Design of a Mars Passenger Ship

Overall Coordination Group

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***Abstract* – A conceptual design of a Mars passenger ship has been developed and discussed in the following report. The ship, known as the Trident, will carry 30-passengers, 10-crew and all the required systems to Mars in 2032. Its designed is heavily influenced from the International Space Station (ISS) in terms of both modular design and international cooperation. The Trident will consist of 6 habitable modules and a be powered by thermal nuclear propulsion. It is expected to launch every 2.5 years with a return journey to Mars taking 540 days. It will be assembled in orbit and travel from Earth orbit to Mars orbit while ascent and descent will be done using Orion 2.0 capsules. Special consideration is paid to the human aspects of the mission due to the high capacity and importance of maintaining healthy, functioning crew and passengers. At an estimated mass of 3,000 tonnes it will cost in the region of $350 billion. This high cost will be spread over 15 years and carried by both the international space agencies and the private sector. Tickets for seats will be available both for private individuals and organisations or countires wishing to send scientists, workers and politcal envoys. The Trident is feasible but it remains to be seen if sufficient politcal support can channel the funding.**

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1 Introduction

For many decades, the lure of the Red Planet has enthralled humanity, in part, due to the possibility that there was in the past, or is now, some form of life. More recently however, there has been an increased interest and discussion in colonizing Mars and making humans a two-planet species. Human exploration of Mars has long been discussed, in fact Wernher von Braun wrote the first thorough technical specification of a Mars mission in 1948, The Mars Project [1]. Almost 60-years later, SpaceX have now put forward an ambitious plan of manufacturing a ship capable of transporting one hundred people to the Martian planet [2].

Based on these recent developments, the project for this year's Human Spaceflight course is to design and build a ship capable of transporting 30-passengers to Mars by the year 2032. This OC report outlines the overall concept delivered by the Blue team, including details on expected cost and feasibility. The following section will outline the team structure and management.

2 Project Management

The Blue team consisted of 20 members which were divided into 5 sub-groups; overall coordination (OC), concept development (CD), human aspects (HA), propulsion and power systems (PP) and operations and logistics (OL). Team meetings were organized once per week, in addition to this each sub-group was expected to meet at least once a week separately. Each team meeting was run by the OC group, one member took the minutes while another chaired the discussions. An agenda was determined before-hand and each meeting followed the same format; outline of the agenda, recap of the previous week decisions, time allocated to each sub-group to present their work to date, a questions and answers period following each presentation, an open discussion and then finally the meetings were closed with the aims and objectives to be completed by next week.

Several measures were taken during the first meeting to facilitate efficient team work which included;

- Slack – A team group was set up on the Slack communications program. This allowed easy, frequent communication between team members.
- Drive – A google drive account was created for storing all important documentation and submissions.
- WBS – Each team was asked to create a Work Breakdown Structure (WBS) which would create clear, obtainable goals and create a timeline.
- Templates – A template was chosen for both the report and the presentation, with the goal of presenting material in a unified and coherent way.
- A/A/T Document – An Assumption, Allocation and Timelines document was uploaded following the first meeting which contained all the assumptions made to-date, the allocation of task responsibility to each sub-group and the timeline of meetings and deadlines. See appendix.

The OC team led all meetings and were the primary point of contact for each group when issues arose. Each member of the team was assigned to a sub-group, this allowed the OC team to know exactly what progress was being made and to ensure every group were working on the same base of assumptions. In addition to project management tasks, the OC group was responsible for collecting the mass and cost budgets and utilizing these for determining project feasibility. The presentation was also designed and coordinated by the OC team. The primary assumptions will now be discussed.

3 Mission Requirements

The project brief is to design a Mars passenger ship. The following points were taken to be the main assumptions or criteria throughout the project;

- 30 passenger capacity , 10 crew
- Capable of multiple journeys
- Operational by 2032
- Reasonable extrapolation of current technology
- Enough supplies for a return journey
- Martian base already in operation

The spacecraft will be manufactured and assembled in space, requiring multiple launches, and be completed by 2032. Once the spacecraft has been fully assembled and tested, the crew and passengers will ascend to the spacecraft in an Orion 2.0 module, which will be in a parking orbit in Low Earth Orbit (LEO). The ship will then launch and proceed to Mars, where once it has inserted into a Martian parking orbit the crew will descend in the Orion modules to the surface. The space craft will remain in orbit for a specified time before returning to Earth. The option will exist for people to return with the ship, although it is assumed the ship will not be at maximum capacity after the first journey.

Using this general outline, each sub-group put forward various designs and a final ship design was eventually decided upon. This design will be outlined in the following sections.

4 Conceptual Design

No craft has ever been launched which can carry the number of crew required for this mission. In fact, excluding the Apollo missions, no manned spacecraft has gone beyond LEO. However, it is assumed that by 2032 there has been numerous launches to Mars and there exists a suitably base station on Martian soil. The CD team designed the spacecraft to be modular and it takes much inspiration from the ISS while still requiring technology not yet developed.

The space environment is a hostile one, and so passengers must be perfectly well-protected from radiation, meteoroids and thermal fluctuations, especially as the route is going relatively close to the sun with a proposed Venus flyby.

4.1 Configuration and Launching

The spacecraft shall be assembled in orbit, to facilitate this the modules will be cylindrical units, utilising the maximum amount of space on the launch system. Several different launchers have been compared and because of the mission duration and capacity needs, there will be a large amount of mass to launch into orbit. Based on this, the Space Launch System (SLS) Block II is chosen, which is NASA's current program to launch heavy payloads in LEO, which should be operational before 2032. The payload fairing is 31 meters long and has a diameter of 10 meters [3]. Thus, the modules of the spacecraft have been dimensioned using the maximum sizes, being 29 meters long with a diameter of 9.5 meters.

The spacecraft will consist of three rows with a total of six modules (excluding propulsion modules). The first iteration of this design had a three-pronged spear-like appearance and so the name of the spacecraft will be the International Mars Spaceship (IMS) Trident. A general, representative depiction of the Trident is shown in Fig. 1.

4.2 Specifications and Layout

The pressurized volume of the Trident, excluding the propulsion system**,** was calculated to 3700 m^3 for a free volume of 1600 m^3. By comparing the ratio of pressurized volume/mass of the USSR MIR Space Station, the mass has been estimated to be 1375 tonnes. Based on this calculation and on the maximum size of the modules, it was determined that six modules would be sufficient.

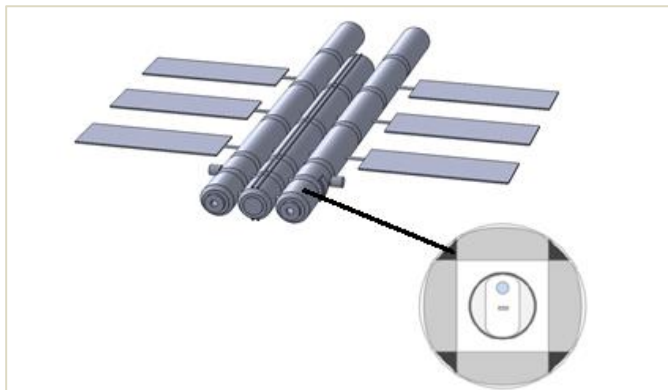

Fig. 1 - IMS Trident (initial depiction showing more than 6 modules) and a callout showing the cross-section of a module.

Fig. 1 shows a cross section of one of the six modules, here the habitable surface is the white square which represents a square of 5.2-meter width and height. The shaded area is space for all the equipment, systems, storage etc. In terms of sharing of volume, almost half of the free volume is dedicated to the crew and passenger personal quarters (PQ). Each quarter has a volume of 67.6 m^3. A plan of the ship is shown in Fig. 2.

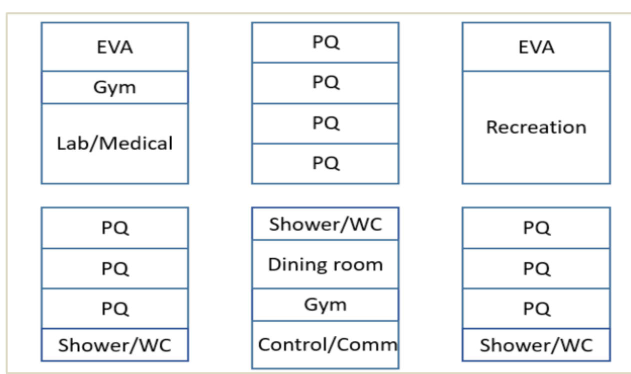

Fig. 2 - Plan-view of the proposed 6 module Trident concept

4.3 Protection

To protect the crew from the harsh environment of space, three different shields will cover the Trident which include;

1) Radiation shielding

To protect the habitat from radiation due to Galactic Cosmic Rays (GCR) and Solar Particle Events (SPE), the ship will be covered by 5 cm of High-Density Polyethylene (HDPE) [9]. The high hydrogen density of the material makes it particularly efficient against radiation. The calculated mass of this shield is 88.4 tonne. However, this shield is not efficient enough against large SPEs and so one module containing a protective water layer will act as a ‘storm shelter’. Crew members will take refuge in this module for a large SPE.

2) Meteoroids shielding

To avoid any damages caused by small bodies such as meteoroids or space debris while in Earth orbit, a Mesh Double-Bumper shield will be used. This is composed of 4 different layers and the calculated total mass of this shield is 15 tonnes.

3) Thermal Protection

The spaceship needs to be insulated from both the very high and very low temperatures, most importantly when it will pass close to the sun. A Multi-Layer Insulation (MLI) is used throughout the ship. It is composed of different layers of aluminized Kapton separated by some fibre to avoid conduction [10].
The mass of this final shield is 1.2 tonnes.

That is the general outline of the Trident’s layout and specifications, for more information please consult the CD team report. Next the operations and logistics work is summarised.

5 Operations and Logistics

The operations and logistics group role was to design the mission route, include operations around planets and the overall communication system. In this project, we are assuming the infrastructure already exists on Mars that supports human survival and the only concern for this study will be to provide all operations and logistics for the journey to and from Mars.

5.1 Routes and Times

Many route options exist when planning an Earth-Mars trip, with a limitless set of parameters in terms of launch date and travel time. However, two primary routes often considered are the long stay and short stay. The long stay option results in a total trip of roughly 900 days which includes the trip to go to Mars (260 days), the time the for the stay on Mars (about 500 days) and the trip to come back to Earth (260 days). With this route, the Trident would have to stay one year and a half orbiting Mars. The second option is the short stay trip, in which you spend 30 days on mars instead of 500 days. The short route option was chosen to facilitate a quick turnaround of the ship, to have a higher frequency of trips and to facilitate those passengers who wish to return to Earth promptly. The short stay route implies a Venus fly-by, which means that the spaceship and the passengers will be exposed to higher doses of radiation during this part of the trip. Hence the ship will need additional shielding to protect the passengers from it. A schematic of the route is shown in Fig. 3.

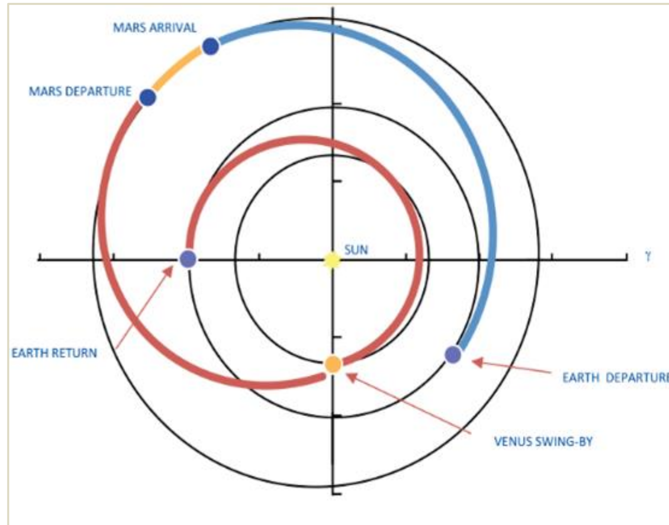

Fig. 3 - Short stay route option chosen for the Trident mission

5.2 Launch Window

For the chosen route, Mars should be ahead by 74 degrees on its orbit relative to the Earth when the spacecraft initiates the first Hohmann manoeuvre. Thus, such a configuration is available every two years and two months. Another parameter is how long the launch window will last. For this kind of mission, it will last approximately three weeks. It means that in case of a bad weather, for example, the launch can be brought forward or delayed during this period of three weeks. On the way back to Earth, the same principle occurs.

5.3 Operations Around Planets

First, the two propulsion modules chosen by the Propulsion group, the hydrogen tank and the Deep Space Habitat (DSH) are launched separately and assembled in High Earth Orbit (HEO, 407-2100 km). The unmanned ship will dock to a Solar Electric Propulsion system (SEP) which has been sent in HEO prior to the different ship parts, providing power to spiral to a Lunar Distance Earth Orbit (LDEO, 407-380000 km). A total of six Space Launch System (SLS) Block 2 launches are needed: one for the SEP system, four for the spaceship, and one for the crew with an estimated launch cost of $500 million.

Crew shall travel to and from the Trident using Orion 2.0 modules, which are expected to have a capacity of 20 people by the year 2032.

5.4 Communication

A communication system is a necessity for all kinds of audio, video and other data transfer. On the ship, there will be two forms of communication. The “internal communication”

(IC) which refers to communication within the spacecraft, amongst the crew and passengers for the whole cruise, including a potential Extra Vehicular Activity (EVA). The second one is “external communication” (EC) which refers to communication with ground control (GC) on both concerning planets and contact between passengers and family, friends etc. Since it’s assumed that human missions to Mars have been done before this tourist-mission, two things are vital for the EC. The first is a pre-established infrastructure on Mars in form of GC on both planets. An international base structure for communication between Mars and Earth already exists on Earth, NASA’s Deep Space Network (DSN), it makes GC on Earth possible. The current DSN is also used for navigation for the spacecraft as it tracks the spacecraft motion and uses X-, S- and Ka-band. The GC on Mars may need to be scattered all over the planet in the same way as it is on Earth, depending on the level of ‘colonization’. Because of the varying distance from Earth to Mars, 100 to 400 million km, there is a delay of 3-21 minutes which makes real time or interactive communication impossible. With GC on both planets the delay time can be cut in half and docking at space ports can be done with direct interactive communication with GC to increase security. The second vital assumption is that a couple of satellites orbit Mars in the same manner that the telecom satellites orbit the Earth today. Three existing spacecraft orbit Mars right now, ESA’s Mars Express, NASA’s Mars Reconnaissance Orbiter (MRO) and Mars Odyssey. Communication from Mars to Earth can be done from these.

That is the general outline of the operations and logistics planning for the Trident mission, for more information please consult the O/L team report. Next the Trident’s propulsion and power system is discussed.

6 Propulsion and Power Systems

Different types of propulsion have been compared: chemical, electrical, and nuclear. The difference is mainly how the propellant is accelerated before it is expelled. For chemical propulsion, the propellant is burned by a chemical reaction. For electrical propulsion, a nuclear reactor and nuclear power generator was assumed to provide enough power to accelerate the propellant for our mission. Because of both their high Isp and their capacity to operate at megawatts power level, two electric propulsion devices were selected: VASIMR (variable Isp magnetoplasma rocket) and MPDT (magnetoplasma dynamic thruster).

Nuclear thermal propulsion works by heating the propellant to very high temperatures and emitting it. For spacecraft, it is still under development [11] but it can be assumed that the technology would be ready by 2032.

The main criterion was the total mass of the whole system of propulsion. The propellant used is hydrogen for the three systems, but methane can be used for chemical propulsion too (LOX/Methane or LOX/Hydrogen). The motivation behind this is to take advantage of In-Situ Resource Utilization (ISRU) where both propellants can be produced on Mars. Thus, the IMS Trident would be refuelled when in Mars orbit, which avoids the need to bring propellant for the return trip.

The conclusion of the calculations was that Nuclear Thermal Propulsion is the best solution in terms of mass (560 tonnes). The IMS Trident has 10 engines (2 are for redundancy). One engine weighs 7.7 tonnes and is of 10 m length, see Fig. 4.

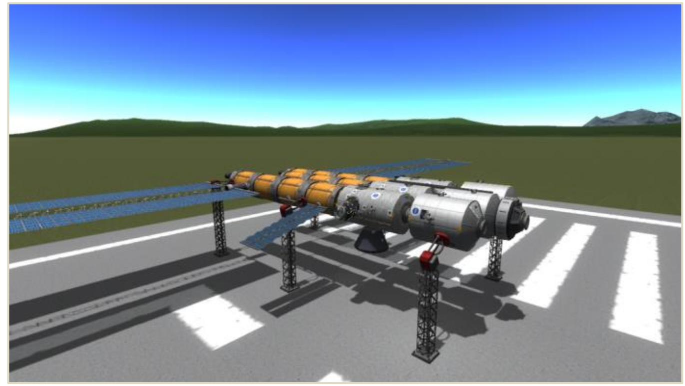

Fig. 4 - Concept with propulsion modules (orange) and solar panels

6.1 Attitude Control

To control the attitude, the Trident will utilize both gyroscopes and attitude control thrusters. The gyroscopes are efficient when assisted by a gravitational force and so nine thrusters using methane are used when out of any significant gravitational field. The total mass of the attitude control system has been estimated to 150 tonnes.

6.2 Power Supply

The request of power for all the onboards systems is about 150 kW. The nuclear power plant used for propulsion is used as the power supply. Indeed, a part of the heat produced will be transformed into electricity by using a Brayton cycle, as it is done on Earth.

6.3 Cooling Systems

To avoid any uncontrolled nuclear reaction, a cooling system is necessary. Contrary to Earth environment, there is no water in space and the water brought on-board is far from being enough. The solution is to use liquid metal that will cool down the nuclear plant where temperatures can reach up to 1500K. This constitutes a very heavy cooling system: 140 tons. This system requires electrical power itself, and for security measures, it can’t be nuclear power. Some solar panels will serve this purpose.

That is the general outline of the Trident’s propulsion system, for more information please consult the PP group report. Next the Human Aspects work is summarised.

7 Human Aspects

The HA group were responsible for all human-related processes including crew/passenger selection, training and metabolic consumables. They were also responsible for all on-board activities and scheduling.

7.1 Crew and Passenger Composition

The crew will be composed of ten astronauts, since the ship will have a capacity of 30 passengers, the 10 astronauts will be divided into a group of two with each group having 5 astronauts and in charge of 15 passengers. In addition to maintaining and running the ship, the job of astronauts will be to assign tasks to passengers and ensure that the passengers follow the prescribed schedules for all the activities that will be taking place on board the ship. Although this is a passenger ship, all passengers will need to be screened (herein referred to as selection) to ensure they are physically and psychologically capable of a long-duration, hazardous journey. The most crucial requirement is a potential passenger must be in very good health, should at least have a class 2 aviation medical certificate and be aged between 25 to 55 years. After meeting this key requirement, the passengers will be subjected to various psychological tests to determine their ability to work in multicultural setup and their ability to work as a team under high stress and pressure. Finally, since passengers will spend the whole trip in a confined and isolated space personality and character test and interviews will take place. This process will not be of the same level of difficulty as that of astronaut training and a normal, healthy adult should be capable of passing. Successful candidates will proceed to be trained in activities related to what they will be doing on board the ship. Detailed information can be found on the HA group report including the designations of each crew member.

7.2 On-board Activities

To keep the physical and emotional wellbeing of the crew and passengers on board there will be a variety of recreational and exercise activities that will be taking place. Entertainment will be a key aspect that will stop passengers from getting too bored and lonely, each passenger’s tablet will be loaded with movies, songs, books and games that s/he likes and there will be organised events such as cinema nights held in the entertainment area. To prevent bone and muscle mass loss due to microgravity environment there will be mandatory exercise machines on board, every day each passenger is expected to spend at least 2 scheduled hours exercising. Finally, in the ship there will be an observation module where it will be possible for passengers to observe the cosmos and possibly get a good view of any EVAs taking place.

7.3 Life Support Systems

A breathable atmosphere is of course one of the most critical aspects of the ship, the composition of air inside the ship will be roughly 79% nitrogen, this has no physiological importance but serves to keep the ship pressure around 1atm. The other 21% will be oxygen, on the ship there will be 3 oxygen sources, the first being oxygen tanks brought from earth, second being oxygen selectors that uses electrolysis to produce the precious gas, the third option is solid fuel oxygen generators known as oxygen candles as back up in case the other systems fails. Recycling of air will also be taking place to produce water and methane in the Sabatier process.

The food must be compact and lightweight so that it does not increase the launch cost, it also must be nutritious and tasty so that it keeps the passengers heathy and it is generally accepted, because one negative effect of space on human it affects one’s sense of smell and taste. Water is another crucial life support system as it is used for drinking, food preparation and maintain hygiene, like air it too can be recycled and in the spacecraft, it means the initial amount carried can be limited with adequate and efficient water recovery systems installed on the ship. All waste water from urine, solid waste and CO2 ejected from human bodies will be recycled and used for various purposes in the ships. There will also be a space suit that a passenger can put on which has water flowing through it, it will be used in place of showering and to keep hygiene/morale high.

7.4 Health and Safety

The health of astronauts and passengers is one of the most important aspects to be considered. Since among the ten astronauts there will be a medical doctor and a surgeon, these people will attend to all medical emergencies that would arise and the ship will be equipped with medical kit and medicines for all the foreseeable diseases that could arise inside the ship. The health care system will be similar to the one currently used on ISS and the medical kit will consist of ambulatory medical pack (AMP), the advanced life support pack (ALSP), the crew contamination protection kit (CCPK), a defibrillator, the respiratory support pack (RSP), the crew medical restraint system (CMRS) and the medical checklist. A surgical system will be installed in the medical lab were an operation can be performed in a watertight contact with skin. In addition, there will be weekly medical check-up by the doctor to ascertain the fitness of the passengers and crew members.

That is the general outline of the Trident’s human-related aspects, for more information please consult the HA group report. It is also the conclusion of the Trident ship overview and in the next sections the feasibility and budgets will be discussed.

8 Design Budgets

Each sub-group was responsible for the estimation of mass, cost and power of their respective systems. This data was requested early in the process with the aim of having a continual update and refinement of these parameters.

8.1 Mass and Power Budgets

The sub-group mass, power and cost estimates are outlined in Table 1. As can be seen, the largest contribution of both mass and cost is the concept groups design. This is due to the way in which they estimated the mass and cost based on previous space stations. These figures include everything inside the station and so it may not be valid to add on the human aspects totals but it is of little significance in either case. The high mass and cost of the system are linked and act is the primary barriers to the Trident mission.

TABLE I
DESIGN BUDGET

Description	MASS [T]	Power [kW]	Cost [$]
Concept	1,375	0	175,000,000,000
Human	99	104	797,000,040
Logistics	-	0	7,075,000,000
Propulsion	1,033	0	392,000,000
Mission Total	2,626	104	183,128,070,040

8.2 Cost Analysis

In the past, human exploration of Mars has been prohibitively expensive. For the last 60 years, whenever a scientist was asked how soon can we get to Mars, the answer was usually within the next 20 years. Following the Apollo years NASA saw its budget drop considerably and it lacked a driving force, such as the Space Race, to push the human spaceflight programme beyond LEO. Meanwhile, neither the budgets nor ambitions of the other space-faring countries had Mars realistically in their sights. With the emergence, in great part due to NASA, of the private space sector it may now be possible to achieve the goals of interplanetary travel while keeping costs low. The following section outlines two estimates of the Trident mission cost and discusses the possible ways to fund such an endeavour.

The first method used to estimate the cost of the Trident programme is the relatively simply estimate by analogy. Each sub-group were asked to provide all relevant cost information based on their design decisions. These are outlined in Table 1 and are sourced from the sub-group reports. The concept groups cost and mass estimate dominates here and this is due to the fact that it is calculated based on reference to previous space stations. Although possibly not the most accurate method, due to obvious differences in design architexture, it is a good rough order of magnitude estimate. For comparison, the ISS is approx. 420 tonne and cost approx. $120 billion. [4]

In addition to the analogy estimate, the cost was estimated using NASA's Advanced Missions Cost Model (AMCM) [4].

$$Cost = \alpha Q^{\beta} M^{\Xi} \delta^{S} \epsilon^{(1/(IOC-1900))} B^{\phi} \gamma^{D} \qquad (1)$$

Eq. (1) above is composed of statistically defined constants, represented by greek lettering, and mission parameters, represented by latin lettering. For values and definitions please refer to [4].

The quantity refers to the number of spacecraft to be manufactured. As this is a modular design and is assembled in space, there will not be any test models created prior to contructions much like the ISS. The mass is self-explanatory and the value is an estimate of the dry mass in pounds. The specification refers to the mission type (e.g. planetary, observation etc.) and this value is 2.39 for planetary human spaceflight missions. IOC is the year of first operation and block number refers to the level of design inheritance whether its new (1) or an iteration of a previous model (2+). This is based on a modular design which has been utilised in the ISS so a Block value of 2 is chosen. Finally, the difficulty is rated between -2.5 (extremely easy) and +2.5 (extremely hard). For this mission an average value of 0 was chosen as it is based on mostly existing technology.

TABLE II
AMCM PARAMETER VALUES

Symbol	Description	Quantity
Q	Quantity	1
M	Mass	5000000
S	Specification	2.39
IOC	Initial Operating Capacity	2032
B	Block Number	2
D	Difficulty	0

The result of this model is a developement and production cost of $233B (2017 dollars). To account for other costs including conceptual studies and management etc. a wrapping factor of 50% is applied, putting the estimated cost at 350B$ (2017 dollars).

Obviously, quite a large difference exists between the two estimates. Estimating costs is always a difficult task, not least when dealing with a mission far beyond what has ever been attempted. NASA has infact had such difficulty throughout the years, with wildly changing estimates of a manned mars mission going so high as $500 billion. Elon Musk has however stated that he could manufacture his ITS for a mere $500 million, which even by an optimistic outlook seems exceptionally ambitious.

Taking this claim into account, the only feasable way to build a passenger ship may be through a Private-Public-Partnership, where an international effort involving all space agencies could be utilised to develop the technology required for Trident while all production and testing was hadled by a private company, similar to SpaceX or Orbital ATK.

Over a period of fifteen years, the most realistic option could be to have space agencies take care of 117B$ (the 50% wrapping cost) while a private firm handles the rest, this is assuming a cost closer to that estimated by SpaceX than by the AMCM. Such an endeavour would require each agency spend 10% of their current space budget per year until 2032, this is obviously a large simplification assuming firstly an accurate cost, then an even distribution over 15 years and it does not account for inflation.

A figure relatively acheivable in comparison to the ISS cost but further detailed analysis is required to determine its accuracy. The rest of the cost in development, production and testing would be handled by a private company assuming it is substatially less than estimated here. As previously stated, it is

TABLE III
POSSIBLE TRIDENT BUDGET CONTRIBUTIONS

Agency	Country	Budget $B*	10%	Total $B
NASA**	USA	17.6	6.2**	93.0
ESA	Europe	5.5	0.6	8.3
Roskosmos	Russia	5.6	0.6	8.4
CSA	Canada	0.5	0.0	0.7
JAXA	Japan	1.3	0.1	2.0
ISRO	Indian	1.1	0.1	1.7
CNSA	China	1.3	0.1	2.0
Other		1	0.1	1.5
				117.4

* 2014 Budget Figures, [8]
** NASA will lead the project and contribute more than 10%

assumed there is already a base of operations on Mars and so some technology and resources will have already been covered during those missions to Mars. This will reduce the development costs of the Trident substantially.

8.3 Tickets and Income

Having discussed the design and budget considerations, little attention has been paid to the actual process of getting a seat on the Trident. It is envisioned that tickets will be available for sale within the final years of construction circa. 2028. Of course tickets will be available to any private individual who can afford it but many seats will most likely be bought by public and private entities. Companies, countries and research institutions are expected to have a high level of interest in sending their own scientists to Mars for various scientific and political reasons. In addition to this, there may be interest in mining the resources of Mars and so it is a real possibility that mining companies will be a primary source of income possibly purchasing all available seats for crew changes. It is also possible that once developed and manufactured, there may be interest in selling entire ships or at least the designs. The long-term benefit to the space stations in having a reliable, high-capacity ship which can be used to ferry personnel to the Mars base station and possibly replace other transport methods.

Just as it was hard to estimate the cost and funding of the Trident, it is also difficult to put a price on each ticket. Private tickets to the ISS have sold for between $10-35 million and for an interplanetary trip it may be logical to increase this number. However, if multiple trips are planned and 30 are to be filled it is logical to keep the cost low. There are also other sources of income, including the ability to add cargo modules carrying satellites (based on SpaceX yearly launches and prices [5])and science equipment, and to have EVAs for an additional fee for

TABLE IV
POSSIBLE INCOME SOURCES

Income	QTY	FEE $M	Total $M
Tickets	30	30	1050
Satellites	10	72	720
Media	5	1	5
		15y Total	14,160

paying customers. This income should pay for operational costs, and prices can be adjusted to increase profits based on expenditures.

9 OFF-NOMINAL CASE: CRIMES IN SPACE

Trident will carry a relatively large group of people for a relatively long time. It may be an inevitability that, in part due to confined space and psychological issues, crimes of passion or intent may occur. How to treat these issues while onboard, far from the courts of humankind and when dealing with an international crew, is a difficult issue to answer. The basic human rights should not be taken away from anyone at the same time as the safety of the crew must be in focus.

9.1 Monitoring

To establish that there has been a crime committed, every room should contain monitor cameras excluding private areas such as sleeping quarters and toilets. The footage can only be accessed from the control room by the crewmembers. The footage cannot be accessed by only one of these crewmembers, but need at least two of them to get access. This is to keep the other crew member's integrity for themselves and if one of the ones having access to the footage is suspected for committing a crime the other two can still get access.

9.2 Conviction

Since one should not be convicted without a trial in court it makes this scenario very difficult. The crew will be of an international aspect, meaning the law for one citizen is not necessarily the law for another. If footage gives convincing evidence that the safety of the crew is at risk, the accused can be confined until the destination is reached and thereafter get a trial. What defines such a situation is of course open to interpretation and so each passenger will sign a contract acknowledging their consent to abide by the ships rules, international laws and any incurred consequences for breaking such rules. The accused must still have access to some of the ships facilities for e.g. training but will otherwise be monitored at all time. It is hoped that such a situation does not arise but every eventuality must be catered for.

10 CONCLUSION AND DISCUSSION

Until recently, the thought of a passenger ship traveling to Mars was, with somewhat of a cliché, more science fiction than science fact. There are a multitude of reasons for this, not least the dangers and risks involved for human spaceflight.

The Trident mission proposal highlights the difficulties of such a mission including radiation, logistics, mass to orbit and extremely high costs. However, if the drive is there then it is possible albeit expensive. As often mentioned there is, most likely, not going to be another ‘Kennedy Moment’ [6]. This means that if the colonisation of Mars is to happen, it will need to be done within a reasonable budget that is linked to the space agency budgets of today.

The Trident design itself is not revolutionary, based on the modular architecture of the ISS, but it is realistic and, most importantly, achievable within the timeframe. It allows for a high degree of customisation and expansion (Bigelow modules could be utilised for future redesigns) while maintaining high levels of safety and redundancy. Special design consideration must be taken into account when dealing with a civilian population and this will be another major hurdle for any agency used to dealing with professional astronauts.

In conclusion, the Trident ship and mission is feasible but the question is more about its cost than its technical possibility, with a price tag of $117-350 billion. Human spaceflight can be a hazardous and risky endeavour, which is magnified when dealing with paying passengers. The emergence of the private space sector however, may be the driving force that finally puts a Martian base, and maybe one day a colony, within humanities reach.

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Appendices

Fig. 5 – Timeline

Fig. 6 - Mission Logo / Patch

TABLE V – Role Allocation

Group	Task Allocation
Coordinators	Schedule Overall budgets Feasibility Off-nominal scenario
Concept & Layout	Size and basic concept Sketches & layouts Mass budget & cost estimate (ROM) Off-nominal scenario
Propulsion & Power	Propulsion Power and thermal systems Mass budget & cost estimate (ROM) Off-nominal scenario
Human Aspects	Crew preparation/training Life support systems Passenger activities Safety & Medical Aspects Resupply & recycling Mass budget & cost estimate (ROM) Off-nominal scenario
Operations & Logistics	Routes & time estimations Planetary Ops. (transfers, resupplies) Communications Resupply & recycling Mass budget & cost estimate (ROM) Off-nominal scenario