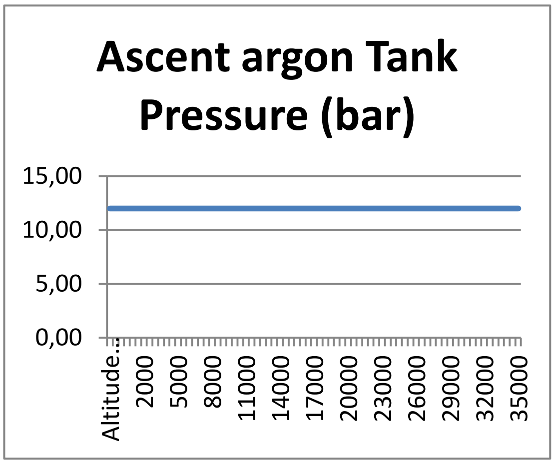
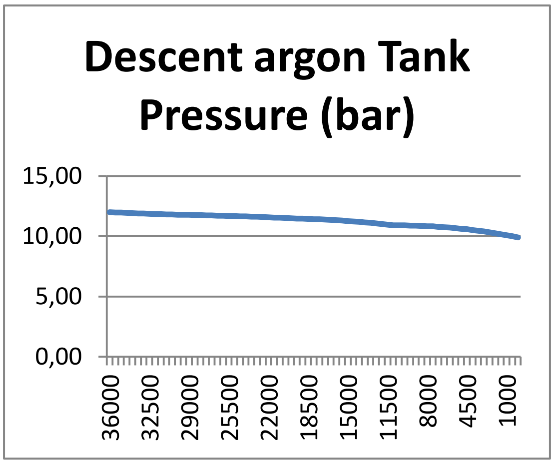


Tabla 1: pressure gradients for window internal layer and external pressure

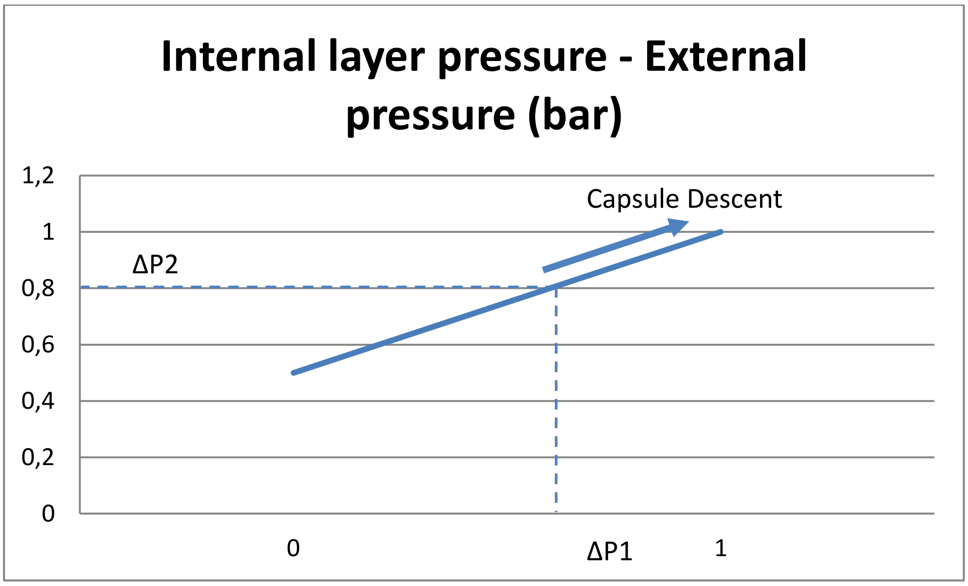
7. As the capsule ascent the inner pressure layer has to lower through time so we assume that the bottles won't contribute with argon pressure and as a result the bottles pressure shouldn't descent.
   The following graphs resume how the bottles pressure should behave during the ascent and the descent:





Descent:

8. Idem case 6 but in a descent mode.



9. In this case we will need to raise the internal layer pressure so we need to inject argon pressure. If the pressure remains on the same value it means that no pressure is being introduced inside the internal layer.
10. During the cruise period there is an altitude fluctuation and that could cause that the vacuum differential valve is working frequently so it is important to establish a limit in order to avoid wasting unnecessary argon mass. If big pressure variations appear during the cruise means that there are many pressure leaks so we have to inject argon depending on the leak size.

The following points resume each possible emergency situation

9.2. External window breakage

An external window breakage shall be considered. In this case, the proportional valve outlet pressure would decrease as well as in every window internal layer since they are connected. Consequently, the proportional valve would consider a too-low outlet pressure allowing an argon flow in order to increase the outlet pressure. Hence, the argon tank would finally remain empty due to the argon flow leakage outside the capsule.

One of the solutions consists on isolating the broken window, stopping the argon tank leakage and allowing the proportional valve pressure to take over control of the remaining windows.

9.3. Internal window breakage

If an internal window break down occurs, the vacuum proportional valve would detect an outlet (2) pressure equal to its surrounding pressure (1 bar, internal minibloon pressure). Therefore, the valve would keep on releasing the supposed extra argon. However, minibloon internal air would be released too and the internal pressure would decrease until it reached 0.5 bar.

9.4. Entry break or capsule depressurisation

Depressurisation could be produced many individual components or by the failure of several elements as we are working with other active systems such as the environmental control and life support system.

The elements that could produce a depressurisation are: Entry break (one polycarbonate dome), relief valve malfunction, differential valve control malfunction.

9.5. Air filter

An air filter is needed in-between en argon tank and the proportional valve for the purpose of keeping the valve free of solid particulates, residual oil, etc.

Figure 38: System air filter

9.6. Pressure loss

Several malfunctions or inevitable pressure loss shall be taken into account. The system design must be strong enough to face all the problems that could be originated.

9.7. Tubing longitude

The very first inevitable pressure loss is due to the tubing longitude.

The solution comes from reducing as much as possible the distance between pneumatic devices.

9.8. Pressure loss at the joints or pneumatic connections

Pneumatic connections and joints are likely the origin of pressure loss. Windows internal layer connection is one of the most critical joint.

Push-in connectors with additional mechanical retainer shall be used instead of quick push-in fittings, with the purpose of improving the pneumatic connection reliability.

9.9. Argon tank leakage

An argon tank leakage shall be considered. In consequence, more than one tank may be installed to avoid an emptying of one of the tanks. A minibloon internal pressure increase would occur, reducing the oxygen percentage as well. As the following calculations show, the pressure variations are negligible.

Argon tank leakage inside minibloon's capsule	
Capsule spherical volume	6.81 m^3
Capsule volume security margin (free-space percentage of the whole volume)	30%
Free-space volume considered	2.04 m^3
Released argon volume @ 1bar	0.024 m^3
Capsule initial pressure	1 bar
Capsule pressure after Argon leakage	1.0118 bar
Pressure increase	**1.18 %**

Table 12 - Argon tank leakage inside minibloon's capsule

An auxiliary argon tank shall be considered in case of an argon tank leakage occurs.

9.10. Proportional valve malfunction

As explained before, the relief valve must allow a maximum pressure differential of 1 bar if a proportional valve malfunction happened. The windows internal layer should never reach the argon tank pressure; otherwise the windows would not be able to resist such a pressure differential.

9.11. Pressure variation resuming table

The following tables resume the different pressures in each volume according to diverse failure or malfunction situations.

Sea level:

Situation	Altitude [m]	External pressure [Pa]	Inner pressure [Pa]	Gap windows Pressure [Pa]		
				W1	W2	W3
Nominal situation	0	101325	101325	101325	101325	101325
Inner window breakage	0	101325	101325	101325	101325	101325
Outer window breakage	0	101325	101325	101325	101325	101325
Entry breakage / Capsule despressurization	0	101325	101325	101325	101325	101325
Diferential valve malfunction	0	101325	101325	101325	101325	101325

Maximum height:

Situation	Altitude [m]	External pressure [Pa]	Inner pressure [Pa]	Gap windows Pressure [Pa]		
				W1	W2	W3
Nominal situation	36000	484,3	101325	50904,65	50904,65	50904,65
Inner window breakage	36000	484,3	101325	101325	101325	101325
Outer window breakage	36000	484,3	101325	484,3	484,3	484,3
Entry breakage / Capsule despressurization	36000	484,3	484,3	484,3	484,3	484,3
Diferential valve malfunction	36000	484,3	101325	from 0 to 101325	from 0 to 101325	from 0 to 101325

CHAPTER 10:
VALVE TESTING

10.CHAPTER 10: Valve testing

10.1. Introduction and objective of the test

Minibloon windows have been designed as two polycarbonate layers, separated by a pressurized volume. Since the most adequate stress distribution is an equitable division between both window parts, the internal volume pressure must be controlled. Hence, a proportional valve is needed to ensure the internal pressure is exactly the average value between both internal and external pressure of the minibloon capsule.

The test is meant to make sure the proportional valve Norgren VP5002BJ111HV1 is working properly.

Figure 39: Image of the test layout

10.2. Material used

- Proportional Valve Norgren VP5002BJ111HV1
- Vacuum pump
- #2 pressure tanks
- Ø4 mm & Ø10 mm Tubing
- #2 Vacuum gauges
- #1 Pressure gauge
- Air compressor
- DC power supply

10.3. Pneumatic connections

The diagram below shows how the test connections were carried out:

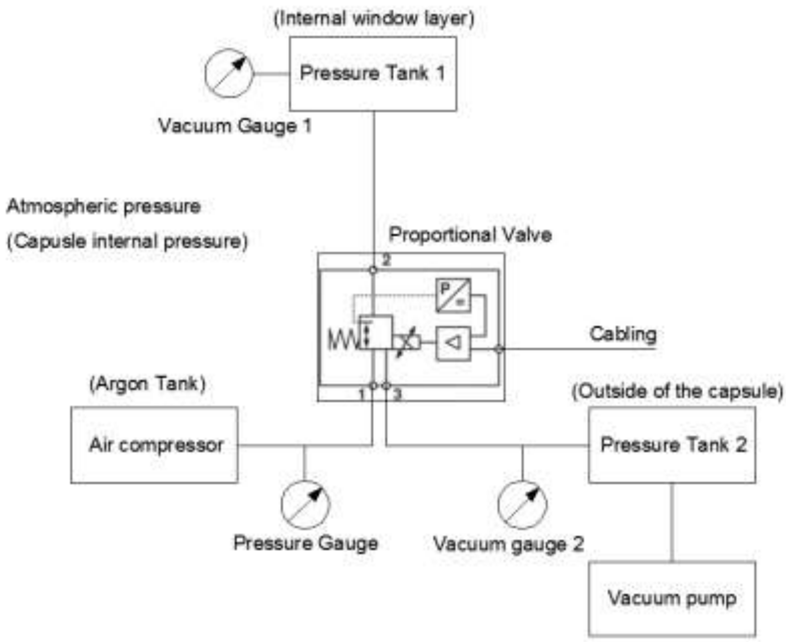


Figure 40: Pneumatic connections layout

The table below shows what all this elements makes reference to in the minibloon pod. Moreover, it shows the pressure value each element is supposed to be submitted.

Item	minibloon item equivalence	Relative Pressure (bar)	Absolute Pressure (bar)
Pressure Tank 1	Internal window layer	-0.5	0.5
Vacuum pump + Pressure Tank 2	minibloon exterior pressure	-1	0
Air compressor	Argon tank	3	4
Atmospheric pressure	minibloon internal pressure	0	1

Table 13: minibloon item equivalence and pressure values

10.4. Electrical connections

As far as the electrical connections are concerned, the proportional valve must be wired as follows:

Pin	Designation	Wire Colour
1	+24 V d.c. supply	Brown
2	0 ... 10 V feedback	White
3	Control signal (+VE)	Blue
4	Common (supply signal and feedback return)	Black
5	Chassis	Grey

Table 14: Proportional valve electrical connections description

The proportional valve provides, in function of the input signal (0 – 10V), an output pressure from -1 to 1 bar (relative pressure). In consequence, we are in need of an **input signal of 2.5 V** to reach an absolute output pressure of 0.5 bar (-0.5 bar relative pressure).

10.5. Future tests and requirements

- **Pressure Relief Valve**
  A pressure relief valve is needed to avoid window internal layer overpressure.

- **Air filter**
  Since dust particles could damage the proportional valve, a filter before the air comes in the valve shall be taken into account.

- **DC/DC system**
  Once the pressure system is suited on the minibloon pod, an adequate power supply system shall be designed.

10.6. Conclusions and results

The proportional valve works properly and as expected.

The following pressure values were observed in each gauge:

Pressure Gauge	Relative Pressure (bar)	Absolute Pressure (bar)
Pressure gauge	3	4
Vacuum gauge 1	-0.5	0.5
Vacuum gauge 2	-1	0

Table 15: Pressure values observed during the test

CHAPTER 11:
MASS BUDGET

The following tables resume the mass budget configured by elements inside and outside the capsule. In conclusion, the sum of all the windows, entry and argon system will be around 38,4Kg.

Total inner weight	38498	[g]
Window 1	6478	[g]
Window 2	6478	[g]
Window 3	7331	[g]
Window 4	6478	[g]
Entry	10006	[g]
Argon system	11776	[g]
Boil test	92958	[g]

Table 16: General mass budget

Detailed table:

Assembly	Part code	Description	Quantity	Weight/unit [g]	Total weight [g]
0002-E-0002	-	Little window	3	6478	19434
	0002-P-0004	Inner frame	1	1761	1761
	0002-P-0020	Outer window	1	1544	1544
	0002-P-0007	Inner window	1	1502	1502
	0002-P-0006	protection plate	1		0
	0002-P-0020	spacer	1	1544	1544
	0002-P-0077	Argon insert	1	7	7
	-	Screws	20	6	120
0002-E-0004	-	Entry	1	10006	10006
	0002-P-0016	Entry dome	1	4530	4530
	0002-P-0015	Outer frame	1	2204	2204
	0002-P-0060	Upper handle	4	57	228
	0002-P-0059	Lower handle	4	63	252
	0002-P-0057	Sealing insert	4	57	228
	0002-P-0056	Joint housing	4	57	228
	0002-P-0083	Joint	1	57	57
	0002-P-0017	Inner frame	1	2279	2279
0002-E-0006	-	Average window	1	7331	7331
	0002-P-0038	Inner frame	1	2556	2556
	0002-P-0041	Outer window	1	1728	1728
	0002-P-0040	Inner window	1	1706	1706
	0002-P-0043	spacer	1	420	420
	0002-P-0046	Joint	1	59	59
	0002-P-0044	protection plate	1	742	742
	-	Screws	20	6	120
Argon System			-		1446
	0002-P-0081	Differential valve	1	609	609
	-	Air tubes	1	300	300
	-	Overpressure valve	4	108	432
	-	Adaptor racor	5	21	105
	-	Electronics+sensors	1	2708	2708
		filter	1	280	280
Test boil	-	-	-	-	92958
	0002-P-0049	Main boil body	1	45327	45327
	0002-P-0050	Removable insert	1	8759	8759
	0002-P-0053	Back cover	1	38472	38472
	-	Screwery	1	400	400

Table 17: Detailed mass budget

CHAPTER 12:
BUDGET

The following table resumes real budgets provided by the listed above manufacturers for each element:

Total budget	8947,9	€
Window 1	1122,73	€
Window 2	1122,73	€
Window 3	1463,57	€
Window 4	1122,73	€
Entry	1949,86	€
Argon system	1595	€
Boil test	571,27	€

Table 18: Budget resume

Detailed budget:

Assembly	Part code	Description	Price/unit [€]	Quantity	Final price [€]
0002-E-0002	**-**	**Little window**	**1122,73**	**3**	**1122,73**
	0002-P-0004	Inner frame	474,6	1	474,6
	0002-P-0020	Outer window	273,54	1	273,54
	0002-P-0007	Inner window	246,82	1	246,82
	0002-P-0006	protection plate	63,27	1	63,27
	0002-P-0020	spacer	37,5	1	37,5
	0002-P-0077	Argon insert	23	1	23
	-	Screws	0,2	20	4
0002-E-0004	**-**	**Entry**	**1949,86**	**1**	**1949,86**
	0002-P-0016	Entry dome	520,46	1	520,46
	0002-P-0015	Outer frame	573,6	1	573,6
	0002-P-0060	Upper handle	32	4	128
	0002-P-0059	Lower handle	35	4	140
	0002-P-0057	Sealing insert	20	4	80
	0002-P-0056	Joint housing	27,5	4	110
	0002-P-0083	Joint	35,3	1	35,3
	0002-P-0017	Inner frame	362,5	1	362,5
0002-E-0006	**-**	**Average window**	**1463,57**	**1**	**1463,57**
	0002-P-0038	Inner frame	672,4	1	672,4
	0002-P-0041	Outer window	331,82	1	331,82
	0002-P-0040	Inner window	322,4	1	322,4
	0002-P-0043	spacer	38,5	1	38,5
	0002-P-0046	Joint	22	1	22
	0002-P-0044	protection plate	72,45	1	72,45
	-	Screws	0,2	20	4
Argon System	**-**	**-**	**-**	**-**	**759**
	0002-P-0081	Differential valve	670	1	670
	-	Air tubes	20	1	20
	-	Overpressure valve	14	4	56
	-	Adaptor racor	12	5	60
	-	Electronics+sensors	836	1	836
		Filter	43.7	1	43.7
Test boil	**-**	**-**	**-**	**-**	**571,27**

	0002-P-0049	Main boil body	434,2	1	434,2
	0002-P-0050	Removable insert	53,5	1	53,5
	0002-P-0053	Back cover	68,57	1	68,57
	-	Screws	15	1	15

Table 19: Detailed budget

CHAPTER 13:

ENVIRONMENTAL ASPECTS

The degree of environmental impact varies according to the nature of the agent introduced into the wild and within the quantity emitted. This project is focused on a single prototype that won't be reproduced for large-runs. Moreover the materials employed are conventional and are suitable for recycling.

The emissions linked to the project come from the manufacturing stage due to the energy consumption and transport of all the materials.

Another important aspect is that the helium inside the balloon is released to the wild but this is an unreactive, non-toxic and inert gas. At very high concentrations it may cause suffocation where the oxygen level is reduced, but this is only critical in a confined space or if a huge amount is released. Helium is a very light gas and disperses quickly. So, in the nominal work pressure and temperature is not harmfull to the environment.

Another important fact, is the amount of material used for the balloon structure. It is built in low density polyethylene which can be processed by thermal depolymerization, heat compression or other process that are commonly employed in the film bags recycling method. After every launch campaign all the materials are recovered avoiding residues and environmental impact is reduced as much as possible.

CHAPTER 14: CONCLUSIONS AND FINAL COMMENTS

We can conclude that the final design allows pressurization theoretically under safe conditions and provides enough redundancies to keep sealing even if one part of the conjuncts fails.

The improved access entry system allows entering and unlocking the capsule almost instantly in contrast with the old system which took more than 4 minutes and 30 seconds to unlock. This part will take a completely important role in an emergency situation.

Argon system allows to see through the window clearly without any fogging phenomena and to take all the necessary media content in a public event.

The manufacturing process has not been treated along this project but I have maintained continuous contact with specialized manufacturers in order to ensure that every design can be built lowering costs as much as possible.

This project justifies my decisions during the design process but I can't afford safety until several tests and non-manned flights have been performed. Putting people's lives in your hands goes further numbers or simulations and for that reason I can conclude that this project is a little part of the long journey in front of me and this company.

It takes courage to climb on board a space capsule because it is an experimental flight and because the crew will be the first ones that go to space with this kind of capsule. In my opinion, it takes much more courage to be the ground crew, to make the decision to launch this vehicle and to afford that everything will run okay.

CHAPTER 15:
FUTURE LINES

This project presents a solution to a specific problem but doesn't allow the capsule to perform an experimental flight. The future works regarding the structural field are described below:

- Design a proper crushable that mitigate the impact and study if it is needed an extra mitigation system in each chair.
- Design the electronic system that controls the internal pressure layer.
- Design minibloon's interior, compartments, the proper avionics and a special platform to ease exit in an exceptional situation.
- Perform a thermal study to know the needed insulation for the capsule.
- Test the all the systems in almost real conditions.
- Design a new flight chain, lighter, shorter and more elegant.

CHAPTER 16:

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