Human Spaceflight - Blue Team Vehicle Concept / Layout

Arjhun Arulkrishnan, Pierre-Yves Cousin, Valerio Lupi

***Abstract*—The aim of this project is to conceptually design an interplanetary transport ship, which can carry 30 passengers with crew members to Mars by 2032. It has been assumed that humans have already colonised Mars. NASA's SLS Block II launcher will be used to assemble the ship in LEO. The global architecture consists of three parallel cylindrical bodies, and the habitable part of the ship consists of 6 modules, each having a diameter of 9 m, and is estimated to weigh 1375 tonnes. The ship is designed keeping in mind the requirements of other groups. Various problems like radiation protection, debris/meteoroid shielding and thermal protection are considered. This paper also presents the internal design, and a detailed volume estimates of each of the compartments. The cost of the habitat is estimated to be $175 Billion. A short off-nominal scenario is also included and a solution to overcome such situation.**

CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. Introduction

INTERPLANETARY travel is getting closer to reality. Reaching Mars or Venus is no longer a dream. Space Missions like Mars One or SpaceX's Mars mission are aimed to be achieved in the 2020's. After successful missions and the start of the colonisation of another planet, a ”space bus” would be required to travel to and from this planet. Building such a interplanetary space travel shuttle presents both technical and political issues, and a lot of possibilities for problem solving and innovations. This project aims at building one such shuttle, named the IMS Trident. This specific paper concentrates on the design and layout of the ship, as well as its structural protection.

A. Problem Definition

The aim of the project is to design an interplanetary spaceship that can carry 30 passengers plus the necessary crew members. The ship must be able to make multiple trips back and forth between Earth and Mars. The ship would not enter Earth's or Mars' atmosphere, but would rally spaceports orbiting around both planets. The ship is assumed to be built by 2032. Hence it can be assumed that humans have already colonised Mars, and the current technologies can be extrapolated to a reasonable extent.

B. Existing spaceships and space stations

The ship has taken its inspiration from existing spacecrafts or stations. Manned spacecrafts are relatively small in dimensions and are designed for short-duration transit between the Earth's surface and Low Earth Orbit (LEO). They often adopt a conical shape. Future capsules such as Orion or Dragon V2 keep the same concept. The exception is the Space Shuttle, which had the shape of a plane, and possessed a heat shield which made it reusable. However it was deemed too expensive and had been retired.

Space stations are built by using cylindrical modules assembled together. The largest one in service, the International Space Station, is composed of modules coming from different space agencies. It can host 6 astronauts for missions of up to a year. Earlier stations, like Mir or Skylab, were more modest in size.

II. Lay-out

A. Configuration of the ship

The basic configuration of the IMS Trident is inspired from space stations such as the ISS or MIR, i.e. using cylindrical modules and integrate them, instead of one big ship. A cylinder is the best suited shape for the payload fairing of a launcher and presents a good resistance to pressure. Having multiple modules aids in assembling by having multiple launches, and also helps in repairing and maintenance. If one of the modules needs to be replaced, it can be undocked and replaced with a new one, thereby increasing the life of the ship considerably. The modules all have the same structure, the interior can be configured depending on the purpose of the module.

The configuration with three parallel cylindrical bodies has been chosen in order not to have a too long spaceship while retaining an easy access to any module. The three bodies are connected by two small passages each. The global configuration gave its name to the ship.

The habitable modules are situated in the front of the ship, with the propellant tanks behind and the engine at the end. Solar arrays are fixed on gimbals on the sides of the tanks. Radiators are installed in the same way.

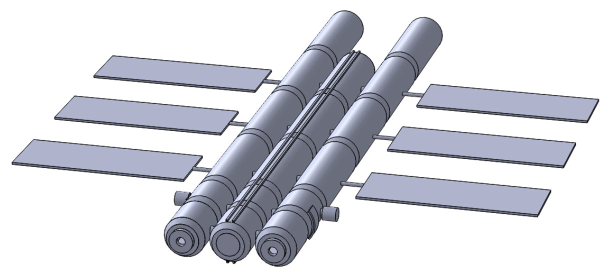

Fig. 1. The IMS Trident

B. Elements needed

To enable 40 people to live in good conditions in deep space for months, the ship requires multiple equipments and facilities. The crew must have personal space where to sleep or rest, and have intimacy. Hygiene facilities are also needed. Food must be stored, with the dedicated equipments to prepare it. Medical tools and medicines must be available to the crew. Entertainment and exercise will be the principal activities onboard, so enough space must be allocated for them. A control and communication room as well as compartments to prepare and carry Extravehicular Activities (EVA) are needed for the ship to be operational.

In terms of structure, the ship must be protected from the space environment. Threats like micrometeoroids, heat and radiation must be dealt with. To do so, dedicated shielding and insulation must be devised.

All these issues have been taken into consideration when designing the ship, allocating space for each function and devising its protection.

III. Sizing the ship

A. Launch limitations

The first limitation for the ship is imposed by the rocket that will be used to launch it into LEO. The launchers available at the time of the mission, in 2032, will define the size and mass of the ship's elements. Various existing/proposed launch vehicles are considered and compared.

The Space Launch System (SLS) is NASA's current program to launch heavy payloads into LEO. The body of the rocket is based on the Space Shuttle's main propellant tank. The boosters for the block 1 are derived from the boosters of the Space Shuttle. For the block 2, new boosters will be used. Block 2 is expected to be in service by 2030.

The Falcon Heavy of SpaceX is another heavy launcher, composed of a Falcon 9 rocket sided by two boosters. It will carry 53t to LEO.

Another potential launcher to be used to launch the modules of the ship to LEO is the "super-heavy lift launch vehicle", which is part of SpaceX's ITS vehicle. It is planned to carry 550t to LEO and would be equipped with 42 Raptor engines. However, it is still in conceptual phase, and it is not clear if it could be used to carry payloads other than the Interplanetary Spaceship of the same company.

Fig. 2. Size Comparison of existing or planned super heavy launchers. From left to right: Falcon 9, Falcon Heavy, Delta IV Heavy, Saturn V, SLS Block 1, SLS Block 2, ITS

Hence, the SLS block 2 is selected for the mission. It will be the most powerful rocket in service by the time the mission is planned, with 130t to LEO [1].The diameter of the payload fairing is 10 m and its length is 31 m. The usable dimensions are 9.1 m in diameter and 25 m in length. [2]. As the modules of the ISS were dimensioned to fit in the cargo bay of the Space Shuttle, the modules of our ship will be dimensioned to fit the payload fairing of the SLS block 2. The diameter of the modules is thus set to 9 m.

B. Volume

The volume of a spaceship is a key aspect of its design, as it is the volume that will set the amount of equipment, supplies and crew that can be embarked once the ship is built. It must be carefully chosen to enable the missions the spaceship is planned for.

Two different volumes are used to define a spaceship, the pressurized and free volumes.The pressurized volume is the volume contained in the pressurized shell of the ship. It includes equipments, furnitures, supplies, experimentations, etc. The free volume is the volume in which the crew can move and circulate. It is important in terms of ergonomic, comfort and habitability of the spaceship.

Studies have linked both the pressurized and free volumes to the duration of the mission and the size of the crew [3]. It is commonly accepted that the longer the mission, the bigger the volumes. For examples, in spacecrafts designed for short-duration missions, the free volume per crew member can be limited to a few cubic meters. On the ISS, where the missions can last up to a year, the free volume per crew member is much higher, between 60 and 90 m^3 [4].

The maximum duration of the mission will be of 290 days, which corresponds to the way back, as we consider that the passengers will stay a long time on Mars between the flights. Using this we can calculate the free volume by using the formula [3],

$$V_p = N_p 1.74 t^{0.744} \quad (1)$$

Where N_p = number of passengers = 40
t = number of days on board = 290 days
Using this, we get the pressurised volume $V_p = 4700 m^3$

However the crew is significantly larger than the one of the ships used to devise this formula. For a larger crew, the volume per person should be lower because common space is shared by more people. To take this into account, the pressurized volume is set to 3700 m^3. On average, the free volume represents 43% of the pressurized volume of a spaceship [4]. Using this value, we can define the free volume of the IMS Trident. Free volume $V_f = 1600 m^3$. This gives an average of $40 m^3$ per person. The rest of the 57% is the storage area where all equipments, cargo, supplies, LSS etc. are placed.

C. Mass

Once the volume of the ship has been chosen, we can approximate the mass of the spaceship, excluding the propulsion system.

To do so, we use existing spacecrafts. The ISS has a mass of 420 tonnes and a pressurized volume of 950 m^3. However, since it possesses a truss to support the solar arrays which doesn't contain any pressurized volume, it cannot be used. The Soviet space station Mir, on the other hand, consisted of modules assembled together, without any other important structure. It is in this respect closer to the lay-out of the IMS Trident. It had a mass of 130 tonnes and a pressurized volume of 350 m^3. If the ratio between the mass and the pressurized volume is assumed to be the same for Mir and the IMS Trident, the mass obtained is 1375 tonnes.

IV. Modules

Since the total volume is 3700 m^3, and the diameter is fixed as 9 m, the total length of the modules must be 58 m. Instead of having one long cylinder, smaller cylindrical modules have been considered. A total of 6 modules having a length of 9.5 m will compose the habitat. All six modules in turn will be separated transversely in slices of different widths. This way, the usable surface is increased, and more practical. The figure 3 presents a cutaway of one module. The outer diameter of the circle is 9m, and the white area in the center is the free surface area having a dimension of 5.2 m x 5.2 m. The shaded area is the area where all the equipments are placed (storage, cables, Life Support System, etc.). Thus, each slice will have a habitable surface of 27 m^2.

Fig. 3. The interior design of each module.

A. Living compartments

The compartments/rooms are categorized based on the need and comfort of passengers. They are split into:

- Crew and passenger quarters
- Kitchen/Dining compartment
- Gym
- Recreation compartment
- Lab/Medical bay
- Command/Communication compartment
- EVA room
- Shower/WCs.

1) Crew and passenger quarters: This compartment occupies nearly 43% of the free volume in the ship. This is the personal space allocated for each person on board. Each room is 3.5 m x 1.5 m in area, which comprises a sleeping area, a table, shelf for storing personal items, etc. Three out of six modules are allocated for personal space. Each slice has a floor area of 5.2mx5.2m and has a height of 2.5m. This slice is internally split and shared among 4 people. Thus a total of 10 slices, 67.6 m^3 each, for 40 people is allocated.

2) Food Kitchen/Dining compartment: As the name suggests, this is the place where food is kept and dined. The volume of this compartment is 3 m x 5.2 m x 5.2 m.There is only one kitchen allocated for 40 people. This is designed considering the fact that all 40 people will not be dining at the same time, but will take turns throughout the day. Thus it can comfortably host a maximum of 15-20 people at the same time.

3) Gym: The ship doesn't have any artificial gravity platform. The reason is discussed in the Discussion section in this paper. Hence, passengers have to exercise daily for few hours to have a healthy life on board. So, as per the advice from Human Aspects and Life Support System department, a gym with prescribed equipments is provided. The dimensions of a gym is 2m x 5.2m x 5.2m. There are 2 gyms placed in two different modules to accommodate more people at the same time, and also to avoid important amounts of CO_2 and heat being generated from a single place.

4) Recreation compartment: Entertainment is an essential function of the ship. The mission will last several months and the passengers will stay confined in a small space for its whole duration, with the exception of a few EVAs. The recreation module will provide a wide range of entertainment, such as movies and games. The compartment will serve as the common room of the ship, the main meeting place on board. That is why it will be the biggest room in the ship, with a length of 7 m. The room can also be converted to a cinema hall.

The compartment will also have an observation window of 3m x 3m. When the solar activity is low, the window opens for the passengers to gaze upon the sky. As the window will have a lower level of protection, a panel with the same protection as the outer shell of the ship will slide on two rails and protect the window when it's not used.

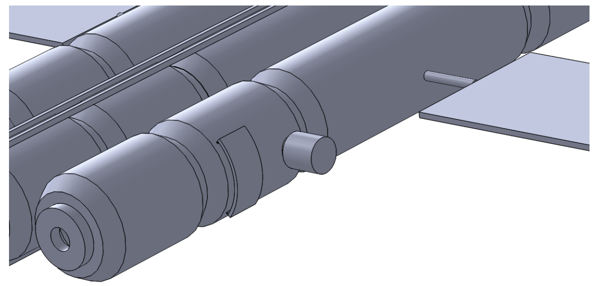

Fig. 4. Close-up view of the observation window. Here the window is covered by its protection panel. On the right is the airlock.

5) Lab/Medical bay: A laboratory is allocated in order to carry out experiments and scientific research during the trip to Mars. It is inspired by the Columbus module on ISS and it will help to get further information for the next trips to Mars. It is 5m long and has a cross sectional area of 5.2m x 5.2m, with a total volume of 135 m^3. It also includes a medical bay, where the medical material is stored and diverse operations can be carried out.

B. Other compartments

1) Command and Communication compartment: As with modern airplanes, the disposition of the command compartment will be greatly simplified with the use of digital touch screens. All the commands will be centralized on a small number of these screens. However, for redundancy purposes, control screens will be dispersed in the other modules.

The command module will also be used as the communication module. Communications will be available to the crew and the passengers. At least two communication desks will be situated in the module.

The control modules is accessible only to the commander and the crew members. Passengers are restricted to go inside this chamber.

2) Cargo: The ship will be able to transport a small amount of cargo to Mars, for example spare parts, tools, small vehicles. The cargo will be stored on the outer circle of the modules, i.e. in the storage area.

3) EVA Room: This room is allocated for EVA purpose only. It hosts all the necessary gears and suits required for EVA. In this room there is a pressure lock through which one can access the outside of the ship. For passengers, tethered suits are used and they allowed to be outside only for few minutes as they may be exposed to radiation. There is also untethered suits which are used by crew members to reach far

side of the ship for maintenance purposes.
There are 2 EVA rooms, each on either side of the ship so that the entire ship can be accessed in case of emergencies.

4) Propulsion/fuel storage modules: The propellant tanks will be based on the same architecture as the habitable module. They will be cylinders of 9 m of diameter and 25 m long. The propellant tanks are located between the habitat and the engines to have a security distance between them. On their sides will be fixed the solar arrays and radiators.

Table I shows the summary of volume estimate of each of the compartment.

TABLE I
VOLUME ESTIMATES OF ALL THE COMPARTMENTS

Name	Volume	Dimensions	%
Crew and Passenger quarters (10)	675	2.5x5.2x5.2	42.3
Kitchen/Dining	81	3x5.2x5.2	5.1
Gym (2)	108	2x5.2x5.2	6.8
Recreation	189	7x5.2x5.2	11.8
Lab/Medical	135	5x5.2x5.2	8.5
Command/Communication	81	3x5.2x5.2	5.1
EVA Room (2)	162	3x5.2x5.2	10.2
Shower/WCs (3)	162	2*5.2x5.2	10.2
		Total	100%

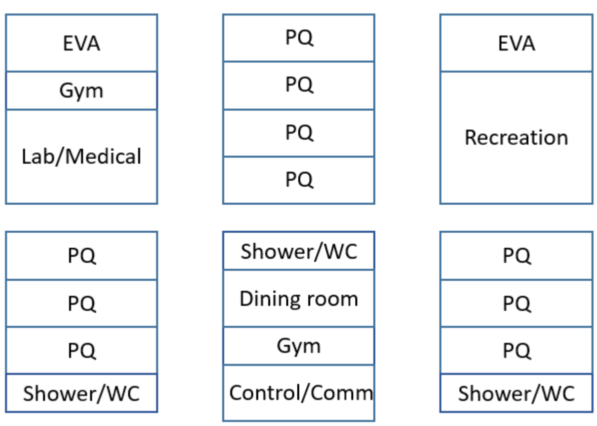

Fig. 5. Arrangement of compartments in different modules.(PQ: Personal Quarters)

V. Module protection

A. Meteoroids/debris

The first threat the IMS Trident can encounter is small objects that could damage its structure or its equipments. To counter this, spacecrafts use Micrometeoroid and Orbital Debris (MMOD) shielding.

The traditional shielding strategy is called Whipple Shield, which consists of two layers of aluminium separated by a void. The first layer splits the projectile, and the fragments created are stopped by the second layer. An improved version of this shield, called the Stuffed Whipple Shield, integrates a fabric layer situated between the two aluminium layers.This type of shield is used for example on the Columbus Laboratory on the ISS.

Other types of shields have been designed, such as the Multi-Shock and Mesh Double-Bumper shields (MDBS). They provide better performances, but have a higher standoff (the distance between the outer and inner layer of the shield) [5]. The MDBS is chosen because it gives the best performances [6].

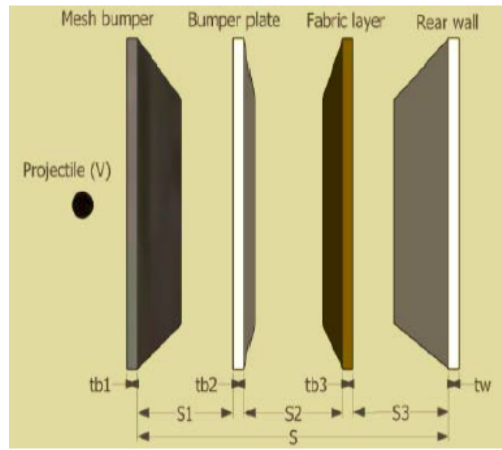

Fig. 6. Mesh Double-Bumper Shield. [6]

The Mesh Double-Bumper shield is composed of 4 different layers.

The first layer is the Wire Mesh Bumper. Its function is to break the projectile up into small fragments. The speed of the projectile is not substantially reduced by the mesh bumper, however it produces less secondary ejecta (debris from the layer itself) than a continuous layer.

The Second Bumper is the next layer. It shocks the fragments of the projectile and pulverizes them. They can then reach temperatures high enough to melt or vaporize. As it is a continuous layer, it can stop particles that were small enough to pass through the mesh.

The following layer is the Intermediate Fabric Layer. Its purpose is to stop or slow the remaining fragments the expansion of the debris cloud.

The final layer is the back plate. It resists penetration of any solid fragment.

To size the shielding, the projectile considered is an aluminium sphere with a diameter of 1 cm.

The distances between the layers are set to have the best performance [7]. The first standoff, S1 on figure 6, is 4 cm. S2 is 22 cm and S3 is also 4 cm. So the total standoff of the shielding is 30 cm.

The area density of the different layers is then calculated using the following formula given by Christiansen and Kerr [7]:

$$m = c_m d \rho_p \tag{2}$$

Where c_m is a coefficient depending on the material, d is the diameter of the projectile and ρ_p is its density. The different coefficients are found in [7].

TABLE II
MASS OF THE MDBS

Layer	Material	Area Density (g.cm^{-2})	Surface (m)	Mass (kg)
Wire Mesh	Aluminium	0.094	1968	1860
Second Bumper	Aluminium	0.25	1953	4882
Intermediate fabric	Kevlar	0.173	1872	3235
Back plate	Aluminium	0.27	1857	5014
			Total	14991

The total mass is thus 15 t for the whole MMOD shielding of the ship.

B. Thermal protection

Without the protection of the atmosphere, the temperature of an object in space can be either really high or really low depending on its exposure to the Sun.

To insulate the ship, a protection called Multi-Layer Insulation is used. As the name implies, it relies on different layers. It will be the outmost protection of the ship, covering both the MMOD and radiation protections.

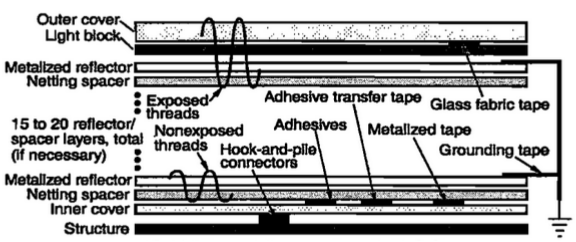

Fig. 7. Structure of a Multi-Layer Insulation. [8]

The outer cover protects the MLI from space environment effects, for example atomic oxygen (AO) that could attack the materials.

The reflector layers are the principal insulation layers, their number usually varies between 15 and 20. For the IMS Trident, 20 reflector layers will be used.

To separate the reflector layers and avoid conduction between them, separator netting is used. Separators are also placed between the outer cover and the reflectors and between the inner cover and the reflectors.

The last layer is the inner cover, that encloses the reflector layers and is in contact with the hardware under the MLI.

The material used for the outer, inner and reflector layers is aluminized Kapton, a polyimide film which can sustain a wide range of temperatures [9].

The separator layers will be made of Nomex netting, an aramide fiber that has a high thermal stability [10].

With the knowledge of the material used for the outer cover, the temperature of this layer when exposed to the Sun can be calculated. To do so, we use the equation given by Wertz et al [11]. S is the solar radiation incidence, ϵ the emissivity of the surface, α its absorptivity, A_p the projected area towards the Sun, A_r the radiating surface area and σ the Stefan-Boltzmann constant (5.67051 * 10^{-8} W.m^{-2}.K^{-4}).

$$T = \sqrt[4]{S\frac{\alpha}{\epsilon}\frac{A_p}{A_r}/\sigma} \quad (3)$$

Aluminized Kapton has an absorptivity of 0.34 and an emissivity of 0.55 [11].

The temperature of the outer cover is calculated with the different values of solar radiation incidence on Mars, Venus and the Earth, and with two different ratios between projected and radiating areas, one for the ends of the modules and one for their sides. The results can be found in table III.

TABLE III
TEMPERATURE OF THE MLI OUTER COVER

Planet	Solar radiation incidence (W.m^{-2})	T_{ends} (K)	T_{sides} (K)
Venus	2635	411.7	309.2
Earth	591	283.3	212.8
Mars	1366	349.3	262.4

The temperatures on the ends of the modules are higher due to a higher ratio between projected and radiating areas.

The highest temperature reached will be when executing the flyby around Venus, where the Solar radiation incidence is almost twice the one for the Earth, with 412K. This temperature is not significantly more important than the temperatures that can be reached by the ISS, around 400K.

The temperature for an object in space that is not exposed to the Sun can be as low as 70K.

The Aluminized Kapton used in the MLI can sustain such temperatures without problems [9].

The masses of the different layers are calculated using area density values from Finckenor and Dooling [12] and summarized in table IV.

TABLE IV
MASS OF THE MLI

Layer	Material	Area Density (g.m^{-2})	Surface (m)	Mass (kg)
Outer cover	Al. Kapton	19	1968	37
Reflector	Al. Kapton	19	39360	748
Separator	Nomex	6.3	41328	260
Inner cover	Al. Kapton	50	1968	98
			Total	1143

The total mass of the MLI for the ship is a little higher than one tonne, which is much lighter than both the MMOD and radiation shields. This is due to the thickness of the layers used and the materials used.

C. Radiation protection

The third threat posed by the space environment is radiations. The effects of those radiations on the crew and the doses received will be treated by the Human aspects group. This section will focus on the shielding installed on the ship to protect the passengers from radiations.

The radiations in outer space are of two types, the Galactic Cosmic Rays (GCR) and Solar Particle Events (SPE).

GCRs consist mostly of high energy protons that are difficult to shield against. SPEs produce mostly electrons which can be effectively stopped by an adequate shieding.

Different materials can be used to shield against radiations. Aluminium is the simplest one, but it is not as efficient as others, like water or polyethylene. The most efficient material is liquid hydrogen [13], however it is hard to implement as it has to be kept at a low temperature.

High-density Polyethylene (HDPE), with its high hydrogen density, is an efficient shielding material [14].

To achieve a satisfying reduction of the radiations, a thickness of 5 cm of HDPE is chosen, which is twice the thickness of the initial storm-shelter protection for the Orion capsule [15]. This protection will cover the six modules of the habitable part of the ship.

The volume of HDPE required is 92.4 m^3, which gives a mass of 86.8 tonnes. The high mass is due to the important thickness of the protection.

1) Storm-shelter protection: In case of a Solar Particle Event, the HDPE-based protection is not enough to efficiently protect the crew. A storm-shelter is then required. The crew, when informed of the imminence of a SPE, would seek refuge in the shelter.

To provide the crew with a storm-shelter, the ”dual use” strategy [14] is used. Water is a good shielding material, and is needed on board. Instead of having a cylindrical tank in one of the modules, the water tank will be disposed around the passenger quarters in the storm-shelter module. This way the water will increase the shielding of the quarters. To make sure that the protection stays constant, the used water will be kept on board to be used as shielding.

The volume of water on board is 15 m^3, which corresponds to a thickness of 7.5 cm on the whole length of the module.

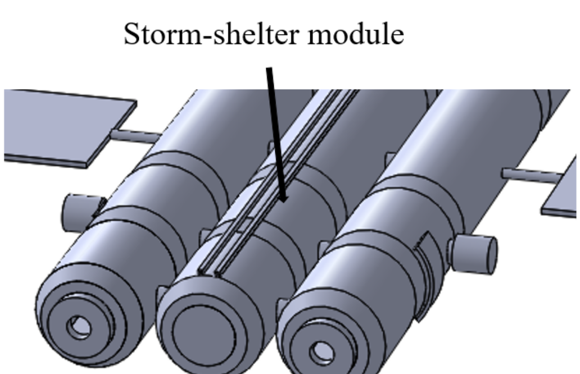

Fig. 8. Localisation of the Storm-shelter module

The module chosen to be the storm-shelter contains quarters for 16 people, but could accommodate 40 people for a short duration.

Moreover, due to its position, it receives an additional protection from the other modules on the sides and front, and from the propellant tanks in the back.

VI. Additional elements

A. Robotic arms

Two robotic arms will be placed on rails, one on each face of the ship. They will help assemble the ship or replace modules. They will be able to carry out simple maintenance operations or assist the crew for more complex ones, and transport passengers during their recreational EVAs.

The robotic arms used will be of the same type as used on the ISS, the Mobile Servicing System. It is composed of three elements. The arm itself is called Canadarm 2 and is 17.6 m long. It sits on the Mobile Base System (MBS), a cart that can slide on rails. The most advanced part of the system is the Special Purpose Dexterous Manipulator (SPDM), that will carry the maintenance tasks. It can either sit on the MBS or be mounted at the end of the Canadarm 2. The total mass of the system is 4.9 tonnes [16].

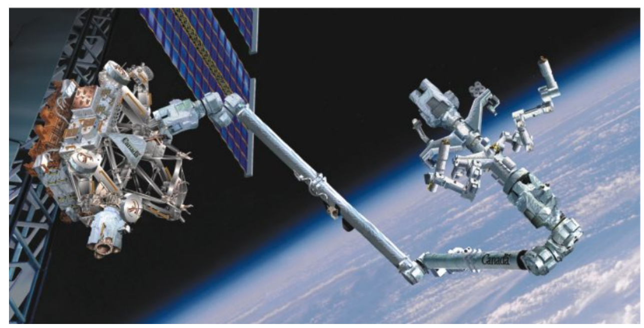

Fig. 9. The Mobile Servicing System, with from left to right: MBS, Canadarm 2, SPDM [16]

B. Air locks

An airlock is placed on each side of the ship in order to allow Extra-Vehicular activities. They are cylinders of 3m diameter and 3m length. They are accessible from the EVA rooms. They are separated from the six habitable modules so that there is no need to pressurize one entire slice of the module, which would require thicker inner walls. It also makes the airlocks more easy to change in case of a failure.

C. Safety capsules

In the unlucky case the ship cannot dock to the spaceport which is in orbit around Mars, it is equipped with two Orion 2.0 safety capsules which allow to land on Mars' surface. These two capsules are derived from the Orion Multi-Purpose Crew and can host up to 20 people. They are hanged under the two EVA rooms. The concept is based on the Orion Multi-Purpose Crew Vehicle. In order to withstand the thin atmosphere of Mars, each capsule has a heat shield and lands with the aid of thrusters which give a braking impulse. They are also equipped with parachutes in case of failure of the thrusters.

VII. Off-nominal scenario - Depressurization

One of the possible undesired and dangerous situations which may happen on board is the depressurization of one module. Assume that a 3cm diameter hole is generated in the shell of the module. From the Bernoulli's law, assuming that the air inside the module is still we have that:

$$v_e = \sqrt{\frac{2\ P}{\rho}} = 404.1\frac{m}{s} \tag{4}$$

The volume flow rate through the hole is computed as:

$$Q = v \cdot A = v \cdot \pi r^2 = 0.28\frac{m^3}{s} \tag{5}$$

The total volume of air present in one module is approximately 270 m^3. This means that all the air will flow outside the module in approximately 16 minutes.
However with such a pressure gradient the hole will expand and then the reacting time will be less than the estimated one. Assuming that not all the 40 passengers will be in the same module at the same time, the time is still sufficient to make them evacuate the module. Once the module is evacuated, it will be sealed and inspected to check the magnitude of the damages. It will then be repaired with spare parts on board mainly performing EVAs and with the aid of the robotic arms.

VIII. Cost Estimate

To estimate the cost, the formula from [8] is used. It gives a rough estimate of how much a deep space ship would cost. According to this, it costs about $0.12 billion/kg. The total mass of the habitable part of the ship is 1375 tonnes, which gives an estimate of $175 billion. This is twice the cost for constructing and functioning of ISS. This cost, however, does not include launch, propulsion or ground operations cost. If any of the modules gets repaired or need to be replaced, only that specific module can be replaced, instead of replacing the entire ship. This cuts down the cost of maintenance. The ship is expected to serve for 30 years.

Since some of the technologies used on the IMS Trident have been developed for other programs, the development costs will be reduced. The modules could be used as the basic "brick" of future spaceships or stations, and a small series of ships similar to the IMS Trident could be built. All this contributes to reducing the costs, so the estimate given here is an upper limit.

IX. Discussion

A. Artificial gravity

The lack or the low level of gravity in spaceships could pose a threat to the health of the crew. Providing artificial gravity in a spaceship could be accomplished through rotating portions of or the whole ship at a certain speed to reach the gravity level wanted.

This idea is not new, the space station imagined by Wernher Von Braun in 1952 featured a rotating wheel to provide artificial gravity .

However this solution poses a certain number of problems. The rotating parts have to be balanced, which could prove difficult if their mass changes during the mission, for example if propellant is consumed. The mechanical joint between rotating and non-rotating parts could be subject to friction, in which case the rotation would have to be maintained, for example using thrusters. In the case of an entire ship rotating, trajectory changes would require to stop the rotation first.

Choosing the right rotation speed is also a challenge. A high spin rate would permit a smaller radius and thus a smaller spaceship. However if it is too high it would be unpractical due to the Coriolis forces. The maximum rotation speed most people can adapt to is 6 rpm [17], however for the comfort of the passengers it should be kept at maximum 2 rpm [18] .

To have a gravity level of 1 g, the radius required would be of 223 m, which is significant. For the gravity of Mars, 0.376 g, the radius is 84 m, which is still important. To limit the weight and mass of the ship, a tether or a truss linking two rotating parts could be used.

A simpler solution to provide artificial gravity would be to have a small centrifuge on board, in which passengers would sojourn for small periods of time. The structure of the ship would require to be reinforced to cope with the vibrations created.

B. Volume and mass estimates

No spaceship with a crew that large has ever been made. The only existing vessels to base the calculations on were either small crafts for 2-3 crew members or space stations for around 6 people. The complement of the IMS Trident is an order of magnitude higher, hence extrapolating the required size of the ship from those might prove inaccurate.

The volume per person is a good indicator to size a ship. Given the variation in mission length of existing spacecrafts, from 1 day up to a year, relations linking the two values can be established. However, the variation of the volume per person depending on the amount of crew members cannot be established in a satisfying way [3], even if it seems logical that the more crew members, the less volume per person needed.

The spacecrafts used to size the ship are space stations, which mission duration is close to the one of the IMS Trident, but with missions differing greatly. Mir or the ISS are filled with scientific experiments that are absent on the spaceship. It was estimated that the lack of these experiments was compensated in mass and volume by the more complex Life Support System, the increased radiation protection, the cargo, the entertainment equipment, etc.

X. Conclusion

The design of the IMS Trident is intended to provide the crew with everything needed for a long outer space mission. Comprehensive equipments, facilities and protections have been incorporated. Technologies from previous programs such as the ISS are used, and a modular architecture makes the ship more practical and can provide a base for other spacecrafts. The values for the mass and volumes for the IMS Trident can be seen as estimates as there is no existing ship of such magnitude to compare it with. The habitable part of the ship has 6 modules each of 9m diameter, and 9.5m length approximately. The estimated mass of the habitat is 1375 tonnes, and the upper limit cost for building it is around $175 billion.

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