11. DESIGN OF A HUMAN POWERED AIRSHIP

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11.1 Introduction

"Would have been highly risky and, in any case, impossible", is a quote from Jules Verne's Around the World in Eighty Days. Such an endeavor is still a challenge today. Therefore, the design of a human powered airship for a round the world flight will be presented here.

Lighter than air vehicles such as balloons and airships primarily use the difference in density between the surrounding atmosphere and the lifting gas inside a large cavity. This in contrast to aerodynamically lifted craft like airplanes, which create lift by moving an airfoil through the surrounding air. An airship is a buoyant aircraft that can be steered and propelled through the air. Airships were the first aircraft capable of performing controlled powered flights over large distances. They were most popular from roughly 1900 to the 1930s. Over time, their capabilities were surpassed by those of airplanes, initiating a decline in use. They also suffered a series of high profile accidents. The most well known example is the accident of the Hindenburg. Today the airship is used for advertisement, TV-coverage of major events, as a sensor platform and for many other applications.

For human powered applications, the airship has the advantage that, unlike helicopters and conventional aircraft, no power is required to keep it in the air. Power is only needed for speed and control. This makes it an ideal aircraft for human powered flight around the world. Based on the advantages and opportunities the mission need statement was formulated as follows:

Design a two-seater human-powered airship for a round the world flight, making at maximum one stop per continent and without making use of the Jet Stream.

So the objective of the project is to propose a conceptual design after the period of ten weeks. The design process is characterised by multiple phases. After defining a clear mission statement a list of all possible requirements was generated. This is followed by a study and analysis to identify all possible design options. Three different concepts were generated from all these options. Using multiple trade-off tables a final concept was selected. During the final design phase this concept is worked out in detail. Also the operational and logistic aspects of the mission, such as the flight route, were further investigated and worked out for the design.

11.2 Requirements

The final design will have to comply with a number of requirements to fulfil the mission. They can be subdivided in the following three categories:

Concept related requirements
- The airship is propelled by human power only
- Around the world flight with only one stop per continent
- Not allowed to make use of jet stream
- Two man crew

Performance requirements
- Maximum speed 25 mph
- Ceiling 10000 feet
- Vertical landing and take-off
- Vertical speed at sea level of 300 ft / min

- Neutral buoyancy attainable at all atmospheric conditions
- Maximum payload: two man flight crew with food, equipment and clothing
- dynamically stable and controllable at all speeds and altitudes
- Sustainable design

Operational requirements
- No hangar required
- Autonomous landing
- Gas must be extractable and reusable

The following requirements are classified as killer requirements:
- do not make use of jet stream
- one stop per continent
- limited available human power
- storable in a sea container

11.3 Concepts and trade-off

From the design option study, the most viable concepts remain. These concepts are shortly explained and a trade-off is performed for the three driving functions; the boom function, the power generation function and the thrust and control function.

Boom trade-off
For the boom layout there are seven different concepts which are investigated, all will be covered in a few words to explain the concepts, followed by a trade-off

Single boom plus collar
The gondola is directly attached to the boom via a collar. Loads are internally transferred to the boom by cables. No gap exists between the gondola and the boom. This is a proven design with an average drag.

Single boom plus collar (integrated)
This is the same as the first option, only now the gondola is partially placed inside the boom to reduce drag. This is a relative complex and heavy solution. The seal between the gondola and the boom also

means that the boom cannot be separated from the gondola which may cause storage problems.

Single boom, cable suspended
The gondola is attached by cables below and on the outside of the boom. Internal boom cables transfer loads to the boom. A gap exists between the gondola and the boom. This option is rather simple and light, but incorporates a large drag.

Single boom plus keel
This incorporates an internal boom construction. The gondola is connected to the outside of the boom. This construction is rather heavy and complex, but has good drag characteristics.

Multiple boom layouts
This is basically the same as the above designs, only using more than one boom, to create a more slender airship. The multiple booms will mean more boom fabric and also more friction drag due to the larger surface area. Therefore these options are dropped.

Performing a trade-off between the concepts, the first concept is chosen because of the average drag, and proven design, other concepts are either too heavy or give too much drag.

Power generation trade-off
In this section the trade-off is described for the power generation systems. The power generated by a crewmember must be converted into available power for the propeller in the best way possible. For this, some criteria have been established to test three options for their viability. Below the three concepts are investigated and the most important advantages and disadvantages are mentioned.

Mechanical cycling
Using mechanical cycling the power generated is transmitted to the propeller shaft by direct mechanical connections. A large disadvantage in a direct propulsion system is that power delivery can only be obtained if the pilots keep cycling. This cannot be the case because the crew must rest a certain time during the flight. Another disadvantage is that it is not possible to reach the required 25 mph minimum maximum speed with mechanical cycling.

Electrical rowing

The second design option is the electrical rowing concept. In this concept the kinetic input from the crew is transformed to electrical power using a generator, converter and battery. An advantage of using a battery to store the power is that the propulsion system can be driven 24 hours per day. The comfort of a rowing machine is however minimal, because the seat is small and the whole body must be used for a correct motion. Furthermore the rowing motion is based on peaks because it is an intermittent process. This makes the effort exhausting for the human body.

Electrical cycling

In the last concept, kinetic energy is converted to electrical energy by cycling. Again a generator, converter and battery are used for this. Compared to the electrical rowing concept the electrical cycling option has a lot in common. The only actual difference is the motion performed by the crew is a lot more comfortable.

Trade-off

The purely mechanical system is not an option as it does not meet the constant power and maximum speed requirements. Also the option of electrical rowing is not usable because it will impose rapid human exhaustion and lower power provided by the humans. Therefore the electric power generated by cycling is the only remaining concept and will be used for further development of the airship.

Thrust and control trade-off

In this section a trade-off is made for the propulsion system. The trade criteria on which the trade-off is based are: low speed control, high-speed control, thrust efficiency, weight, complexity, risk, cost, maintainability and sustainability.

Control surfaces and fixed propeller

This classic, proven design requires sufficient airflow over the control surfaces in order to become active. This presents controllability problems even when one would use huge surfaces at low speeds such as during critical flight phases as landing, take-off and hover, which is simply unacceptable. On the contrary, for high-speed control, where there is sufficient airflow, the control surfaces provide an effective method of control.

Thrust vector controlled (TVC) propellers and fins

With a thrust vectored propulsion system, controllability at low speeds is achievable by directing thrust to steer the airship. It is only limited by the amount of degrees in which the thrust can be swivelled. During high-speed flight with no control surfaces, thrust will need to be vectored in order to control the airship. This means that not all thrust will be directed into providing propulsion.

Cycloidal propellers and fins

The cycloidal propeller reigns supreme for low speed control with its high thrust output, 360 degree directional capability along the rotation axis and very rapid response. The complexity of this design is high because of the control mechanism and the many parts that make up the system. The weight of this system is going to be heavier than conventional propellers if the same level of thrust needs to be provided.

Trade-off

The first option, control surfaces and fixed propeller, is considered not suitable because it fails on one of the most important criteria, being low speed control. Judged on overall performance, the TVC propellers and cycloidal propellers score even.

After careful study, a new criterion being public relations came into the picture. It then became clear that from a PR point of view, the cycloidal propeller would be a winner because of its exotic nature that was really something different and not often seen. The TVC propellers were still kept in mind as a backup in case the cycloidal propellers would prove to be not viable after all.

During the final design problems were indeed encountered. Mounting the entire cycloidal propulsion system with its complex control mechanisms, heavy weight and large dimensions, turned out to be structurally not feasible in a blimp. Therefore the decision was made to abandon the cycloidal propeller and fall back on the backup propulsion concept consisting of the TVC propellers.

11.4 Final design

Having performed a concept trade-off, the airship can be designed in detail. The final design is still “merely” a conceptual design and some extra design iterations will be needed before the airship can continue into the production phase. This section will describe the airship’s subsystems and total layout as well as the airship’s performance characteristics. The airship will be called the HPA-1 Phileas, after *Phileas Fogg*, the fictional character is Jules Verne’s “Around the World in 80 Days”.

The airship subsystems

The airship is subdivided in multiple subsystems to enable a concurrent design process to take place. An exact impression of all systems can be found at the end of this section. The first of these subsystems is the boom, which holds the buoyancy gas, carries the gondola and provides support for the engines. It primarily determines the airship’s aerodynamics. For structural integrity of the boom, an inflatable internal support structure is used. The gondola is suspended to the boom using a so called “curtain” and Dyneema cables. The smaller engines are supported by the fins and the large engine by inflatable cones.

The buoyancy control system provides the means to control the lifting capacity of the buoyancy gas, helium, and the mass balance of the buoyancy gas inside the boom. This way both the altitude and the pitch angle can be controlled. In order to do this, use is made of gas bags or ballonets, which can be filled with air. Pumping more air in the ballonets means that the helium will be compressed, thus decreasing its lifting capacity, as can be seen in figure 11.1, in which the ballonets are visualized by the solid black areas.

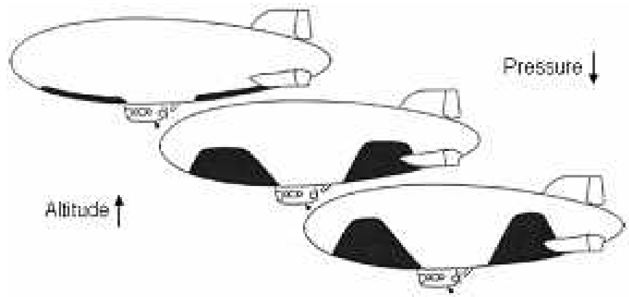

Figure 11.1: Altitude control using the buoyancy control system

By alternating the amount of air in the front and rear ballonets the pitch angle is varied as well. This basic principle is visualized in figure 11.2 below.

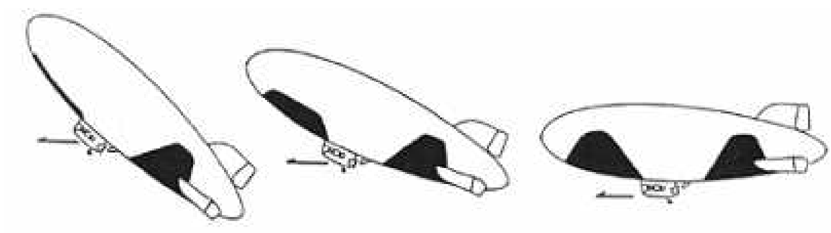

Figure 11.2: Pitch control using the buoyancy control system

Apart from going up and down, it is also important that the airship can acquire forward speed. As the cycloidal propeller design proved to be unfeasible, three conventional propellers are used. Two small 2 m diameter propellers with their corresponding engines are mounted on the two horizontal fins for cruise. These two side propellers can swivel up to 90 degrees outward in order to provide yaw control as well. Because no existing DC motors can provide the huge power range between cruise and maximum, an extra 4 m diameter large propeller is mounted aft of the airship. This propeller will only be used in “sprint mode”.

In order to power the DC motors, a human power generation system is needed. This system incorporates two parallel reclined bicycle-like models. The crewmembers’ pedal power is converted into an electrical current using an AC generator. This current can be used to charge the batteries or to directly power the propulsion system. The latter option avoids a battery charging and discharging efficiency penalty and a power provision efficiency of up to 62 percent can be achieved.

As only human power is used to drive the propulsion system, an extra energy supply is needed for all other electrical systems, including flight management systems, communication systems and cabin systems. This energy is obtained from a solar array, with a total area of 32 m^2, placed on top of the airship boom. This provides a little over 9000 Wh of energy per day.

In order to land safely, a landing and anchoring system is designed and procedures for take-off and landing are set up. This incorporates an inflatable air cushion system and a harpoon anchoring system. At a low altitude above the ground prior to landing, a harpoon is shot into the ground, providing enough support for one crewmember to disembark and further anchor the airship using ropes. Then the other crewmember can disembark as well.

The gondola will provide a habitat for the crew during the whole journey. It also houses most airship systems, food, water and spare parts. Figure 11.3 gives the gondola layout.

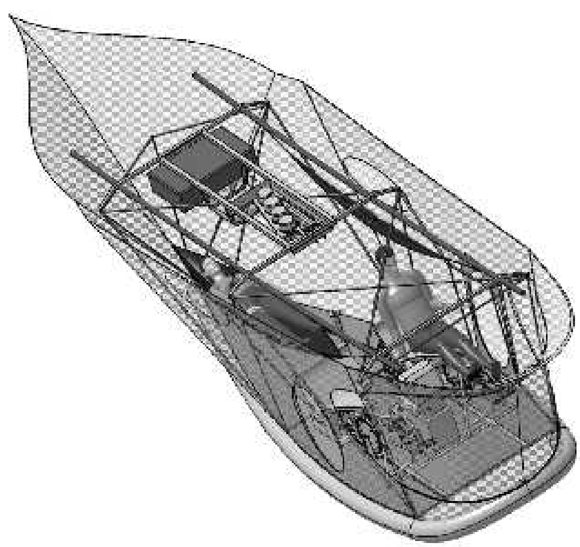

Figure 11.3: The gondola layout

The total airship

With all subsystems treated separately, the total airship can be build up. The whole design can be seen in figure 11.4. Figure 11.5 specifies the main dimensions in a 3-view drawing and figure 11.6 gives an in-flight artist impression of the airship.

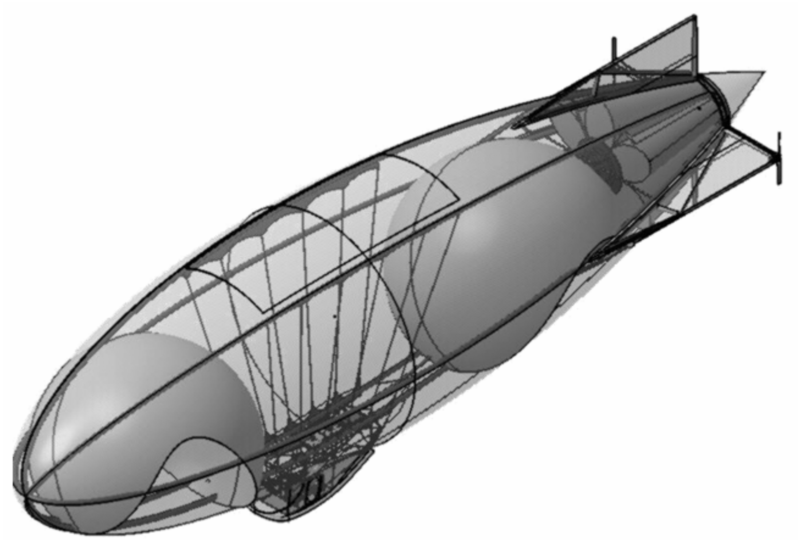

Figure 11.4: The total airship design

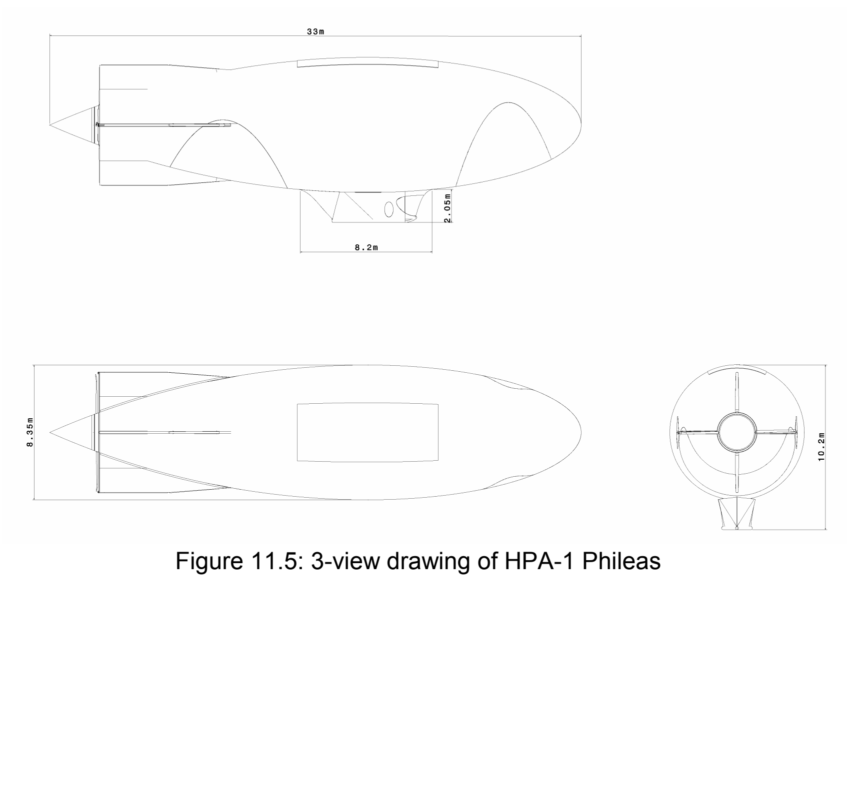

Figure 11.5: 3-view drawing of HPA-1 Phileas

Figure 11.6: An in-flight impression of HPA-1 Phileas

Airship size and performance

Table 11.1 specifies the most important airship sizing and performance characteristics.

Quantity	Value	Quantity	Value
Length	33 [m]	Max. Take-off Mass	855 [kg]
Width	8.35 [m]	Ceiling	10000 [ft]
Height	10.2 [m]	Cruise Speed	13 [km/h]
Boom Volume	1050 [m^3]	Max. Speed	40 [km/h]
Empty Mass	570 [kg]	Range/Endurance	9000 [km]/14 [days]

Table 11.1: Airship sizing and performance characteristics

11.5 Conclusions and recommendations

The final design has resulted in an airship that fulfils the requirements posed by the mission statement. The total airship mass is 855 kg, 105 kg heavier than the initial set target. The maximum speed of 11.2 m/s can be met by using a lot of power in a short time. Human propulsive energy is limited, so savings are made by avoiding speeds higher than the cruise speed of 3.6 m/s. Since the payload forms one third of the total weight and can vary, this has to be compensated by the buoyancy control which results in pressure issues in the boom.

Human power is attractive for sustainability, but for a trip around the world this implies problems concerning the lack of power available for propulsion. Above wind speeds of 3.6 m/s, straight forward flight is not possible due to lack of thrust for control.

Given the short time span, limited design iterations were possible to obtain more accurate results. Higher efficiencies can be reached on components such as the propeller by applying a customized design. CFD or wind tunnel analysis data would yield a much more accurate insight into aerodynamics, stability and control characteristics.