ELSEVIER
Available online at www.sciencedirect.com
ScienceDirect
Energy Procedia 45 (2014) 977 – 986
Energy Procedia

68th Conference of the Italian Thermal Machines Engineering Association, ATI2013

# High altitude airship cabin sizing, pressurization and air conditioning

Antonio Dumas, Diego Angeli, Michele Trancossi

*Di.S.M.I. - Università di Modena e Reggio Emilia, Via Amendola 2, 42122 Reggio Emilia (Italy)*

**Abstract**

This paper aims at defining a design methodology for the global thermodynamic performance of a high altitude airship cabin. This design method applies to different systems, which could not use the traditional air conditioning plant layout based on bleed air intake from the compressor stage of jet engines. In the case of electrically propelled green vehicles and airships, other energy sources must be exploited. The MAAT EU FP7 project presents an innovative, energetically self sufficient, airship system based on cruiser-feeder architecture. Both the cruiser and feeder are fed by photovoltaic energy. The energy storage system by electrolysis and fuel cells with intermediate energy storage by hydrogen and oxygen is characterized by high temperature energy dispersions (about 800-1000°C for High temperature SOFC cells). This situation encourages the definition of a novel pressurization and air conditioning system. A preliminary cabin sizing with some structural considerations, an energetic evaluation of the thermal insulation of the cabin and a general balance of the energy production system are provided


Selection and peer-review under responsibility of ATI NAZIONALE

*Keywords: high-altitude airship, cabin, pressurization, aclimatization, plant design, energy evaluation*

## 1. Introduction

The MAAT project is designing a novel green cruiser-feeder airship system, which can connect major populated centres all over the world. The MAAT system aims at define a fully electrically propelled system by photovoltaic energy. Such a system is composed by two unconventional airships [1,2]:

1. the cruiser, which remains airborne for long times, connecting major populated areas;
2. the feeders, which connects the cruiser to the ground lifting up and down passengers and freight..

The particular choices regarding the energy supply and propulsion of the airship, which is entirely driven by electrical motors, forces to define a novel cabin pressurization system, because of the absence of the jets such as the ones present on traditional airliners, and to redefine the onboard systems and the air conditioning plant architecture.


Selection and peer-review under responsibility of ATI NAZIONALE
doi:10.1016/j.egypro.2014.01.103

In this work, a suitable design methodology for the cabin is introduced. The cabin is supposed to have a space for passenger more than three times higher with respect to a traditional aircraft, thus virtually increasing the comfort of passengers. Structural calculations and energetic balances are performed by considering high altitude conditions (15÷16 km).

**Nomenclature**

| | |
|---|---|
| $\rho$ | density |
| σ | mechanical stress |
| ξ | mixing ratio |
| $A$ | area |
| $J$ | enthalpy |
| $P$ | pressure |
| $U$ | total thermal transmittance of walls |
| $c_p$ | specific heat capacity |
| $\dot{m}$ | mass flow rate |
| r | radius |
| t | thickness |
| $x$ | absolute humidity |

## 2. Specifications for cabin design

The main specifications, which must be fulfilled by the MAAT cruiser-feeder transport system, are reported in the following paragraphs.The feeder has to minimize its own energetic consumption during take-off and landing operations and during the entire flight, which is mostly vertical, much alike to an aerostatic balloon. Hence, the system design requires an accurate energetic evaluation to minimize the energy demand, complying with operational specifications. The preliminary specifications for the feeder and the cruiser design are reported in Table 1.

Table 1 - Specifications for the design

| Feeder | | | | Cruiser | | | |
|---|---|---|---|---|---|---|---|
| Sym. | Quantity | Values | Units | Sym. | Quantity | Values | Units |
| $n_p$ | Number of passengers | 50 | | $n_p$ | Number of passengers | 200 | |
| $n_c$ | Number of crew | 5 | | $n_c$ | Number of crew | 15 | |
| $m_p$ | Average mass for person | 125 | Kg | $M$p | Average mass for person | 125 | kg |
| $M_p$ | Maximum mass for passengers and crew | 6750 | Kg | $M_p$ | Maximum mass for passengers and crew | 26875 | kg |
| $A_p$ | Minimum Area for passengers | 1 | $m^2$ | $A_p$ | Minimum Area for passengers | 3 | $m^2$ |
| $A_t$ | Minimum Area of transit areas | 10 | $m^2$ | $A_t$ | Minimum Area of transit areas | 60 | $m^2$ |
| $A_c$ | Minimum Area of cockpit | 10 | $m^2$ | $A_c$ | Minimum Area of cockpit | 40 | $m^2$ |
| $v_{y,av}$ | Average vertical velocity | 10 | m/s | $v_{y,av}$ | Average absolute velocity | 35 | m/s |
| $a_{y,max}$ | Max vertical acceleration | 1 | $m/s^2$ | $v_{y,max}$ | Max Horizontal velocity | 40 | m/s |
| $h_{s,max}$ | Max operative ceiling | 17 | Km | $a_{y,max}$ | Max Horizontal acceleration | 2.5 | $m/s^2$ |
| $h_s$ | Service ceiling | 16 | Km | $h_{s,max}$ | Max operative ceiling | 17 | km |
| $t_s$ | Time to the service ceiling | 1600 | S | $H$s | Service ceiling | 16 | km |

The cruiser specifications are defined in the same way as done for the feeder. In particular, it can be assumed that the load capacity is equivalent to 4 feeders and the area for passenger is increased to at least 3 $m^2$ for passenger.

## 3. Generalities about cabin design

Considering the data in Table 1, it is possible to proceed to the design of the cabins of cruiser and feeder. In particular, it is possible to evaluate cabin dimensions and weights. The material adopted for the cabin design is carbon fiber with internal polyurethane insulation and windowing in reinforced PVC.

To operate an effective design of the cabins, it is necessary to consider the atmospheric data, reported in Table 2.

Table 2 - Atmosphere data

| Elevation - h - (m) | Temperature - T - (K) | Pressure - p - (Pa) | Density - ρ - ($kg/m^3$) | Cinematic Viscosity - ν - x $10^{-5}$ ($m^2/s$) |
|---|---|---|---|---|
| 0 | 288.15 | 101325 | 1.225 | 1.46 |
| 2000 | 275.2 | 79500 | 1.007 | 1.72 |
| 4000 | 262.2 | 61660 | 0.819 | 2.03 |
| 6000 | 249.2 | 47220 | 0.660 | 2.42 |
| 8000 | 236.2 | 35650 | 0.526 | 2.90 |
| 10000 | 223.3 | 26500 | 0.414 | 3.53 |
| 12000 | 216.7 | 19400 | 0.312 | 4.56 |
| 14000 | 216.7 | 14170 | 0.228 | 6.24 |
| 15000 | 216.7 | 12110 | 0.195 | 7.30 |
| 16000 | 216.7 | 10350 | 0.166 | 8.54 |
| 17000 | 216.7 | 8850 | 0.142 | 9.99 |

Internal cabin pressure can be equal to the one at any height between 1000 and 2000 m. The reference pressure for internal pressurization has been conservatively assumed equal to the atmospheric pressure at ground level for calculations purposes. Material properties are extracted from [3] and [4].

The cabins are assumed circular cylinders with two hemispheric ends. Sizing formulas are derived from the traditional calculation formulas for the design of pressurized vessels [5].

Let us consider a cylindrical pressure vessel with radius r and wall thickness t, subjected to an internal gauge pressure p. The coordinate system used to describe the cylindrical vessel can take advantage of its axial symmetry. This choice allows the hypothesis of zero shear stress to be considered as valid. The hoop stress $\sigma_h$ and the longitudinal stress $\sigma_l$ are the main stresses. Longitudinal stress can be evaluated by ideally cutting the vessel with a plane as represented in Fig. 1-a. Considering the cut element as a free body, its equilibrium condition can be evaluated, leading to (1):

$$\sigma_l = P \cdot r / 2t \qquad (1)$$

Figure 1 - Sample cabin design and dimensioning schema

To determine the hoop stress $\sigma_h$, it is possible to cut the system with a longitudinal plane such as in Fig. 1-b. The equilibrium of forces leads to (2):

$$\sigma_h = P \cdot r / t \qquad (2)$$

These relationships allow for a general evaluation of the structural thickness and of the weight of the cabin. Assuming from [3,4] a Standard carbon fiber with epoxy matrix, it is possible to assume a circumferential tension $X_t$ of about 1200 MPa and a longitudinal textile strength $Y_t$ of about 50 MPa.

Assuming a safety coefficient of 2.5, it can be verified that a cylinder with a radius of 2.5 m and thickness 0.003 m satisfies perfectly the requirements. It also resists perfectly to the wind pressure at ground level, if a conservative reference wind of 100 m/s is assumed for structural calculations. Concerning the thickness of internal insulation, assuming that it is constituted by polyurethane foam with a density of 40 $kg/m^3$, it can be evaluated that a polyurethane thickness of about 0.125 m is sufficient to ensure an overall heat transfer coefficient *U* of about *0.26* $W/(m^2K)$.

## 4. Feeder cabin preliminary design

Assuming the cabin section described in Figure 1, it is possible to evaluate the dimensions of the cabin in a length of about 17 m plus spherical terminations. To ensure an adequate surplus in term of projected area, this can be assumed as 20 m. The internal radius can be considered 2.375 m long, while the cord section of basis can be taken of about 2.05 m.

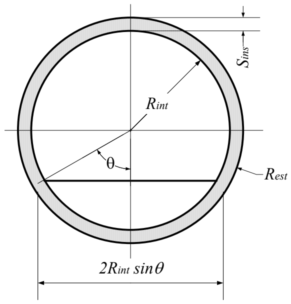


Figure 1 - Section of the cabin

The final cabin design will be the one presented in Figure 1. The total weight of the cabin structure can be then estimated assuming 0.002 m of external carbon fiber, 0.125 m of polyurethane insulation and 0.001 m internal carbon fiber reinforcement. The overall mass of the structure sums up to about 3,520 kg. The internal structure needs to be added, which is estimated to be of about 1,800 kg. Hence, the total structural weight can be estimated in about 5,350 kg. Considering the system equipments including controls, chairs and controls, pressurization and air conditioning systems, avionics, hydrogen cylinders, etc., the global mass is conservatively incremented of 5,000 kg. The total weight of the cabin at maximum payload including minor equipments is then about 11,000 kg. The internal mass of air is evaluated (conservatively assuming ground level pressure) to be about 425 kg. Batteries and fuel cells must be considered in the system weights, but these are not possible to be precisely evaluated, because many necessary data are still not available. Hence, a preliminary weight of batteries and energy storage systems about 2,000 kg can be initially considered.

## 5. Cruiser Cabin

Similar calculations can be produced for the cruiser cabin, which can be assumed to have a cylindrical shape with a radius $r_1$ = 4 m. Assuming equation (2) as the reference equation for calculation, the maximum thickness of the walls can be computed. Applying it to the minimum design radius, which is clearly the critical radius, it emerges that a safe thickness equals about 0,004 m. A polyurethane insulation layer about 0.125 m has inserted for insulation. The cabin results about 3 m high and has a useful planar width of about 7.5 m.

The minimal area for passengers is then 300 $m^3$ plus 200 $m^3$ for common areas and 100 $m^3$ for the crew. The dimensions of the cabin also entail a minimal length of about 80 m, which can be extended up to the final diameter of the feeder, fixed at 100÷110 m, assuming a prudential length about 115 m. The cabin will be then formed by an 80 m corridor for traditional cabin activity, plus an additional supplemental space of 15 m. It is possible to add two extremity system connections about 10 m long. They act as a connection during linking and transfer operations and can be pressurized when needed. The total mass of the cabin can be estimated about 46,000 kg.

The Cruiser can be incremented by internal masses for equipments (preliminary evaluated about 20,000 kg), energy storage (preliminary evaluated 16,000 kg). The mass of the air for the pressurization system is about 2,000 kg (equal to the mass of the pressurized air). The total mass of the cruiser cabin sums up at about 85,000 kg.

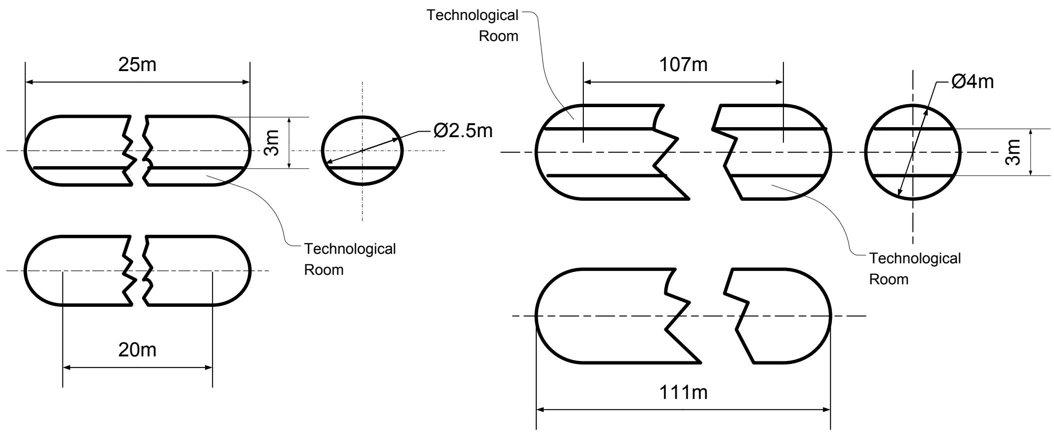


Figure 2 - Feeder and Cruiser Cabin schema.

## 6. Cabin Air System Operation

In traditional aircrafts, pressurized air for the cabin comes from the compressor stages of the jet engines. Moving through the compressor, the outside air gets very hot as it is pressurized, because it reaches the adiabatic temerature. This process is commonly known as "bleed air" exploitation. The cooled air then flows to a chamber where it is mixed with an approximately equal amount of highly filtered air from the passenger cabin. This mix of air is pumped to the cabin and it is distributed through overhead outlets. Inside the cabin, the air flows in a circular pattern and exits through floor grilles on either side of the cabin or, on some airplanes, through overhead intakes. The exiting air goes below the cabin floor into the lower lobe of the fuselage. The airflow is continuous and quickly dilutes odors while also maintaining a comfortable cabin temperature.

Most important producers of commercial jet plane Boeing and Airbus ensure several air changes per hour inside the fuselage. About half of the air exiting the cabin is immediately exhausted from the airplane through an outflow valve in the lower lobe, which also controls the cabin pressure. The other half is aspired in the lower part of the cabin and is filtered through filters under the cabin floor, and then is mixed with the outside air coming in from the engine compressors.

These high efficiency filters are similar to those used to keep the air clean in hospitals. Such filters are very effective at trapping microscopic particles as small as bacteria and viruses. Some authors estimated that between 94 and 99.9 percent of the airborne microbes reaching these filters are captured [10].

### *6.1. Key Characteristics and Overall Effectiveness*

Several characteristics of the cabin air system deserve special emphasis:

1. Air circulation is continuous: air is always flowing into and out of the cabin.
2. The cabin has a high air-change rate: the incoming mixture of outside air and filtered air replaces the air in the cabin during intervals of only two to three minutes, depending on airplane size (about 20 air changes per hour).
3. Outside-air mixing replenishes the cabin air constantly:
   the outside-air content keeps carbon dioxide and other contaminants well within standard limits and replaces oxygen far faster than the rate at which it is consumed (replenishment also assures that the recirculation portion of the air does not endlessly recirculation, but need to be diluted and replaced with outside air).

### *6.2. Differences Between Older and Newer Cabin Air Systems*

Engines that produced all or most of their thrust directly from the engine core powered early-generation jetliners. Bleed air extracted from the compressor in these older aircraft provided the cabin with 100% outside air, with only a modest impact on fuel economy. However, by today's standards, the engines themselves were very noisy, emitted much higher levels of pollutants into the atmosphere and were much less fuel-efficient.

By contrast, new jetliners are powered by high-bypass-ratio fan engines, which are much quieter, much cleaner burning, more powerful and much more efficient. At the front end of this engine type there is a large-diameter fan, which is powered by the core. The fan moves a large volume of air through the core, and actually generates most of the thrust. Every unit of pressurized air extracted from the engine core has the effect of reducing fan thrust by an even greater amount, and that degrades fuel efficiency more severely on this type of engine than on the older type. By providing the cabin with a mixture of about 50 percent outside air taken from the compressor and 50 percent recycled air, a balance has been achieved that maintains a high level of cabin air quality, good fuel efficiency and less impact to our environment.

## 7. Cabin pressurization and air conditioning on MAAT

The pressurization and air conditioning system design takes into account the results of the preceding analysis on the cabin dimensioning process. The internal schema of the MAAT cruiser and feeder has been defined starting from the above-considered schema of Lockheed L-1011 cabin (Figure 3).

Ten total air changes per hour are supposed. A parametric dimensioning of the air conditioning system is granted for a reference volume of both cruiser and feeder. A preliminary layout of the air supply, recycling and conditioning system for both feeder and cruiser is reported in Figure 4. The system is designed to maintain the desired temperature and humidity conditions inside the cabin, and to provide a fixed flushing rate of the whole volume.

Exhaust air is taken out of the cabin and filtered first (1), then it is cooled down and dehumidified in a condenser (2), which exploits outside air as thermal sink. The condensed water is gathered in a suitable vessel (3), to be used for further humidification needs. Recycled air is re-heated to stray from saturation conditions, by exchanging heat, once again, with air from the outside, which now acts as a thermal source (5).

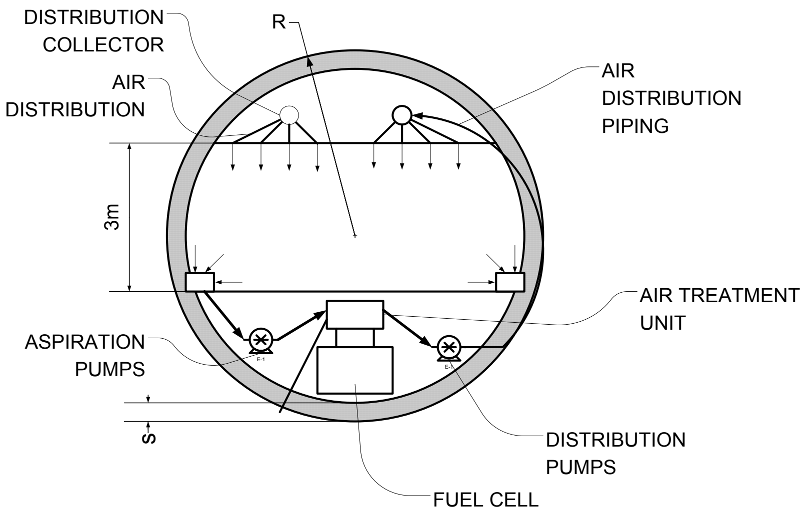


Figure 3 - Cabin airflow on the schema of Lockheed L-1011

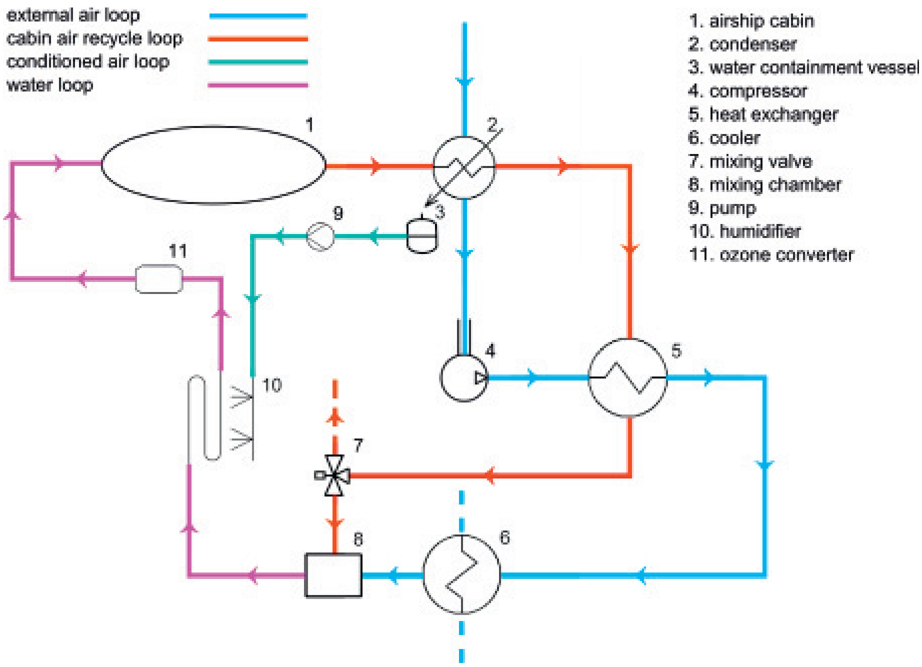


Figure 4 – Schematic of the air conditioning system

Since no turbojet engines are foreseen in neither cruiser nor feeder designs, the common practice of exploiting bleed air cannot be applied here. Instead, air supply from the outside must undergo a compression up to the cabin pressure (4). The above considerations, if the compression is adiabatic, produce an increase of temperature up to the adiabatic temperature, which typically increases with altitude. It is therefore necessary to cool down the outside air. This goal can be achieved partly by exploiting the recycle air loop (5), and partly by an auxiliary heat exchanger (6), which could use once again the atmospheric air as thermal sink. A fraction ξ of the recycle air is sent to a mixing chamber (8) to be mixed with fresh air from the outside. The rest of the recycle air is discharged in the atmosphere, after that most of its thermal and humidity and content has been recovered. The mixture is then properly re-humidified (10). It is treated to decrease its ozone content (11) before being sent back to the airship cabin. If we call $\dot{m}_t$ the total mass flow rate providing the desired air flushing rate, it is $\dot{m}_t = \dot{m}_r + \dot{m}_e$, where $\dot{m}_r$ is the fraction of the air which is effectively recycled, while $\dot{m}_e$ is the external air which is introduced in the loop. Using the definition of ξ, we may write:

$$\dot{m}_r = \xi \cdot m_t \tag{3}$$

$$\dot{m}_e = (1-\xi)\cdot \dot{m}_t = \rho \cdot q \tag{4}$$

The desired internal conditions can be achieved by adjusting two main parameters: the mixing rate ξ, and the net dehumidification of the recycled air, expressed by the absolute humidity after the condenser, $x_2$. The total enthalpy of the conditioned air stream, $J_8$, which is fixed by the problem requirements, depends on these two parameters:

$$J_8 = \xi \cdot J_5 + (1-\xi)\cdot J_6 \tag{5}$$

$$x_8 = \xi \cdot x_5 = \xi \cdot x_2 \tag{5}$$

The target temperature of the external air (which can be safely considered almost totally dry) is then uniquely determined. The net mechanical and thermal power, required to compress and cool down the outside air, respectively can be expressed as follows,:

$$W_{comp} = \rho \cdot q \cdot (c_p - R_d) \cdot (T_4 - T_{ext}) \tag{8}$$

$$Q_{cool,e} = \rho \cdot q \cdot (J_6 - J_4) = \rho \cdot q \cdot c_p \cdot (T_6 - T_4) \tag{9}$$

$$W_{comp} = \rho \cdot q \cdot (c_p - R_d) \cdot T_{ext} \cdot \left[ \left( \frac{p_{cabin}}{p_{ext,Z}} \right)^{\frac{R_d}{c_D}} - 1 \right] \tag{10}$$

where $T_{ext}$, is the external temperature at a given altitude, and $T_4$ is the adiabatic temperature defined above.

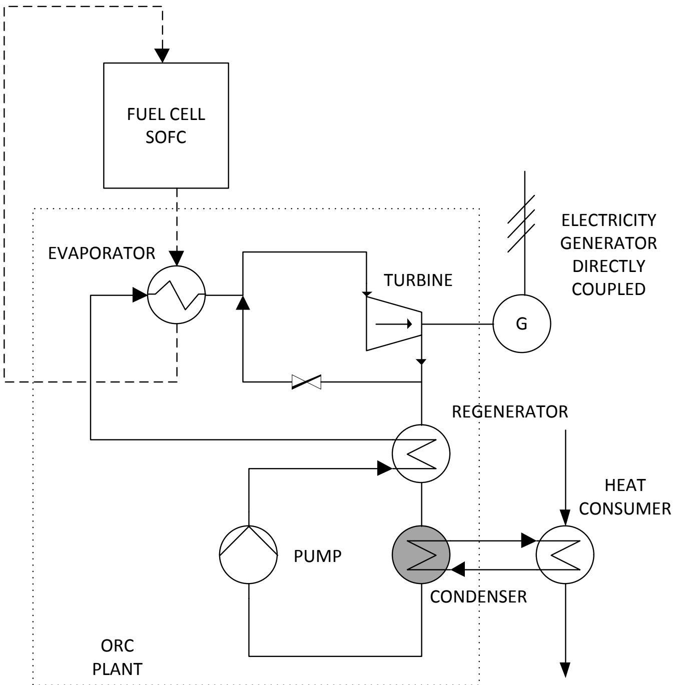


Figure 5 – Schematic of the energy production system

If we assume that:

1. no recycle air is mixed back to the conditioned stream ($\xi = 0$);
2. the total transmittance of the cabin walls is U = 0.35 W/m$^2$K, the total cooling energy need can be quantified as:

$$Q_{cool} = Q_{cool,e} + Q_{loss} = Q_{cool,e} + U \cdot A \cdot (T_{in} - T_{ext}) \tag{11}$$

A preliminary estimate of these quantities is provided in the table below, for a spherical volume of 1000 m$^3$, and for a number of 10 flushing cycles per hour, at an altitude of approximately 16 km (Table 3).

This plant has a large amount of energy disposable at high temperature using the SOFC fuel cells refrigeration plant with a source about 1000°C.

Table 3 - Cabin plant parametric dimensioning (for 1000 $m^3$)

| | | |
|---|---|---|
| Volume | 1000 | $m^3$ |
| Altitude | 16000 | m |
| Internal Desired Pressure: | 101325 | Pa |
| Internal Desired Temperature: | 22 | °C |
| Internal Desired Relative Humidity: | 15 | % |
| External average temperature: | 56.46 | °C |
| External pressure temperature | 10350 | Pa |
| Cp | 1004 | J/ kg K |
| Rd | 287 | J kg K |
| Number of flushing cycles per hour | 10 | |
| Reference density | 1.225 | kg/ $m^3$ |
| Net compression power | 1.225 | W |
| Total cooling power | 13279 | W |

*7.1. Cabin Pressurization Safety Systems*

The air is then cooled, humidified, mixed with recycled air if necessary and distributed to the cabin by one or more environmental control systems. The outflow valve regulates the cabin pressure. Pressurization becomes necessary at altitudes above 3,800 m above sea level to protect crew and passengers from the risk of a number of physiological problems caused by the low outside air pressure above that altitude; it also increases the comfort of passengers.

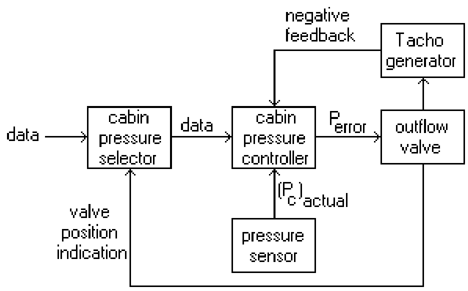


Figure 6 - Pressurization system and control

The lower partial pressure of oxygen at altitude reduces the alveolar oxygen tension in the lungs and subsequently in the brain, leading to sluggish thinking, dimmed vision, loss of consciousness, and ultimately death. In some individuals, particularly those with heart or lung disease, symptoms may begin as low as 1,500 m, although most passengers can tolerate altitudes of 2,400 m without ill effect. At this altitude, there is about 25% less oxygen than at sea level. Hypoxia may be addressed by the administration of supplemental oxygen, either through an oxygen mask or through a nasal cannel. Without pressurization, sufficient oxygen can be delivered up to an altitude of about 16,000 m. It is because a humans are used to live at sea level. The ambient air pressure falls to about 0.12 bar and to maintain a minimum partial pressure of oxygen of 0.2 bar requires breathing 100% oxygen using a oxygen mask. Emergency oxygen supply masks in the passenger compartment of airliners do not need to be pressure-demand masks because the flight stays at 12,000 m. Above that altitude, the partial pressure of oxygen will fall below 0.2 bar even at 100% oxygen and some degree of cabin pressurization or rapid descent is essential to avoid the risk of hypoxia. The schema of controls has been reported in Figure 6. Cabin pressure selector contains controls and circuitry necessary for automatic or manual cabin pressure selection, setting the landing altitude & the rate by which the cabin pressure increases/decreases.

Cabin pressure controller controls the outflow valve, by either opening or closing it. It receives its data from the cabin pressure selector and it processes this data to calculate the required cabin pressure ($P_c$), it also receives the actual pressure reading ($P_c$) from the pressure sensor, and uses it to calculate the pressure error ($P_{error}$), which is then used to control the angle by which the outflow valve will be opened. Each controller monitors the other controller to check whether it has failed, and to check if the results correspond.

Outflow valve is driven by two 115 VAC, 400 Hz motors which operate with the dual automatic control systems, and a 28 VDC motor which is used with the manual control system.

## 8. Conclusions

This paper has demonstrated the preliminary design methodology for the cabins of both cruiser and feeder of the MAAT airship concept. It has also presented the general design guidelines for both the pressurization and acclimatization systems considering that despite common aircrafts cabin it is not possible to use the heat taken from the engines. In this case it has been adopted the utilization of a cogeneration system relating to the recovery of the thermal dissipation of high temperature fuel-cells. The present schema could be a future reference for future green and electric aerial vehicle. The calculation schema has been included.

This activity is actually continuing inside the MAAT EU 7FP project. An effective dimensioning and a complete design of a novel completely green aerial vehicle are expected in future. The complete definition of this innovative cabin concept and of its plants is a fundamental part of this project because energetic self-sufficiency will not be possible without a proper design of the pressurization and acclimatization plants. Further activities will also consider the phenomena of adiabatic heating/cooling during

## Acknowledgements

The present work was performed as part of Project MAAT | Multibody Advanced Airship for Transport | with ref. 285602, supported by European Union through the 7th Framework Programme.

## References

1. Dumas, A., Madonia, M., Giuliani,I., and Trancossi, M., “MAAT Cruiser/Feeder Project: Criticalities and Solution Guidelines,” SAE Technical Paper 2011-01-2784, 2011, doi:10.4271/2011-01-2784, 2011.
2. Dumas, A., Trancossi, M., Madonia, M., and Giuliani,I., “Multibody Advanced Airship for Transport,” SAE Technical Paper 2011-01-2786, 2011, doi:10.4271/2011-01-2786, 2011.
3. Mazumdar S. K., “Composites Manufacturing: Materials, Product, and Process Engineering,” CRCpress, 2002.
4. Campbel F. C., “Structural Composite Material,” ASM, 2010.
5. VV. AA., “ANSI/AIAA S-080-1998, "Space Systems - Metallic Pressure Vessels", Pressurized Structures, and Pressure Components,” ANSI, 1998.
6. VV-AA., "Polyurethane Handbook", Hanser Fachbuch-verlag; Hanser / Gardner Publications. ed. 2009.
7. Khoury, G. A. and Gillett, J. D., "Airship Technology", Cambridge Aerospace Series: 10, 1999.
8. Munk M., "The Aerodynamic Forces on Airship Hulls", Technical report n. 184, U.S. Government Printing Office, 1923.
9. SAE Ac-9 Aircraft Environmental Systems Committee, "Aerospace Pressurization System Design", AIR1168/7, Stabilized July 2011.
10. SAE Ac-9 Aircraft Environmental Systems Committee, "Air Conditioning Systems for Subsonic Airplanes", ARP85, Rev. F, 2012.
11. SAE Ac-9 Aircraft Environmental Systems Committee, "Bleed Air Contamination Limits for Safety, Health, and Comfort of Aircraft Occupants", AS6263, Works In Progress Version.
12. SAE Ac-9 Aircraft Environmental Systems Committee, " Ozone in High Altitude Aircraft", AIR910, Stabilized Oct. 2011.
13. SAE Ac-9 Aircraft Environmental Systems Committee, " Aircraft Electrical Heating Systems", AIR860, Stabilized Oct. 2011.