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MAAT SYSTEM DESIGN – WEIGHT MODEL OF VERY LARGE LIGHTER-THAN-AIR VEHICLE

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ABSTRACT

The main objective of this paper is to provide a realistic weight model, based on the physical-mathematical foundations, for the design of the new very large lighter-than-air vehicle, called Multibody Advanced Airship for Transport (MAAT), the ongoing European FP7 project, which is currently under intensive research and development activities.

The Modeling and Simulation (M&S) principles, aided with simulations and visualization tools, have been extensively used, as the key enablers to combine, manage and structure such highly complex engineering process, which emerged as a natural integration mechanism and evidence provider of the encountered complexity, successfully encompassing the MAAT multidisciplinary design requirements.

The authors experience, in solving the M&S problems, gained within the European R&D projects, was efficiently reused, where the use of such software technologies have been successfully demonstrated, and today, further applied for the new generation transportations solutions, as envisaged by MAAT, especially addressing the best practices in taking advantage of the variety of multi-physics software and their related analysis tools.

The MAAT system is envisaged to be composed of two airships: the Cruiser, which stays at a constant altitude of 16 km, travelling horizontally; and the Feeder, which acts like an elevator system connecting the Cruiser to the ground.

In this paper, the proposed weight model is similar to the typical one applied in the aircraft design process. The main difference is primarily the airship teardrop shape, which is commonly applied for the currently produced airships. The main challenge is that MAAT has a very large shape, which has required the introduction of new elements and references, as being presented in this work.

The achieved results show that MAAT can be realized, by taking into account the significant weight estimated for such aircrafts, to be for the Cruiser about 533 tons, while the Feeder weight is about 12 tons.

As highlighted before, the MAAT design is still under intensive developments, and thus, it is expected that in the coming years, by taking into account the new emerging technological solutions, the lightening of such aircrafts structure is inevitable. In addition, the authors plans are to further investigate new materials and their related applications, in order to improve the structural part of the MAAT system, as one of the essential parts in such new transportation system, expected to become the reality in the forthcoming future.

NOMENCLATURE

Cruiser:

A_{bnet}	[m^3]	Cruiser - internal balloon area (ballonet)
b	[m]	Cruiser - width of the balloon
$d_{e,beam}$	[m]	Cruiser - external diameter of beams
$h_{end,cab}$	[h]	Cruiser - emergency endurance of energy in control cabin
$h_{end,prop}$	[h]	Cruiser - emergency endurance of energy for engines of the cruiser
$h_{fus,lat}$	[m]	Cruiser - fuselage height of the lateral part
l	[m]	Cruiser - length of the balloon
l_{beam}	[m]	Cruiser - total length of beams
$l_{fus,lat}$	[m]	Cruiser - fuselage length of the lateral part
$q_{fus,lat}$	[m]	Cruiser - fuselage width of the lateral part
W_{env}	[kg]	Cruiser - cloth envelope weight

Feeder:

A_{ball}	[m^2]	Feeder - area of the balloon
A_{cone}	[m^2]	Feeder - cone area
A_{cyl}	[m^2]	Feeder - cylindrical area of the hole through which the central column is passing
A_{dome}	[m^2]	Feeder - dome area
d_{cyl}	[m]	Feeder - diameter of the hole through which the central column is passing
$d_{e,cul}$	[m]	Feeder - external diameter of the central column
$h_{cone,to}$	[m]	Feeder - height of the conical lower section of the ball at sea altitude
$h_{dome,to}$	[m]	Feeder - height of the spherical upper dome at

		sea altitude
h_{max}	[m]	Feeder - maximum height of the balloon
$P_{r,g}$	[kW]	Feeder - general power of onboard users, excluding propulsion and winches
r_{feed}	[m]	Feeder - radius of the lower base of the conic section
V_{cul}	[m^3]	Feeder - volume of the feeder central column
W_{ball}	[kg]	Feeder - balloon mass
$w_{feed,max}$	[N]	Feeder - maximum lifted weight
$W_{feed,max}$	[kg]	Feeder - maximum lifted mass

General:

A_{cei}	[m^2]	Surface of the fuselage ceiling
A_{fl}	[m^2]	Surface of the fuselage floor
A_{fus}	[m^2]	Lateral surface of the fuselage
A_{wall}	[m^2]	Surface of the fuselage wall
C.A.		Cruiser altitude
D_c	[N]	Aerodynamic drag at the cruiser altitude
d_{fus}	[m]	Fuselage diameter
E_{dist}	[kg/kW]	Weight/power ratio of the power cable distribution system
E_{duc}	[kg/kW]	Power to weight ratio for the conduit
$E_{duc,pr}$	[kg/kW]	Power to weight ratio of the propeller fan
E_{eng}	[kg/kW]	Weight/power ratiofor the engine installed
E_{prop}	[kg/kW]	Weight/power ratio for the free propeller
$E_{s,batt}$	[kWh/kg]	Specific energy of the battery
$E_{s,fuel}$	[kWh/kg]	Specific energy of fuel cells
E_{winch}	[kg/kW]	Lifting winch for sheets: weight- power ratio
h_{batt}	[h]	Endurance of the batteries of the feeder in emergency
h_{end}	[h]	Endurance
J	[-]	Global value across the spectrum of the coefficient of atmospheric attenuation for Threlked and Jordan atmosphere (depending on the day of the year - here on December 21-)
k	[-]	Percentage of overpressure
k_{cat}	[-]	Weight percentage of the catenary ball
k_{lin}	[-]	Weight percentage of the gas line ball
k_{pat}	[-]	Weight percentage of the ball patches, reinforcement
l_{fus}	[m]	Fuselage length
l_{rope}	[m]	Ropes - length
l_{wiring}	[m]	Electric wiring length
m_p	[kg]	Mass of the lost gas
n	[-]	Structural safety factor
N	[-]	Number of pulleys
N_{bath}	[-]	Number of bathroom
N_{rope}	[-]	Number of ropes
N_{seat}	[-]	Number of seats
p	[l/m^2/h]	Permeability coefficient of the cloth-film with hydrogen gas
P_0	[Pa]	Air pressure at sea level
Pa	[Pa]	Air pressure
P_{hyd}	[K]	Pressure of the hydrogen
$P_{ref,e}$	[kWh/Nm^3]	Power per unit volume of H_2 produced by electrolysis
R_{hyd}	[J/(kgK)]	Specific constant of the hydrogen
S.A.		Sea altitude
T_a	[K]	Absolute air temperature
T_h	[K]	Absolute overheating temperature of the hydrogen
T_{hyd}	[K]	Absolute temperature of the hydrogen
V_c	[m/s]	Flight Speed at the cruiser altitude
V_{cl}	[m/s]	Cloth speed to descent/climb
V_p	[Nm^3]	Volume of the lost gas
W_{1seat}	[kg]	Weight of the unit seat
W_{batt}	[kg]	Battery weight
W_{batt}	[kg]	Battery weight
W_{cat}	[kg]	Weight of the catenary
W_{cei}	[kg]	Weight of the fuselage ceiling
$W_{cockpit}$	[kg]	Weight of the cockpit
W_{fl}	[kg]	Weight of the fuselage floor
W_{food}	[kg]	Weight of the food
$W_{general}$	[kg]	Weight of the ballast and general components
W_{HP}	[kg]	Weight of hydraulic and pneumatic system
W_{lin}	[kg]	Weight of the gas-line
W_{main}	[kg]	Access/maintenance weight
W_{ot}	[kg]	Weight of other components (fill valves, rip system, through fabric gaiters and cable conduits)
W_{pat}	[kg]	Weight of patches, reinforcement
W_{pt}	[kg]	Weight of the paint
W_s	[kg]	Weight of the structural part
$W_{total,fan}$	[kg]	Propulsion system weight at the cruiser altitude
W_{wall}	[kg]	Weight of the fuselage wall
W_{wiring}	[kg]	Electric wiring weight
X	[-]	Safety coefficient for eventual overload
z	[m]	Reference altitude (sea or cruiser levels)

Greek characters:

η_{pu}	[-]	Efficiency pulley
ρ_{bnet}	[kg/m^2]	Fabric ballonet surface density
ρ_{cei}	[kg/m^2]	Surface density of the fuselage ceiling
ρ_{fl}	[kg/m^2]	Surface density of the fuselage floor
ρ_{hyd}	[kg/m^3]	Hydrogen density
ρ_{paint}	[kg/m^2]	Surface density of the paint
ρ_{rope}	[kg/m]	Ropes - linear density
ρ_{wall}	[kg/m^2]	Surface density of the fuselage wall
ρ_{wiring}	[kg/m]	Linear density of the electric wiring

INTRODUCTION

Nowadays, due to the intrinsic advantages of Lighter-Than-Air vehicles, characterized by minimal energy consumption and Vertical Take-Off and Landing (VTOL), significant efforts are being taken to investigate their new applications. In this context, the MAAT project has been conceived as the future green air transport system. The MAAT system is designed to consist of the two components: the Cruiser, which stays at a constant altitude of 16 km, travelling horizontally; and the Feeder, which acts like an elevator, flying from the ground to the Cruiser. After the docking procedure, when the Feeder reaches the Cruiser, the cargo and passengers are transferred between the both airships. Figure 1 shows the virtual model of the conceptual MAAT system design.

Figure 1 MAAT system conceptual design

For the Lighter-Than-Air vehicles, it is critical that the vehicle is not overweighed. This is even more important parameter to consider, if compared to the heavier-than-air aircraft design. The Lighter-Than-Air vehicles are dimensioned in such a way that the buoyancy force counteract the weight, which means that the buoyant gas volume has to be sufficient to equal the total airship weight. Thus, it is vital to accurately estimate each component weight, as the unrealistic estimates will cause problems along the design process [1].

The MAAT airships have been initially conceived as non-rigid airships, which mean that their principal structural element is the envelope. For the non-rigid airships, the envelope membrane is pre-stressed, by applying an adequate internal overpressure, in order that the envelope is able to withstand the impacting loads and maintain the desired aerodynamics geometry. In addition, there are structural elements aimed to distribute the loads along the envelope, as a suspension system (catenary cable system), where the gondola is attached with cables. If necessary, the frontal part might include a nose cone structure, in order to reinforce the main structure and decrees the internal overpressure. The main advantage of the non-rigid airships is their lightweight characteristics, since the main structural component is the, membrane fabric material. Another significant advantages are related to the easiness to be: designed, built and maintained [2]. However, there are drawbacks in the non-rigid solutions of the large-non-conventional airships, and they encouraged the development of a novel lightweight structure solution based on the Tensairity concept, and found appropriate to be applied to the MAAT airships. However, this paper, considers the initial non-rigid solution, in which the Tensairity airship keel has not yet been introduced [3], [4].

Besides being non-rigid, the two MAAT airships types fall in the non-conventional category, due to their uniqueness and originality of the shape design, which is very different from the commonly applied cigar-shaped forms. However, based on the recent advancement in the non-conventional design, the explored alternative shapes where especially considering the dependences on the airship mission. The researched examples are the lenticular airships; where their upper surface is maximize to allow larger space for the placement of the solar panels. The MAAT airships shape has resulted from an extensive optimization process, which aims to minimize the drag force and longitudinal airship stability equilibrium, as presented in details in [5], [6], [7] and [8].

The MAAT research comprises the general analysis and design process of both Cruiser and Feeder airships types. The design process starts by the identification of the mission requirements, which define the initial conceptual design, integrating the inputs from the multidisciplinary research domains involved. From the results and their analysis obtained within the involved disciplines, the airships are designed (mass, inertias, gravity center, aerodynamic coefficients…) and their equation of motion can be computed, enabling the study of their controllability. This multidisciplinary collaborative design process is an iterative loop supporting the re-defining of the initial conceptual design, by accordingly taking into account the obtained results from the multidisciplinary teams and leveraging them to achieve the possible solution, which final aim is to meet the MAAT mission requirements. Such collaborative design process is graphically represented in Figure 2.

In this paper, the physical-mathematical modeling along the mentioned iterative loop for the design of the airships characteristics is introduced. This approach considers the non-conventional airship shape, as the traditional formulations found in the classical airship design cannot be directly applied for the MAAT components dimensioning. Thus, it is expected that the presented mathematical model for the different components weights, as required during the applied multidisciplinary iterative design, will drive the MAAT design to the final solution.

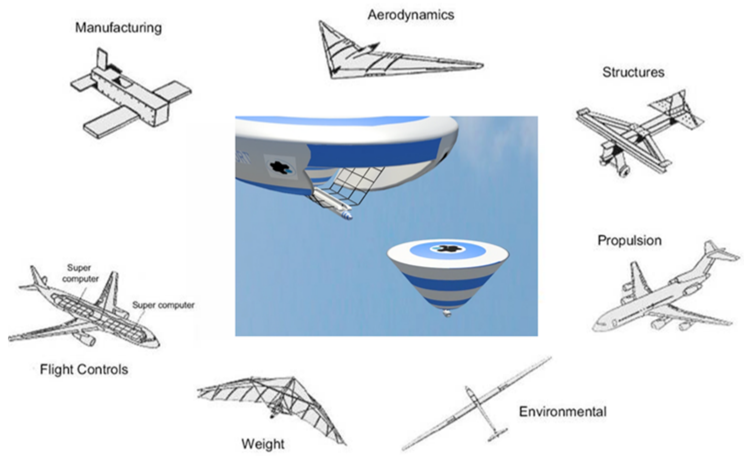

Figure 2 Multidisciplinary collaborative design

The MAAT system components are divided in groups to ease the definition of the weight model, as follows:

a) **Hull group**: envelope, ballonet, suspension system and access areas for everyday operations and maintenance activities,
b) **Energy group:** photovoltaic, fuel cells, batteries, and support equipment,
c) **Auxiliary group:** pneumatic and hydraulic systems distribution pipelines, actuators, pressurized air storage, air conditioning, compressors, filters, reservoirs, accumulators, valves, emergency and flight control systems, etc.
d) **General group:** cabin (gondola), with associated integration structure including the suspensions-attachments, which integrates the previous mentioned groups (a-c), and further integrates the other sub-systems: propulsion, docking, landing gear, external mountings, ballasts and any other auxiliary components.

The mathematical modeling for the determination of the above-mentioned components for Feeder and Cruiser airships [1] is further detailed in the following sections of this paper.

MAAT CONFIGURATION: CRUISER AND FEEDER AIRSHIPS

MAAT consists of a set of more airships: the cruiser that is always at a predetermined flight altitude, and 2 or more feeders (taking off from the ground) for the passengers and cargo transfer to the cruiser.

The MAAT system does not fall into the category of classic non-rigid airships, it is an unconventional, but it is nevertheless a non-rigid airship. It maintains its envelope shape through the pressure difference with the outside atmosphere.

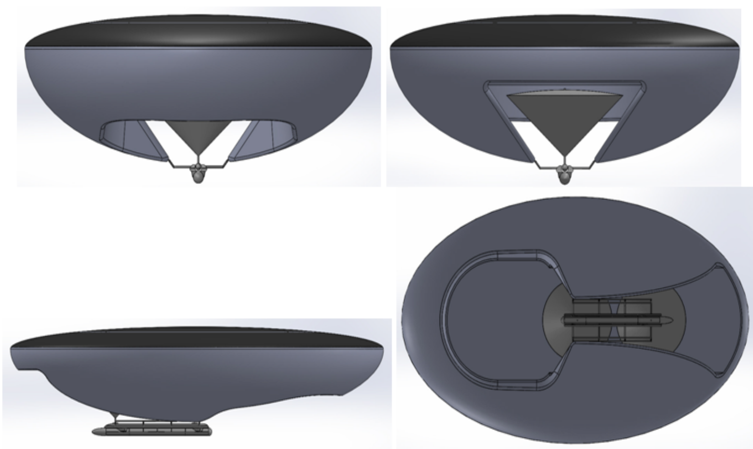

Figure 3 Cruiser and feeders shapes

The sizing of the cruiser was done by considering one specific cruising altitude, however, for the feeder this was not possible, because it has to support a very different mission profile: to take off from the ground, to reach the altitude of the cruiser, to dock to the cruiser, to cruise with the cruiser, to undock from the cruiser, to descent and finally land to the earth.

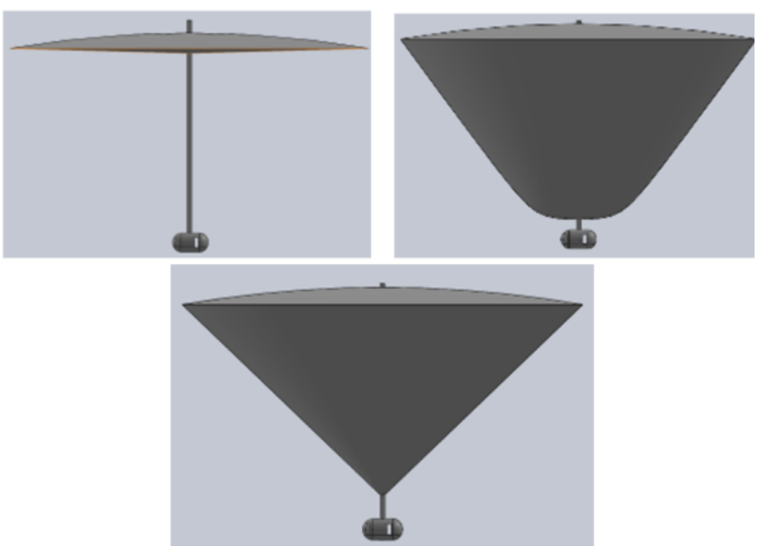

Figure 4 3-volume variations of the feeder

These different operating conditions require an appropriate model in analyzing such system. For the preliminary investigation, the authors have chosen 2 fixed altitudes: (1) sea level (zero altitude) and (2) that of the cruiser. This choice was due to the feeder characteristics to change its volume during its mission from the ground to the cruiser and back to earth.

The cruiser has been sized by considering the full load, while the feeder has been sized with no passengers on board, thus, not including the crewmembers. This was done because only the additional volume was considered to reach the cruiser altitude, which variation has to be controlled by applying more ropes, in order to extend it with the conical flask.

The initial cruiser shape had the pure ellipsoidal form. Subsequently, the authors have decided to use the cruiser shape (having the same volume), with the central zone, in which the feeders are docked, as shown in Figure 3, where the cruiser and feeders are arranged for the cursing mission.

In Figure 4, the feeder is shown in 3 versions: (1) ground version, (2) cruiser level version and (3) unloading version, when it is inside the cruiser.

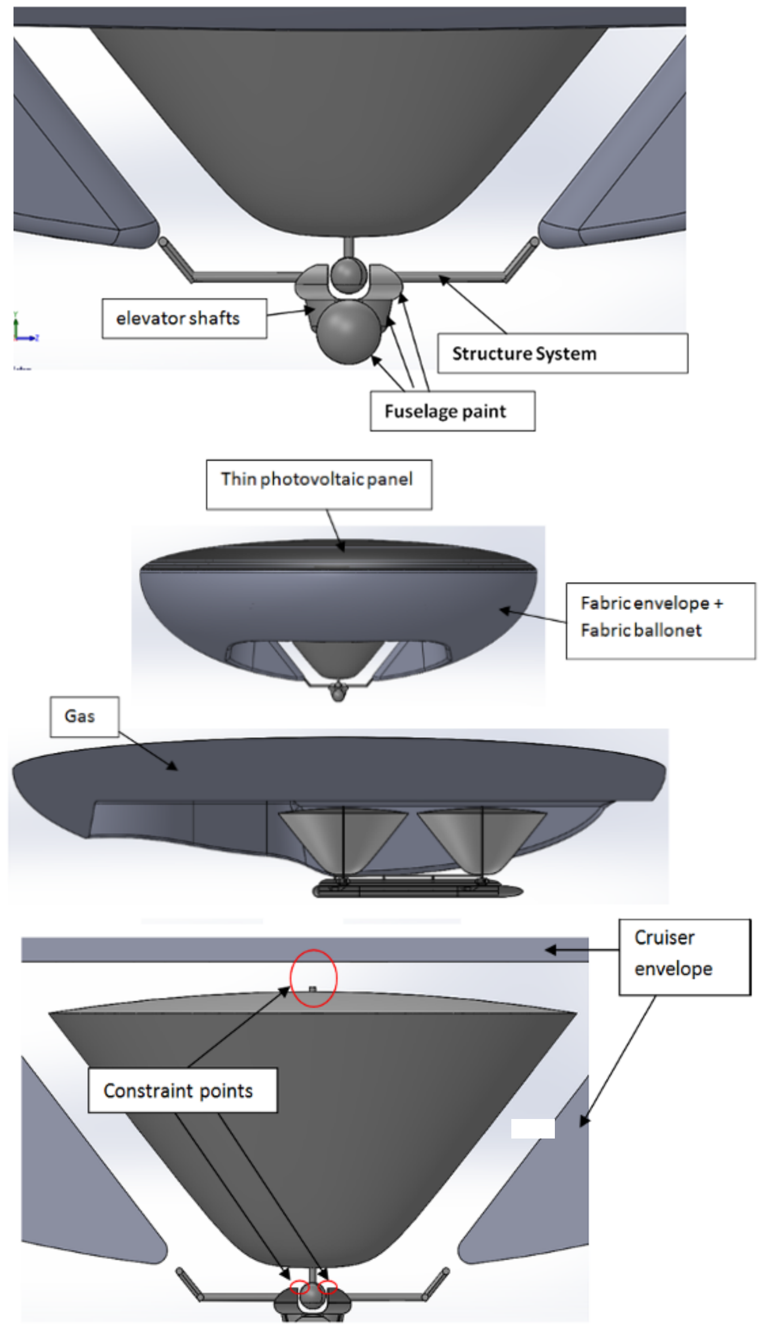

Figure 5 3-constraint points and nomenclature of some parts on the cruiser

Each feeder is connected to the cruiser at 3 points (isostatic structure). In addition, each attachment point is equipped with the guide and tow system. The tow system allows the controlled displacement of the feeder during the docking, enabled by 2 electric motors supporting the tow action, where the electromechanical clamps lock the feeder to the guides. The lateral docking system is defined for such configuration. Once the feeder is correctly position inside the cruiser and the door openings are totally matching, the door system opens and slides inside the vehicles external wall. During this process the closing mechanism encloses the openings by securing them to be air tightness.

Once such condition is obtained inside the passage, the interior doors open by sliding inside the external wall of the both vehicles, and in such way preserve the pressurized volume for the passengers transfer. The reverse operation will be applied for the closing of the doors. Figure 5 shows the 3 constraint points and the nomenclature for the cruiser parts. Figure 6 shows the passengers loading/unloading area, as envisaged conceptually in the docking system. This area consists of the walkway, which is placed inside the cylindrical arm that connects to the feeder. The docking system is only located on one side of the cruiser, but at 2 different locations: (1) in the front and (2) in the rear part of the fuselage, as shown in the bellow images.

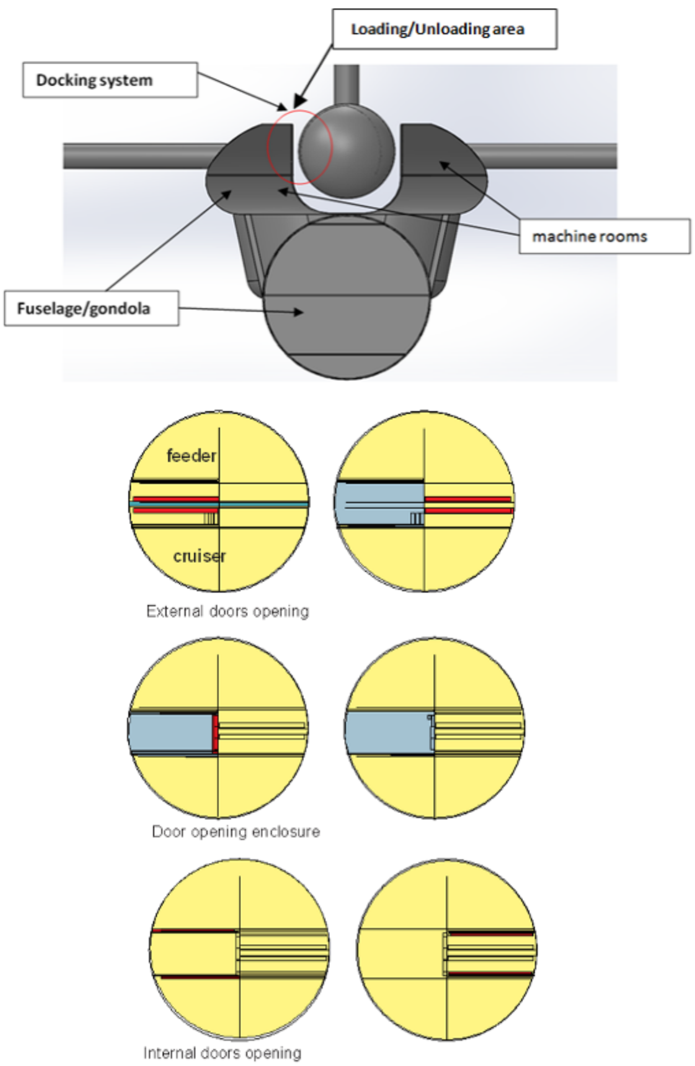

Figure 6 Loading/unloading area in the conceptual docking system

PHYSICAL-MATHEMATICAL MODEL FOR THE SIZING

The sizing of the MAAT airships (cruiser + feeders) is based on the methodology presented in Figure 7. The diagram shows an iterative cycle that involves all the sub-systems constituting the aircraft (propulsion, structures, energy, aerodynamics, etc.). Every part interacts closely with each other, and thus affecting the size and weight of the designed aircraft. The solution resulting from the modeling approach presented in this diagram is simplified, because of the assumptions made for the respective aircrafts, but nevertheless it is close to the final CAD shape designed. The defined equations for the sizing of the 2 airships have been selectively used for feeder and cruiser respectively.

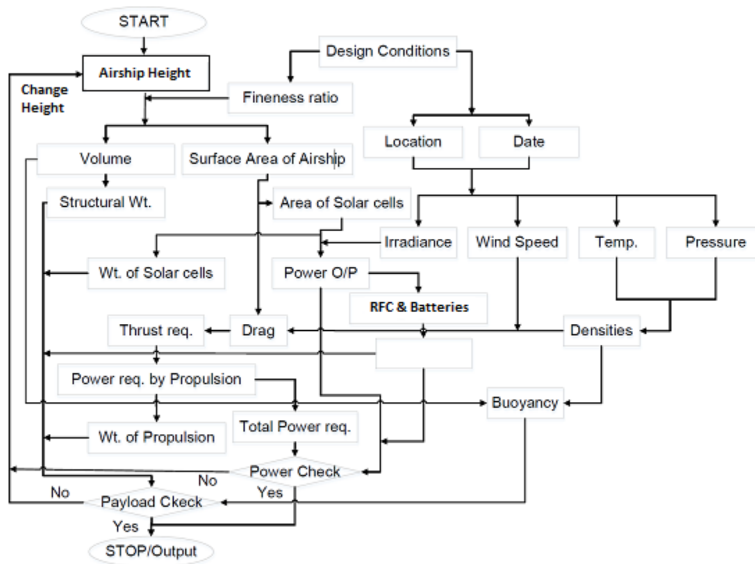

Figure 7 Methodology to size the MAAT system

Feeder

For the calculation of the required volume needed to reach the cruiser altitude, the condition was to use only the variation of the volume of the ball, i.e. aircraft volume estimated without crew and passengers, its variation (with ropes) will give the needed volume expected to take off and be sufficient to the feeder to reach the cruiser altitude.

The defined model required some preliminary hypothesis to be taken into account, as follows:

i. Spherical upper dome. It has fixed l_{dome}, but V_{dome} and h_{dome} are estimated in an iterative way (an initial volume is set); these latter two parameters are estimated at sea level. They are kept constant throughout the mission.

ii. Conical lower section of the ball. It has h_{cone} at sea level fixed and V_{cone} to be estimated in an iterative way. An initial volume at the cruiser altitude has been set.

iii. Standard International Atmosphere model to estimate environment conditions at various altitudes.

iv. Completely cylindrical fuselage. In this way, it is possible to simplify the model (and the real weight has a margin because the fuselage has two domes (nose and tail).

v. Engine with air jets: ducted fans as distributed propulsion system.

vi. Passengers and crew are not considered in the sizing of the volume. The volume will be increased to fly with these extra weights. It will be considered as an additive term to the estimated volume with the unloading feeder.

vii. Fuel cells and batteries are used.

The first design iteration was performed by the following equations:

$$\begin{cases} h_{dome,to}(1) = \dfrac{\left(\dfrac{l_{dome}}{2}\sqrt[3]{2}\right)^2 + \left(\sqrt[3]{\sqrt{4\left(\dfrac{l_{dome}}{2}\right)^6 + \left(-6\dfrac{V_{dome}(1)}{\pi}\right)^2} - 6\dfrac{V_{dome}(1)}{\pi}}\right)^2}{\sqrt[3]{2}\sqrt[3]{\sqrt{4\left(\dfrac{l_{dome}}{2}\right)^6 + \left(-6\dfrac{V_{dome}(1)}{\pi}\right)^2} - 6\dfrac{V_{dome}(1)}{\pi}}} & \text{S.A.} \\ h_{dome}(1) = h_{dome,to}(1) & \text{C.A.} \end{cases} \quad (1)$$

$$\begin{cases} h_{cone}(1) = h_{cone,to} & \text{S.A.} \\ h_{cone}(1) = \dfrac{3V_{cone}}{\pi\left[\left(\dfrac{l_{dome}}{2}\right)^2 + \dfrac{l_{dome}}{2}r_{feed} + r_{feed}^2\right]} & \text{C.A.} \end{cases} \quad (2)$$

The volume of the conical balloon is defined by the simple ball geometry at the cruiser altitude:

$$V_{cone}(1) = \frac{h_{cone,to}\pi}{3}\left[\left(\frac{l_{dome}}{2}\right)^2 + \frac{l_{dome}}{2}r_{feed} + r_{feed}^2\right] \quad (3)$$

The total volume is estimated as the sum of the dome and cone volumes.

$$V_{total} = V_{dome} + V_{cone} \quad (4)$$

This above relationship is valid for the sea level, but also for the cruise altitude.

The value of the maximum height of the balloon is estimated from this first iteration, and used as the reference for sizing of the aircraft and its central column at the cruise altitude. The buoyancy force is equal to the maximum lifted weight $W_{feed,max}$ (or maximum mass, $W_{feed,max}$), which is latter estimated with the V_{tot} [1].

$$h_{\max} = h_{dome} + h_{cone} \quad (5)$$

$$\begin{cases} B = g\rho_a V_{tot} \\ B = w_{feed,\max} & \rightarrow W_{feed,\max} = \rho_a V_{tot} \\ w_{feed,\max} = W_{feed,\max}g \end{cases} \quad (6)$$

where ρ_a is at C.A. and equation (5) is valid for every iteration.

Equation (6) defines the initial reference weight of the aircraft.

The hydrogen temperature, pressure and density is estimated by ISA model [9], [10] and [11], as these parameters allow obtaining the mass of the hydrogen inside the balloon [1].

$$\begin{cases} T_{hyd} = T_a + T_h \\ P_{hyd} = (1+k)P_a \rightarrow W_g = \rho_{hyd}V_{tot} \\ \rho_{hyd} = \dfrac{P_{hyd}}{T_{hyd}R_{hyd}} \end{cases} \quad (7)$$

The area of the balloon is estimated at C.A., because there must be enough fabric to sustain the required volume. A larger volume can exploit the elasticity of the envelope material. The surface is obtained as the summing the areas of the dome, cone and cylindrical hole through which the central column passes.

The envelope surface allows computing of its mass W_{ball}.

$$\begin{cases} A_{ball} = A_{dome} + A_{cone} + A_{cyl} \\ A_{dome} = \pi\left[\left(\dfrac{l_{dome}}{2}\right)^2 + h_{dome}{}^2\right] \\ A_{cone} = \pi\left[\left(r_{feed} + \dfrac{l_{dome}}{2}\right)\sqrt{h_{cone}{}^2 + \left(\dfrac{l_{dome}}{2} - r_{feed}\right)^2} + r_{feed}{}^2\right] \\ A_{cyl} = d_{cyl}\pi h_{\max} \end{cases} \quad (8)$$

$$W_{ball} = \rho_{bnet}A_{ball} \quad (9)$$

The weight estimations of (1) gas-lines (fabric tunnels to inflate the gas into the balloon), (2) catenary (fabric structure to hang from the suspension cables), (3) patches and reinforcements needed, defined in the percentages of the ball cloth weight [1]. These parameters are estimated at a cruiser altitude, and calculated the sum of these 3 masses, $W_{fab,\,str}$.

$$\begin{cases} W_{lin} = k_{lin}W_{ball} \\ W_{cat} = k_{cat}W_{ball} \\ W_{pat} = k_{pat}W_{ball} \\ W_{fab,str} = W_{lin} + W_{cat} + W_{pat} \end{cases} \quad (10)$$

Equations (7-10) are valid regardless of the number of iterations made.

The total fuselage weight and the interior furnishing is defined according to the following criterion.

$$\begin{cases} W_{wall} = \rho_{wall}A_{wall} \\ W_{fl} = \rho_{fl}A_{fl} \\ W_{cei} = \rho_{fl}A_{cei} \\ W_{fus,str} = W_{wall} + W_{fl} + W_{cei} \end{cases} \quad (11)$$

$$W_{furn} = N_{seat} W_{1\ seat} + N_{bath} W_{1\ \mathrm{bath}} + W_{food} + W_{cockpit} \tag{12}$$

$$W_{fus,tot} = W_{fus,str} + W_{furn} + W_{general} \tag{13}$$

The access/maintenance W_{main} and other components W_{ot} (fill valves, rip system, with fabric gaiters and cable conduits) are defined by interpolation from the data provided by G. A. Khoury [1].

$$W_{main} = 0.004 V_{tot} - 32.07 \tag{14}$$

$$W_{ot} = 0.004 V_{tot} + 23.78 \tag{15}$$

The interpolated data are shown in Figure 8, and they are valid for large airships.

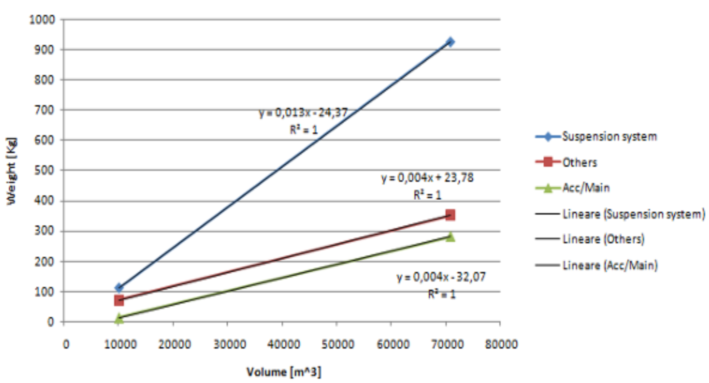

Figure 8 Interpolation data for suspension system, others items, access and access/maintenance [1]

The weight of the paint is estimated by the following equation:

$$W_{pt} = \rho_{\mathrm{paint}} A_{fus} \tag{16}$$

The next equation defines the propulsion system weight, at the cruiser altitude.

$$W_{total,fan} = P_{r,c}\left(E_{eng} + E_{duc,pr} + E_{duc}\right) \tag{17}$$

where $P_{r,c}$ is the required propulsion power at the cruising altitude, which is estimated as function of the aerodynamic drag and the flight-cruise speed [12]:

$$\begin{cases} P_{r,c} = D_{feed} V_c \\ D_{feed} = \dfrac{1}{2} C_D \rho_a V_c^2 V_{tot}^{2/3} \end{cases} \tag{18}$$

The aerodynamic drag takes into account the effect of the ball and of the fuselage.

	Boeing 737-200	Boeing 727-100	Boeing 747-100	Airbus A-300 B2	McDonnell Douglas DC-9-30	McDonnell Douglas MD-80	McDonnell Douglas DC-10-10
Length [m]	30.53	46.69	59.64	53.62	36.3	45.06	55.5
Heigth [m]	11.29	10.36	19.33	16.53	8.38	9.02	17.7
Mean Volume of the fusolage [m^3]*	3056	3936	17502	11507	2002	2879	13656
Passenger Capability	232	189	452	250	115	142	380
	Weight [lb]	**Weight [lb]**	**Weight [lb]**	**Weight [lb]**	**Weight [lb]**	**Weight [lb]**	**Weight [lb]**
Avionics+Instrum.+Electrical & Electronic systems	2647	4489	9686	7026	2780	3850	8780
Hydraulic & Pneumatic System	873	1418	4471	3701	760	830	4120
Electrical System	1066	2142	3348	4923	1330	1720	5370
Electronics	956	1591	4429	1726	Included in avionics and instrument		
Air condit. Systema (with pressurization siystem) & Anti-icing System	1416	1976	3969	3642	1600	2130	2810
*cylindrical fuselage							

Figure 9 Reference airplanes [13]

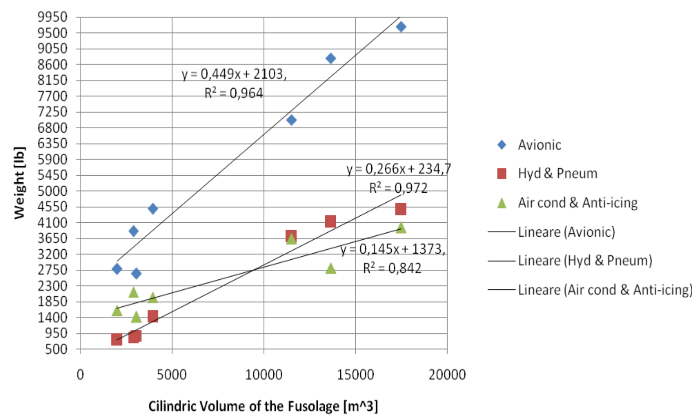

Figure 10 Airplane component weights

The power plant includes: emergency batteries, electric wires for normal users, electrical power cables and board avionics. The equation of interpolation for the avionic weight was obtained using the data for commercial airplanes, as shown in Figure 9 [13]. Figure 10 shows the trend of the weight increase, in respect to the theoretical cylindrical volume V_{fus} of a possible fuselage. The latter is defined as the theoretical volume that can be obtained from the maximum height and length of the aircraft.

$$W_{avio} = 0.454(0.449 V_{fus} + 2103) \tag{19}$$

The power plant is sized in respect to the total power required $P_{r,tot}$ at cruiser altitude, because it is lower at sea level. It includes the power required by the propulsion $P_{r,c}$, by users $P_{r,u}$ and by electric winches $P_{r,w}$.

$$\begin{cases} P_{r,tot} = P_{r,c} + P_{r,u} + P_{r,w} \\ W_{dist} = \mathrm{E}_{dist} \dfrac{P_{r,tot}}{\cos(120)} \\ W_{batt} = \dfrac{P_{r,tot} h_{batt}}{E_{s,batt}} \end{cases} \tag{20}$$

$$W_{wiring} = \rho_{wiring} l_{wiring} \tag{21}$$

$$W_{PP,A} = W_{batt} + W_{wiring} + W_{dist} + W_{avio} \quad (22)$$

The electric users and winch powers are defined as

$$P_{r,u} = \frac{0.4N_{pass} + P_{r,g}}{\cos(120)} \quad (23)$$

$P_{r,g}$ reference value is shown in Table 1.

Table 1 General power of users on board

General feeder power for the on board users	**Power [kW]**
Avionic system	1.5
Emergency lighting (internal & external)	2
Freight transport	3
Light (internal cabin, external)	2
Situation awareness and structural monitoring (48V)	3
Total Power $P_{r,g}$	**11.5**

$$\begin{cases} P_{r,w} = \dfrac{TV_{cl}X}{102N\eta_a\eta_v\eta_{pu}} \\ V_{cl} = h_{cone}/h_{end} \end{cases} \quad (24)$$

The total load T, to move the feeder is given by the sum of the weight of ropes W_{rope} and the fabric of the balloon:

$$\begin{cases} T = W_{ball} + W_{rope} \\ W_{rope} = N_{rope}\rho_{rope}l_{rope} \end{cases} \quad (25)$$

The total weight of the system winch W_w is defined as:

$$W_w = P_{r,w}E_{winch} + W_{rope} \quad (26)$$

The weight of the fuel cell is given by the following equation:

$$W_{fuel} = \frac{P_{r,tot}h_{end}}{E_{s,fuel}} \quad (27)$$

The weight of the docking system (pressurized unloading area) is estimated by taking as an example, the system of the International Space Station ISS, see Figure 11. It is called PMA 3 (Pressurized Mating Adapters) [14]. It allows the docking systems used by the Space Shuttle and by Russian modules to attach to the Node's berthing mechanisms. It provides a pressurized interface between the U.S. and Russian ISS modules and between the U.S. modules and the Space Shuttle orbiter.

The dimensions and the weight of such a system are shown in Table 2. The authors estimated the equivalent weight in the case of the feeder with the assumption of completely cylindrical module.

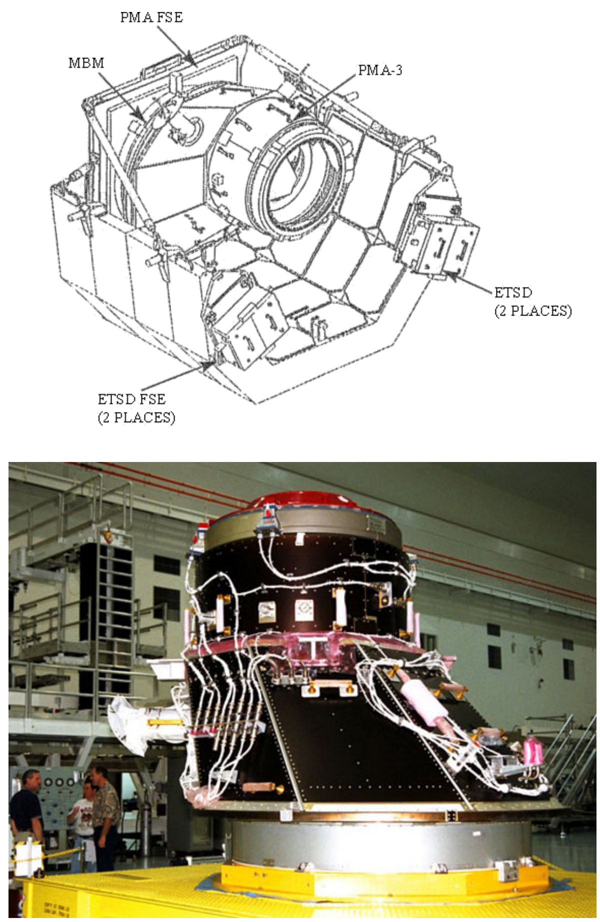

Figure 11 PMA-3

Table 2 PMA-3 docking System

Length l_{PMA}	[m]	1.86
Width d_{PMA}	[m]	1.9
Mass M_{PMA}	[kg]	1183

$$\begin{cases} W_{dock} = \dfrac{M_{PMA}}{V_{PMA}}V_{dock} \\ V_{PMA} = \pi l_{PMA}\left(\dfrac{d_{PMA}}{2}\right)^2 \\ V_{dock} = \pi l_{dock}\left(\dfrac{d_{dock}}{2}\right)^2 \end{cases} \quad (28)$$

The pneumatic and hydraulic systems are defined as:

− Pneumatic Systems: distribution, accumulators, filters, valves, compressors, emergency systems, emergency, instruments,

− Hydraulic Systems: distribution, accumulators, filters, valves, compressors, emergency systems, and flight control.

Figure 9 shows data, which allows interpolation for the weight W_{HP} of these 2 elements. Even the air conditioning (pressurized system) with anti-icing systems can be estimated from the data in **Figure 9**. The sum is defined with $W_{A,H,P}$.

$$\begin{cases} W_{A,H,P} = W_{api} + W_{HP} \\ W_{HP} = 0.454(0.266V_{fus} + 234.7) \\ W_{api} = 0.454(0.145V_{fus} + 1373) \end{cases} \quad (29)$$

The suspension system is defined as the set of items that allows the suspension of the gondola from the envelope, though excluding itself and central column. Figure 8 also allows obtaining the interpolation equation for such estimates.

$$W_{susp} = 0.013V_{tot} - 24.37 \quad (30)$$

The central column is sized by considering the carbon tube. It is assumed to be a tube with an internal diameter $d_{i,cul}$ and external diameter $d_{e,cul}$. The initially assumed criterion is to define the weight of the total fuselage as load. This hypothesis is too restrictive, because in reality, the airship may be subject to various other loads, such as the aerodynamic loads on the ground and in flight. A high safety factor *n* corrects this simplification. Thus, the weight of the column is estimated by considering the density of the typical carbon tube and the volume of the column that takes n into account.

$$\begin{cases} W_{cul} = \rho_{carb} V_{cul} \\ V_{cul} = V_{cul}\left(n, d_{e,cul}, h_{\max}, W_{fus,tot}\right) \end{cases} \quad (31)$$

The total mass of the airship $m_{tot,max}$ is then defined as the total sum of the previously estimated weights. This mass is used to estimate the new total volume at the sea and cruise levels, performing the following iteration:

$$\begin{aligned} W_{feed,\max}\left(i+1\right) = {} & \mathrm{W}_{general} + \mathrm{W}_{furn} + \mathrm{W}_{fus,str} + \mathrm{W}_{pt} + \mathrm{W}_{A,H,P} + \\ & + \mathrm{W}_{dock} + \mathrm{W}_{g} + \mathrm{W}_{ball} + \mathrm{W}_{fab,str} + \mathrm{W}_{susp} + W_{cul} + \\ & + \mathrm{W}_{main} + \mathrm{W}_{ot} + \mathrm{W}_{total,fan} + \mathrm{W}_{PP,A} + \mathrm{W}_{fuel} + \mathrm{W}_{w} \end{aligned} \quad (32)$$

$$V_{tot}\left(i+1\right) = \frac{W_{feed,\max}\left(i+1\right)}{\rho_a\left(z\right)} \quad (33)$$

Knowing the total volume for the i+1 iteration at the sea level, it is possible to compute the new volume of the dome by subtracting it from the cone volume (which remains the same for each iteration made at the sea level). The new height of the dome is estimated with the equation (1), which is also valid for the various iterations. The hypothesis of its height at the sea level is equal for the cruiser level, as the dome volume is kept unchanged at different flight altitudes. The new dome volume is used to estimate the new cone volume at the cruiser level.

$$V_{dome}\left(i+1\right) = V_{total}\left(i+1\right) - V_{cone} \quad \text{S.A.} \quad (34)$$

$$V_{cone}\left(i+1\right) = V_{total}\left(i+1\right) - V_{dome}\left(i+1\right) \quad \text{C.A.} \quad (35)$$

If the passengers weight W_{pass} is considered, then the effective volume required at sea level, as the one at the cruiser level is defined by:

$$\begin{cases} V_{tot,e} = \dfrac{W_{s,tot}}{g\left(\rho_a - \rho_{hyd}\right)} \\ W_{s,tot} = W_{pass} g + W_s \end{cases} \quad (36)$$

Each person is assumed to have 110 kg (with luggage) and the number of people (including crew) is 28 on board.

Instead, the percentage change of the two volumes is given by:

$$\Delta V_{tot} = 100\left(1 - \frac{V_{tot}}{V_{tot,e}}\right) \quad (37)$$

Cruiser

The preliminary hypotheses for the cruiser are:

i. The balloon is ellipsoidal. This hypothesis allows estimating the minimum volume required to float in the air.
ii. An internal balloon (ballonet) and an external balloon (envelope) are considered. They have the same size.
iii. After reaching the convergence of the iteration, then the balloon is changed in its form, which is shown in Figure 3.
iv. The new shape allows a new estimate (using the same formulas, but with the volume and surface of the cloth set) not in an iterative way of the gas, thin photovoltaic modules, batteries and regenerative fuel cells. Weights of other items are maintained equal to the case of the ellipsoidal balloon. Then total lift and total weight, drag, volume gas loss, total power request etc. will change.
v. Standard atmosphere model is adopted.
vi. The fuselage of the cruiser consists of 3 different shapes: a partially cylindrical body (for simplicity, it is considered entirely cylindrical), 2 bodies of approximately parallelepiped shape. While the cylindrical body is estimated by considering the effect of the internal pressure, the approximate weight estimate per square meter is made for the 2 lateral bodies (because they are machine rooms). The needed surface is provided by the CAD. In this way, it is possible to simplify the model (and the real weight has a margin).
vii. Engines are equipped with free propellers.
viii. Passengers and crew are considered in the sizing of the volume.
ix. Regenerative fuel cell system and batteries are used.

The total volume of the balloon and the two plane axes made possible to estimate its height with the equation of the ellipsoid. From the given volume the mass of gas is estimated.

In this case the equation (7) can be used. As for the feeder, the new volume will be estimated by the iteration, where even new associated variables can be determined.

$$h = \frac{6V_{tot}}{\pi l b} \tag{38}$$

The internal balloon area is estimated by the equation of the ellipsoid balloon.

$$A_{bnet} = 4\pi \left\{ \frac{\left(\frac{1}{2}\right)^{1.6075} \left[\left(\frac{l}{2}\right)^{1.6075} \left(b^{1.6075} + h^{1.6075}\right) + \left(bh\right)^{1.6075} \right]}{3} \right\}^{1/1.6075} \tag{39}$$

Equation (9) can be used to estimate the weight of cloths of the two balloons. Areas of the sheets must be multiplied by the respective surface density. Instead, equation (10) will be used to estimate the total fuselage weight and the interior furnishing, but the reference weight will be the cloth envelope weight W_{env}. This weight is defined as the product between the surface density the external fabric (ρ_{env}) and the area A_{bnet}.

The equations (11) and (13) are also applicable to the cruiser, but $W_{general}$ must also take into account passengers and their luggage. The number of people is assumed to be 240 and the their total weight is 26400 kg. Equation (12) must be amended for the other furnishing, which is on board, for example weights of glass, stairs, elevators, sofas, cabins, bar, kitchen, and in general, it needs to consider all the furniture of the fuselage.

The calculation of the weight of the lateral bodies is made with the first and the second formula given in the equation (11). The latter case uses values for the wall and floor surfaces, as retrieved from CAD.

The sum of the result resulting from the equation (13), and the weight of the 2 lateral bodies is considered as the fuselage weight of the cruiser.

Equations (14-16) remain valid for the cruiser. However, the equation (16), must consider that the area of the fuselage is not only the cylindrical (as obtainable from the 2nd expression of the equation (16)), but also has to take into account the total area of the 2 lateral bodies.

The following algorithm gives the equation for the propulsion system weight.

$$W_{total,pr} = P_{r,c}\left(E_{eng} + E_{prop}\right) \tag{40}$$

$P_{r,c}$ is the propulsive power required at the cruising altitude as defined by the first expression in equation (18), where aerodynamic drag is defined by:

$$D_c = \frac{1}{2} C_D \rho_a V_c^2 V_{tot}^{2/3} + D_{feed} \tag{41}$$

The final geometry had shown the large aerodynamic drag, because of its complex configuration, and the authors have decided to set the high drag coefficient, to be C_D=0.15. In this way, the considered aerodynamic drag of the ball and the fuselage, taken into account by the cruiser C_D also includes the presence of the fuselage and external structure.

The power plant uses the equations (22), but authors have considered the weight of batteries, as the sum of 2 types of batteries: those applied for the cabins and those used for the propulsion.

$$W_{batt} = \frac{P_{r,c}\left(h_{end,prop} - h_{end,cab}\right) + P_{r,tot} h_{end,cab}}{E_{s,batt}} \tag{42}$$

In addition, an following this modeling line, the authors have also considered the weight of the photovoltaic film; for which the value increases by 30%, because the equation does not take into account the curvature of the aircraft back shape. In fact, the radiation is considered as the normal direct solar flux D_z provided by the Sun rays, as follows:

$$W_{PV} = 1.3 \frac{P_{r,tot}}{D_z \gamma_t} \rho_{PV} \tag{43}$$

It is expressed as a function of the solar altitude [1] and the pressure at flight altitude, by the expression taken from [15]:

$$D_z = D_0 C_n e^{-\frac{J}{\sin A}\left(\frac{P_a}{P_0}\right)} \tag{44}$$

$$\sin A = \cos N \cos L + \sin N \sin L \tag{45}$$

This equation does not consider the hour angle because the authors consider the solar noon for the calculation of the altitude.

N is the declination, which represents the seasonal variation in the Sun's apparent position. N varies between +23.45° at the Summer solstice and -23.45° at the Winter solstice. If the time of the year is measured in days from the Spring Equinox (March 21st) the declination is approximately given by Cooper formula [16]:

$$N = 23.45 \sin\left(360\left(\frac{284+d}{365}\right)\right) \text{ degrees} \tag{46}$$

January 1 has d=1, while December 31 has d=365.

The UNI regulation [17] gives reference days on d and the calculation of the declination. They are shown in Figure 12.

Gen	Feb	Mar	Apr	Mag	Giu	Lug	Ago	Set	Ott	Nov	Dic
17	47	75	105	135	162	198	228	258	288	318	344

Figure 12 Days of calculation for the declination by the regulation

December is taken as a reference value for the calculation, because the solar radiation is smaller for the Modena region.

The total efficiency of the system must take into account the onboard systems (avionics and engines) and the chain: photovoltaic, regulators, inverters, batteries, regenerative fuel cells, etc… Consequently, the incident solar energy on the balloon suffers from a considerable reduction, when it must be converted into the electrical energy for the cruiser plants, for which the total efficiency of the system is fixed to 12%.

The first equation in (20) is valid for the cruiser, but the term refering to the winch is replaced by the term $P_{r,e}$. The latter is the power produced by the electrolysis, which compensates the loss of gas V_p from the balloon due to the permeability:

$$\begin{cases} P_{r,e} = \dfrac{P_{ref,e} V_p}{h_{end}} \\ m_p = 0.001 p h_{end} A_{bnet} \rho_{hyd} \\ V_p = 273.15 \dfrac{m_p R_{hyd}}{P_0} \end{cases} \tag{47}$$

Equation (23) is valid, and $P_{r,g}$ for the cruiser is given in Table 3.

The weight of the regenerative fuel cell system is given by equation (27).

The weight of the docking system (pressurized area of unloading) is estimated with the equation (28). In this case, the docking system is doubled, because the cruiser involves 2 feeders, and hence 2 landing zones are required.

Table 3 General power of users on board

General cruiser power for the on board users	Power [kW]
Avionic system	10
Emergency lighting (internal & external)	10
Freight transport	10
Light (internal cabin, external)	22
Flight entertainment (48V)	22
Galley	150
Situation awareness and structural monitoring (48V)	10
Total Power $P_{r,g}$	**234**

The pneumatic and hydraulic systems are estimated with the equation (29). However, this equation was corrected by a coefficient (it is 2.5), which allows considering a possible system for the 2 lateral bodies of the fuselage. Without this factor the equation would be valid only for the main cylindrical body.

The suspension system is estimated with the equation (30).

The beam structural supports W_{beam} for the fuselage is sized considering a carbon tube. Equation (31) is applied for this estimate, but instead of height of the feeder, the total length of the beams is set.

Table 4 General requirements

z	[m]	16000
L	[°]	44.6568
T_H	[K]	0
k	[%]	5
l_{dock}	[m]	1.8
d_{dock}	[m]	1.8

Table 5 Feeder general and interior furnishing requirements

V_c	[m/s]	5
N_{pass}	[-]	28
h_{batt}	[h]	0.25
h_{end}	[h]	1
N_{seat}	[-]	28
N_{bath}	[-]	1
A_{wall}	[m^2]	24
A_{floor}	[m^2]	32
A_{cei}	[m^2]	32
W_{food}	[kg]	1000
$W_{general}$	[kg]	498

Table 6 Feeder requirements: geometry

l_{dome}	[m]	80.0
$h_{cone,to}$	[m]	1
r_{feed}	[m]	0.5
Initial parameters for the first iteration		
V_{dome}	[m^3]	40000
V_{cone}	[m^3]	40000
Central pylon		
n	[-]	4.6
$d_{e,cul}$	[m]	1
Lower-cloth winch extension		
N_{rope}	[-]	6
Fuselage		
l_{fus}	[m]	8
d_{fus}	[m]	4

Table 7 Cruiser general and interior furnishing requirements

V_c	[m/s]	28
$h_{batt,cab}$	[h]	1
$h_{batt,prop}$	[h]	0.25
h_{end}	[h]	12
N_{seat}	[-]	118
N_{bath}	[-]	13
A_{wall}	[m^2]	1388.5
A_{glass}	[m^2]	128
A_{floor}	[m^2]	646.9
A_{cei}	[m^2]	177.4
$W_{general}$	[kg]	65702
W_{food}	[kg]	5600

Equation (32) allows obtaining the cruiser weight $W_{cruiser}$ by using the specific data.

The sizing of the aircrafts has the general requirements identified in Table 4 and Tables 5, 6 for the feeder and Tables 7 and 8 for the cruiser; general constants used in defining the weights estimates, powers and surface areas, are shown in

Table 9, while other parameters are shown in Table 10, for the feeder, and in Table 11, for the cruiser.

Table 8 Cruiser requirements: geometry

Geometric characteristics of the fuselage and structural support		
Cylinder part		
l_{fus}	[m]	127.2
d_{fus}	[m]	7
Lateral part		
$l_{fus,lat}$	[m]	112
$h_{fus,lat}$	[m]	3.8
$q_{fus,lat}$	[m]	3.6
l_{beam}	[m]	515.8
$d_{e,beam}$	[m]	1
Geometry of the balloon: pure ellipsoidal balloon (Volume of first iteration)		
l	[m]	400
b	[m]	240
V_{total}	[m^3]	4100000

Table 9 General sizing constants

g	[m/s^2]	9.81
R	[J/(kgK)]	287
P_0	[Pa]	101325
R_{hyd}	[J/(kgK)]	4124
ρ_{paint}	[kg/m^2]	0.1
E_{eng}	[kg/kW]	0.136
ρ_{wiring}	[kg/m]	5.5
l_{wiring}	[m]	80
E_{dist}	[kg/kW]	0.7
$E_{s,batt}$	[Wh/kg]	350
ρ_{carb}	[kg/m^3]	1600
$E_{s,fuel}$	[Wh/kg]	1500

Table 10 Sizing constants for the feeder

ρ_{bnet}	[kg/m^2]	0.25
$E_{duc,pr}$	[kg/kW]	0.168
E_{duc}	[kg/kW]	0.50
W_{1seat}	[kg]	2.2
ρ_{wall}	[kg/m^2]	4.05
ρ_{fl}	[kg/m^2]	8
W_{1bath}	[kg]	40
W_{cei}	[kg/m^2]	4.05
$W_{cockpit}$	[kg]	170
E_{winch}	[kg/kW]	17.9
η_a	[-]	0.8
η_v	[-]	0.8
η_{pu}	[-]	0.98
N	[-]	1
X	[-]	1.1
ρ_{rope}	[kg/m]	0.158

RESULTS

Figure 13 shows the pattern with the indication of areas where to apply the loads on the feeder. Some items are not present in this schema. They are related to the distributed loads, such as the weight of the gas, the fabric cloth, the air conditioning system etc. Two circles indicate areas of interest for docking systems (part of the constraint for the cruiser).

Table 11 Sizing constants for the cruiser

ρ_{env}	[kg/m^2]	0.12
ρ_{bnet}	[kg/m^2]	0.25
E_{prop}	[kg/kW]	0.235
W_{seat}	[kg]	6.8
ρ_{wall}	[kg/m^2]	4.5
ρ_{fl}	[kg/m^2]	8.8
W_{bath}	[kg]	50
ρ_{cei}	[kg/m^2]	8.80
$W_{cockpit}$	[kg]	300
ρ_{PV}	[kg/m^2]	0.8
l_{wiring}	[m]	1400
D_0	[KW/m^2]	1.353
C_n	[-]	1
J	[-]	0.142
$E_{s,batt}$	[Wh/Kg]	350
$E_{s,reg}$	[Wh/kg]	1500
$P_{ref,e}$	[kWh/Nm^3]	5.6
p	[l/m^2/h]	0.031
γ_t	[-]	0.12

On the column, some loads are indicated in a general way, because more precise structural analysis to better understand how the weight will be distributed. Subsequent studies need to be done to define the position of the engines too.

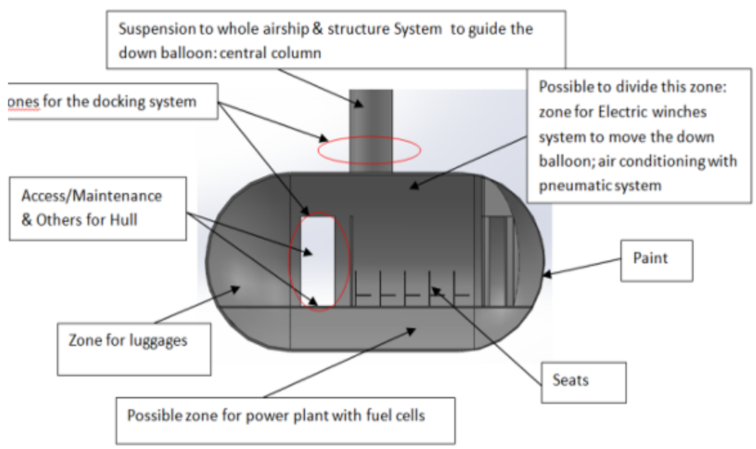

Figure 13 Distribution loads on the feeder fuselage

Tables 12 and 13 show estimated sizes for the feeder (generic characteristics such as height and volume) and weights. While the data obtained for the cruiser are in Table 14 and 15. The comparison is shown between the CAD model and the theoretical ellipsoidal balloon.

Table 12 General estimated characteristics of the feeder.

h_{max}	[m]	41
$h_{dome,to}$	[m]	3.2
h_{dome}	[m]	3.2
$h_{cone,to}$	[m]	1
h_{cone}	[m]	37.8
l_{dome}	[m]	80
D_{feed} S.A.	[N]	0
D_{feed} C.A.	[N]	3784

$P_{r,u}$	[kW]	23.3
$P_{r,c}$ S.A.	[kW]	0
$P_{r,c}$ C.A.	[kW]	13.8
$P_{r,tot}$ S.A.	[kW]	23.3
$P_{r,tot}$ C.A.	[kW]	37.1
V_{cone} S.A.	[m^3]	1697
V_{cone} C.A.	[m^3]	64132
V_{dome} S.A.	[m^3]	8046
V_{dome} C.A.	[m^3]	8046
V_{total} S.A.	[m^3]	9743
V_{total} C.A.	[m^3]	72178
ΔV_{total}	[%]	21.8
A_{ball}	[m^2]	12144

Therefore, the feeder is capable of transporting 28 people (passengers and crew) with a variation of 21.8% of its volume, which corresponds to a load carrying capacity of 3080 Kg.

Table 13 Feeder weights

W_g	[kg]	872
W_{ball}	[kg]	3036
$W_{fab,str}$	[kg]	395
W_{susp}	[kg]	914
W_{cul}	[kg]	275
$W_{fus,str}$	[kg]	630
W_{furn}	[kg]	1272
W_{main}	[kg]	257
W_{ot}	[kg]	313
W_{pt}	[kg]	13
$W_{total,fan}$	[kg]	11
$W_{PP,A}$	[kg]	1473
W_{fuel}	[kg]	25
W_{dock}	[kg]	1028
W_w	[kg]	178
$W_{A,H,P}$	[kg]	748
$W_{feed,max}$	**[kg]**	**11939**

Table 14 General estimated characteristics of the Cruiser; comparison between CAD and ellipsoidal balloon

	Units	CAD Model	Mathematical Model
h	[m]	86.0	59.6
l	[m]	400.0	400.0
b	[m]	240.0	240.0
V_{tot}	**[m^3]**	**3228186**	**2995572**
D_c	[N]	312511	306382
$P_{r,u}$	[kW]	458	458
$P_{r,c}$	[kW]	8750	8579
$P_{r,e}$	[kW]	4.99	3.94
m_p	[kg]	0.96	0.76
V_p	[Nm^3]	10.7	8.4
A_{bnet}	[m^2]	211033	166405

Table 15 Cruiser weights with comparison between CAD and ellipsoidal balloon

	Units	CAD Model	Mathematical Model
W_g	[kg]	39000	36200
W_{env}	[kg]	25300	20000
W_{bnet}	[kg]	52800	41600
$W_{fab,str}$	[kg]	5571	4393
W_{susp}	[kg]	41942	38918
W_{beam}	[kg]	56862	56862
$W_{fus,str}$	[kg]	38000	38000
W_{furn}	[kg]	20655	20655
W_{main}	[kg]	24000	11950
W_{ot}	[kg]	12880	12006
W_{pt}	[kg]	5600	5600
$W_{total,pr}$	[kg]	3247	3183
$W_{PP,A}$	[kg]	62470	61300
W_{fuel}	[kg]	73706	72325
W_{dock}	[kg]	2056	2056
$W_{A,H,P}$	[kg]	4105	4105
$W_{cruiser}$	**[kg]**	**533896**	**494855**

CONCLUSION

All new transportation systems are subjected to many considerations, which have to satisfy different design requirements, and particularity for the MAAT system, they consider weight, dimensions, connections, docking procedures etc. The MAAT weight model has been studied and finally defined, by the modeling procedure described in this paper, and based on which, the first weights estimation of the MAAT Feeders and Cruiser airships have been computed. The aid of CAD was found indispensable, because of the complex geometry, which has been adopted for the MAAT shape. The CAD design (when compared to the ellipsoidal balloon) requires a significant change in volume in order to compensate for the heavier weights, resulting from this weight model.

However, additional studies are required to be made in order to make MAAT possible to build. An example is the aerodynamic analysis, which is currently in progress to validate this design shape.

Nevertheless, it is obvious that this configuration will be further improved, and this process is inevitable and in light of the ongoing technological developments. It is expected that all these follow up studies will allow advancing the exploration of such very large airships that have been heavily conditioned by the last century Zeppelin experience. What is important to mention for MAAT is that such Zeppelin like solutions do not take into account the multiple vehicle requirement, as MAAT is proposing.

The authors plans are to explore further such new possibilities, with objective to improve the MAAT system architecture, which is still under continuous development, and especially, the research focus is on the docking system design, as considered to be one the most challenging problem to be solved in MAAT. In our knowledge the solution, to this challenging problem, has not been researched or investigated till today.

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