European Mars mission architecture using an enhanced Ariane launcher

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Abstract

A heavy version of the Ariane launcher is hypothesized for a manned mission to Mars. This enhanced Ariane has 100 mt LEO capability and 36 mt capability for transMars injection ($V\infty$=3.5km/s). In order to simplify the scenario and minimize the costs, it is proposed a pre-deploy semi-direct architecture with several rather small spaceships, 3 astronauts and an aerocapture maneuver for Mars orbit insertion. There are several advantages: First, as the payload to the Mars surface is split into equal parts, the same landing space vehicle can be used with mass and size compatible with the payload capability of the launcher. Second, the choice of relatively small landers allows the use of simple deployable rigid heatshields, which could be used both for aerocapture and entry, descent and landing. The use of small landers also reduces the complexity of the tests for the qualification of the descent and landing systems and procedures, which is a critical aspect of the preparation phase. 5 launches are required in this architecture.
Keywords: human mission, Mars mission, Ariane Super Heavy

Acronyms/Abbreviations

EDL: Entry, Descent and Landing
ERV: Earth Return Vehicle
ISRU: In Situ Resource Utilization
LEO: Low Earth Orbit
mt: metric tonnes
SLS: Space Launch System (NASA launcher)

1. Introduction

We address the problem of designing a European human mission to Mars by means of an enhanced version of the Ariane launcher. Several important assumptions are made in this study to design the architecture of the mission:

- The objective is to send at least 3 astronauts to the surface of Mars and to bring them back to Earth.
- The launcher is a Super Heavy Ariane. Its capabilities are defined and discussed in a paper from Iranzo-Greus et al [5]. A summary is proposed in the next section.
- As the launcher is imposed, the maximum payload to LEO is 100 metric tonnes (mt).

An important issue is to determine the best propulsion system for interplanetary transportation. In several NASA studies, it is shown that scenarios based on chemical propulsion generally require much more mass in LEO and a long and complex assembly process to build giant spaceships [2], [3]. Other strategies based for instance on nuclear thermal or solar electric propulsion were preferred [3]. However, in several recent papers, it has been highlighted that these comparisons were biased by inappropriate options, such as the elimination of aerocapture for Mars orbit insertion without looking for possible tradeoffs [7], [9]. Aerocapture for Mars orbit insertion is indeed a must and should drive the design of the mission and the choice of the other options, not the other way round. Another issue is to look at the impact of the number of astronauts on the design and complexity of the mission. In NASA studies, the number of crew was generally predefined (5 or 6 astronauts) at the expense of the overall complexity, the risks and the acceptability of the mission [2]. If aerocapture is chosen for all interplanetary vehicles and if the crew is reduced to 3 astronauts, we already showed that a semi-direct architecture based on the SLS launcher and chemical propulsion could be relatively simple and efficient: no LEO assembly and only 4 SLS launches to send the astronauts to the surface of Mars and bring them back to Earth [7]. For similar reasons, we propose to follow the same principles: Aerocapture is assumed and is a driving parameter of the mission. It might imply the use of a rather small and rigid heat shield, which in turn might imply that the vehicles are rather small. In the proposed study, an important issue is to determine if it is possible to use a single Ariane Super Heavy to send each lander directly to the surface of Mars, without LEO assembly. In the previous study from Iranzo et al, it was shown that an Ariane Super Heavy could send at the maximum 36 mt directly to Mars. 36 mt is therefore a key parameter of our study.

The paper is organized as follows. In section 2, a summary of a previous study on a possible evolution of the Ariane launcher is presented, it is called Ariane Super Heavy. In Section 3, we propose a discussion on possible options for sending space vehicles to Mars and preparing the return.

2. Ariane Super Heavy

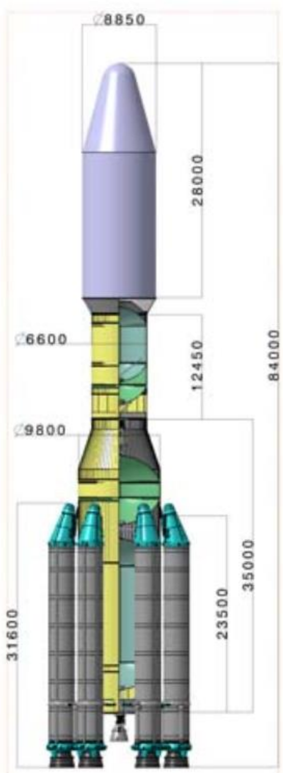


Fig. 1. Ariane Super Heavy (courtesy of Iranzo [5])

The Ariane Super Heavy concept is based on a possible evolution of the current Ariane launcher with the use of already developed engines and solid boosters. The main core of the first stage would be constituted by 5 Vulcain II engines. Complementary thrust would be provided by 6 EAP solid boosters. For the second stage, another Vulcain II engine is proposed. This concept is very interesting because the proposed engines and solid boosters have a high TRL. Development costs would therefore be small. Finally, according to the authors, if a Super Heavy Ariane launcher is used, 100 mt payload can be sent to LEO and 36 mt can be sent to Mars. More information is available in the paper from Iranzo et al [5].

3. Aerocapture and EDL

Aerocapture has been assumed from the start to minimize propellant requirements for Mars orbit insertion. There are numerous studies showing that aerocapture is feasible, provided that the entry velocity is not too high and the drag can be controlled [1], [2]. There are indeed 2 advantages with aerocapture:

- First, a space vehicle following an interplanetary trajectory must decelerate for insertion into Mars orbit. The ΔV depends on the desired orbit and the velocity on arrival. It is usually in the range 1 to 1.9 km/s at the end of a Hohmann transfer. Without aerocapture, the consequence of that ΔV would be to double the mass of the vehicle at Mars entry due to the mass of the propulsion stage. With aerocapture, a heat shield and other systems would be required, but the mass would only increase by an order of 30%. In addition, if it is a lander, a heat shield would be needed anyway and the additional mass would be even less.
- Second, if it is desired to reduce the travel time, the velocity would be increased at departure from Earth and the velocity on Mars arrival would be greater, resulting in a greater ΔV for Mars orbit insertion. Without aerocapture, the impact could be high with new propellant requirements and additional mass for the propulsion stage, which in turn might necessitate a LEO assembly of a giant spaceship. With aerocapture, provided that it is still possible to follow the required corridor [1], the impact would be quite low. In fact, aerocapture allows minimizing the impact of planetary configuration and Earth departure velocity on the size and mass of the space vehicle.

A critical issue of a Mars mission architecture is the test and qualification of EDL (Entry, Descent and Landing) systems during the preparatory phase [1]. The heaviest Mars lander to date had a mass of 1 mt on the surface. Many difficulties have to be overcome to be able to land 20 mt, or even more. The simplest approach is to use rigid heat shields but their size is limited to the diameter of the launcher. Inflatable heat shields can be used instead but the gigantism of those systems, the difficulty to use them also for aerocapture and the required control on the trajectory of the descent could make the qualification very complex and expensive. A possible tradeoff is to use deployable rigid heat shields and to limit the size and mass of the landing vehicles. According to a previous study, a 34 mt vehicle can be efficiently slowed down in the Martian atmosphere if the diameter of the heat shield is in the order of 12 meters [4]. Within an 8 meters' large fairing, the diameter of a deployable heat shield could expand to 12-14 meters. As the capability of the launcher is limited to 36 mt to Mars, the deployable rigid heat shield is a logical choice. Interestingly, the use of deployable rigid heatshields has already been studied by a European team and the concept has been deemed feasible [6].

4. Possible options for a human mission to Mars

4.1 Methodology

In several NASA studies, the mass of the manned interplanetary vehicle largely exceeds the 36 mt capability of the Ariane Super Heavy launcher and the sizing of deployable rigid heat shields for aerocapture or descent and landing maneuvers would not be reasonable [2]. However, mass and size are driven by 3 important parameters. The first is the maneuver for Mars orbit insertion, which can be performed with a propulsion system or with aerocapture. The second is the number of crew, which is known to have a huge impact [9] and the third is the number of days, which is directly linked to the amount of consumables needed for the crew. In a number of scenarios, the number of days is equal to the total trip duration, as it is expected that the crew would stay in the space habitat if the mission to the surface is aborted. Other abort strategies nevertheless exist. In order to keep the mass of the space vehicle below the 36 mt limit, different options have to be considered.

In a previous study, it was proposed to use the heaviest version of the SLS to send 4 space vehicles directly to Mars without LEO assembly [7]. It was called a semi-direct architecture in reference to the original proposal from Zubrin [11]. In the revisited version, a rendezvous between the two return modules was required in Mars orbit, but that strategy allowed aerocapture for all modules. Let us examine the details of the scenario. The first module was the Mars ascent vehicle. The second and the third were the two parts of the Earth return vehicle (return habitat + wet propulsion system). And the fourth was the manned spaceship, which served as habitable module for the outbound trip and on the surface. However, it is expected that the heaviest version of the SLS will have 130 mt LEO capability and 45 mt to Mars. This is significantly higher than what is assumed here with Ariane Super Heavy. Let us review the details of the previous study and determine if some adjustments can be performed.

4.2 Sending the Mars ascent vehicle

The mass of the interplanetary vehicle carrying the Mars ascent vehicle was estimated at 22 mt plus 22 mt for structure and EDL systems, which were estimated by a rule of thumb at 50% of the total entry mass [2], [10]. 44 mt is above the 36 mt limit that is assumed in this study for a spaceship sent to Mars. Nevertheless, 5 mt of life support consumables were provisioned in the previous architecture. The mass of the MAV alone is 17 mt. Adding structural mass and then EDL systems mass with the same rule of thumb, the total mass would be only 36 mt which is now compatible with our assumption. It is important to notice that margins were included in mass estimates. Approaching the 36 mt limit should not be a critical issue. See annex 1 for the details of the mass for the MAV.

4.3 Sending the Earth return vehicle

For the Earth return vehicle (ERV), it was clearly shown in the previous study that the best option is to split that vehicle into two parts, to send them directly to Mars and to assemble them in Mars orbit. Indeed, the total mass of the habitable module, the wet propulsion system for the outbound trip, the atmospheric Earth reentry capsule and the systems for Mars orbit insertion was so high that 2 SLS were required to send all modules to LEO, and then to Mars. With the limitation of 36 mt to Mars, 2 parts might be considered too little. However, there are several ways to save mass. The first idea is to choose a light capsule. Orion is not the best choice because it has been designed for 5 astronauts, 21 days life support and important ΔV transfers, while in this study, the crew size is 3 astronauts and the reentry capsule would be used only the last day of the trip [7]. Based on the experience of existing small capsules and the impact of reinforced heat shields, a pragmatic and reasonable assumption is to allocate only 5 mt for it. Second, as the mass of consumables is driven by the number of days in space, some adjustments can be made. In the consumables budget mass for a crew of 3, it is necessary to take backup options into account. If it is required to abort landing, it should be possible for the crew to join the ERV and to wait here the start of the launch window for the return. As a consequence, there should be enough consumables for approximately 700 days (450 days in orbit and 250 days for the inbound trip). Another optimization is to jettison the excess consumables or the numerous wastes before the departure of the return trip. By doing so, some propellant can be saved or the trip time can be reduced. All in all, some calculations have been made (see annex 3 and 4 for the details) and it seems indeed possible to use only two Ariane Super Heavy launchers to send the two parts of the ERV without compromising with the risks (e.g., consumables for the backup option).

4.4 Sending the crewed vehicle to the Martian surface

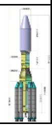
In the previous study, only one space vehicle was necessary to send a crew of 3 astronauts first to Mars orbit, and then to the surface, with consumables for a rather long period. In the proposed architecture, because of the new 36 mt limitation, there is much less consumables and there is no mass budget for rovers and scientific tools. In addition, the complementary consumables sent with the MAV have been removed. The only way to cope with these constraints is to add another launch with an Ariane Super Heavy in order to send to the surface all the consumables, rovers and tools that are missing. Fortunately, that amount is compatible with the 36 mt limit of the Ariane Super Heavy launcher. See annex 2 and 5 for a detailed mass budget.

4.5 Mission architecture

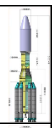
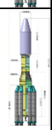
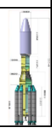
The result is an architecture based on 5 Ariane Super Heavy. As consumables are of primary importance for the survival of the crew, it is imperative that the cargo mission does not fail to bring consumables to the surface and also that the Mars ascent vehicle is ready for departure at any time when the astronauts are on the surface. In order to reduce the risks to the strict minimum, a simple strategy is to split the mission in two phases. In the first phase, the Mars ascent vehicle and consumables are sent to the surface. If that phase is successful, two years later (next interplanetary window to Mars), the second phase starts with three other launches, as explained Table 1. See annexes 1 to 5 for the detailed mass allocation of all vehicles.

Table 1: Mars Mission architecture

First phase, 2 years before the astronauts' trip:

	A cargo spaceship is sent to the surface of Mars. It brings to the surface the Mars ascent vehicle. It includes CH4 propellant but does not include oxygen as it will be produced on Mars using an ISRU system (which is included).
	A cargo spaceship is sent to the surface of Mars. It brings consumables, rovers and scientific tools before the crewed mission.

Second phase:

	A cargo spaceship is sent to Mars orbit. It brings the habitable module of the Earth return vehicle.
	A cargo spaceship is sent to Mars orbit. It brings the wet propulsion system of the ERV and the atmospheric Earth reentry capsule.
	The crewed vehicle is sent to the surface of Mars.

A possible issue is to be able to send several spaceships during the same Mars transfer window, which lasts approximately three weeks. There are several options to solve the problem. The first option is to send the first vehicle to LEO and to wait for the start of the transfer window. Meanwhile, other vehicles can be launched and sent to LEO. When the Mars transfer window opens, all vehicles can be sent to Mars according to an appropriate timetable. The drawback of this approach is having to store cryogenic propellant during long period of times, which is a well-known difficult task with possibly significant losses, especially for LH2. However, as there is no LEO assembly in the proposed architecture, there is no need to send the vehicle to LEO a long time in advance. The waiting period might therefore be limited to a few months. Another approach is to prepare several launch vehicles at the same time and to store them in adapted hangars located close to the Launchpad, as it was performed in the Apollo program for the launch of the Saturn V rocket. If the transportation of the launcher to the launch pad does not take too long and if the final preparation can be carried out in two weeks, two launches can probably be operated during the Mars transfer window. Otherwise, a tradeoff would have to be found between waiting in Mars orbit and speeding up the launch process.

4.6 Risks

In NASA studies on risk issues, two types of risks are distinguished: loss of crew risk and loss of mission risk [2]. The loss of crew risk must be reduced in priority. The top risks are in general associated with space maneuvers: launch from Earth, Earth orbit rendezvous if any, transMars injection, Mars orbit insertion, entry, descent and landing on Mars, ascent from Mars, rendezvous in Mars orbit, transEarth injection and finally Earth entry, descent and landing. In this long list of maneuvers, one is particularly risky, the descent and landing on Mars. There are two reasons for that. The first is because there is a long sequence of complex descent and landing maneuvers with very severe constraints on velocity, orientation and timing to succeed. And the second reason is because once the entry in the Martian atmosphere is initiated, there is no return to orbit option, the long sequence of descent and landing maneuvers have to be triggered, it is not possible to come back to Mars orbit. In order to minimize the risks, several variables have to be examined:

- Shape: The shape of the landing vehicle has an important impact on the guiding and control systems used for the descent. A capsule, for instance, has a simple symmetric shape and its center of mass can be chosen such that even in case of GNC or RCS failure, the vehicle would keep its attitude and would follow a ballistic but possibly acceptable descent trajectory. In the case of a winged vehicle, guidance and control would be much more complicated.
- Size: The size is not directly linked to the risk, but there are many advantages with light and small landing vehicles. In order to reduce the ballistic coefficient to acceptable values, large heatshields have to be used. However, if the mass of the vehicle is very high, the width of the heatshield might exceed the width of the launcher. Several options exist to deploy giant heatshields, but usually at the expense of the complexity and robustness of the systems and therefore at the expense of the risks. Also, if a change is required for the thrust direction or for the attitude of the vehicle, it takes less time with a smaller vehicle. Last, for the final braking phase, if the thrust cannot be controlled as expected, provided that the mass of the vehicle is not too high, large backup parachutes might be used to help reducing the terminal velocity before impact.

In this proposal, the mass and size of the landing vehicles are relatively small and the heatshield can be rigid and deployed in space. The EDL risks are therefore reduced in comparison with other mission architectures and options.
Another issue is to provide backup options at critical moments of the scenario:

- During the outbound trip, in case of emergency, it should be possible to abort the mission. A possible solution is to transfer the crew onboard the habitable module of the return vehicle. Then, the aerocapture maneuver could be implemented as expected or the heatshield could be jettisoned and all modules of the Earth return vehicle could be joined in order to proceed to an insertion into a free return trajectory.
- Once in Mars orbit, if for any reason, it is risky to start the entry, descent and landing maneuvers with the crewed vehicle or if the consumables of the landed cargo are not available anymore, or if an unexpected problem occurs with the Mars ascent vehicle, the landing must be aborted and the crew vehicle must stay in Mars orbit. In this case, the Earth return vehicle provides a safe haven for the crew with enough consumables for the waiting time in Mars orbit and the inbound trip (see Section 4.3).
- Once on Mars, if there is any health problem of life support systems failures, the Mars ascent vehicle can be used at any time to come back to Mars orbit.

The proposed architecture therefore provides several important backup options that help reducing loss of crew risks.

4.7 Roadmap

Key elements of the mission have to be developed and qualified:

a) Ariane Super Heavy with upper stage for TMI.
b) Dual use habitable module for 3 astronauts.
c) ISRU system to produce oxygen.
d) Mars ascent vehicle.
e) Rendezvous in Mars orbit and return vehicle.
f) Atmospheric Earth reentry capsule for 3 astronauts.

Two preliminary space missions would be appropriate and sufficient to qualify the key elements of the Mars mission [3]:

- A 3-years human mission in high Earth orbit with several rotating crews. The objective will be to qualify b) and at the same time maturing a) and f). This mission is important to make sure that life support systems are efficient (high recycling rate for water and other consumables) and safe with appropriate lifetime (no resupply mission during 3 years). It is also an opportunity to study psychological issues and to gain experience on monitoring a distant crew with communication delays.
- A heavy Mars sample return mission. The objective will be to test c), d) and e) and at the same time maturing a). Collecting Mars samples and bring them back to Earth will be an added value.

A possible planning of the project is presented Figure 2.

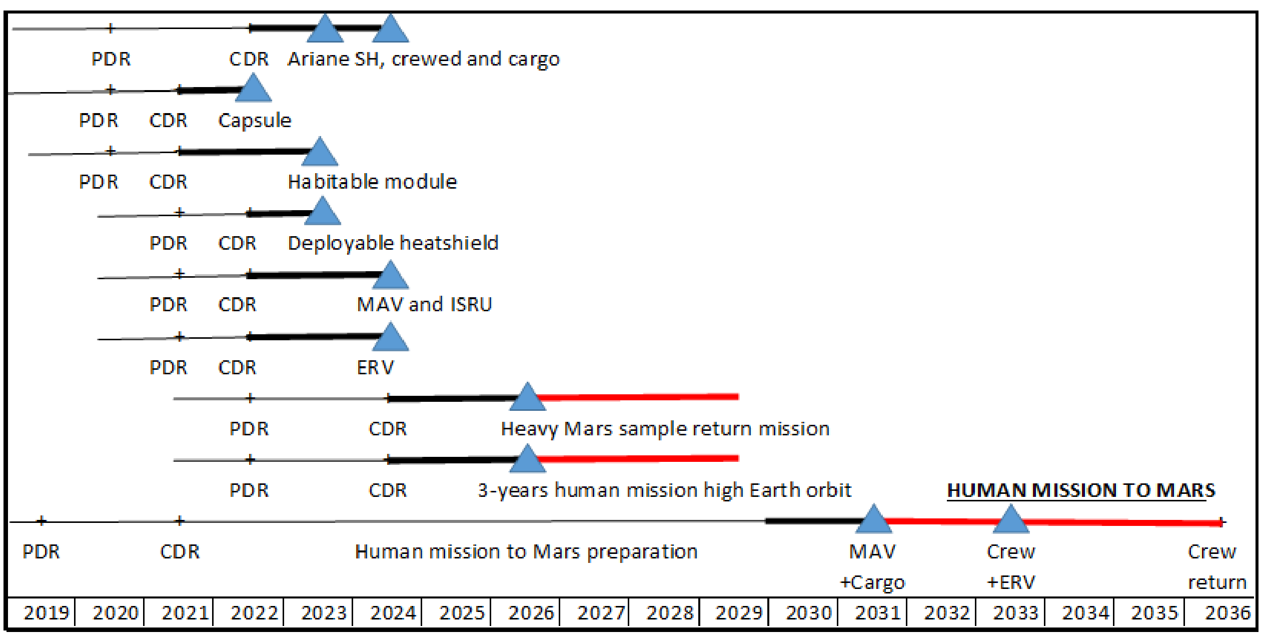


Fig.2. Proposed roadmap.

5. Conclusion

A European human Mars mission architecture has been proposed. It is based on a super heavy Ariane launcher concept, which exploits existing Vulcain II engines and solid boosters. Thanks to aerocapture and a semi-direct architecture, only 5 launches are required to send a crew of 3 astronauts to the surface of Mars and bring them back to Earth. A key advantage of the proposed scenario is the use of rather small spaceships that can be sent directly to Mars without LEO assembly. Another advantage is the possible integration of rigid deployable and dual use heat shields, which would reduce the complexity of EDL qualification and EDL risks. Two important space missions are proposed to qualify and test all modules before the first human mission. All in all, thanks to its simplicity, if the decision is taken now, the preparation phase could last 14 years and the total cost would be around 50 billion Euros, which would be affordable for European Union.

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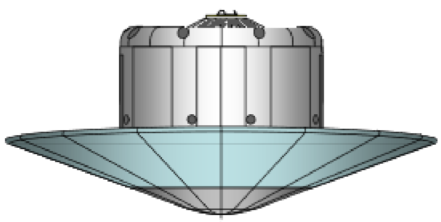
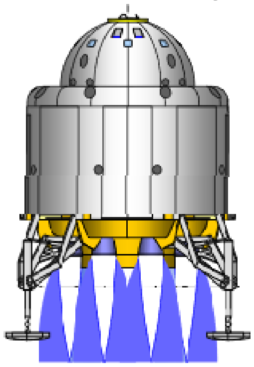
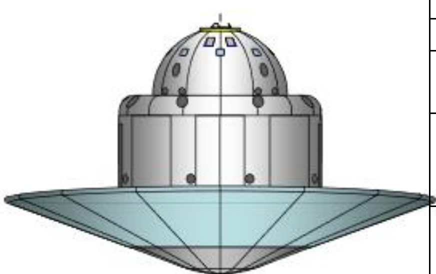
Appendix 1: 1st interplanetary vehicle: Mars ascent vehicle

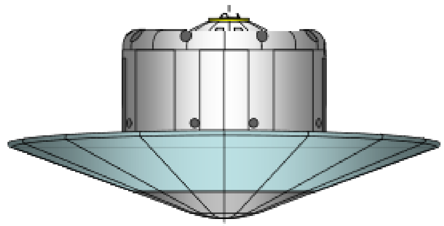
<table>
<tr><td colspan="3"></td><td>Mass in kg</td></tr>
<tr><td rowspan="9">Payload to the surface: Mars ascent vehicle, 3 astronauts

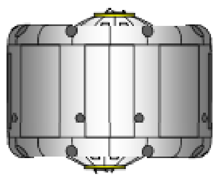
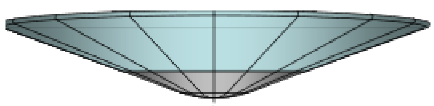
(Credit NASA)</td><td rowspan="4">1st stage</td><td>Inert mass</td><td>2557</td></tr>
<tr><td>Propellant: LOX</td><td>0</td></tr>
<tr><td>Propellant: LCH4</td><td>1925</td></tr>
<tr><td>Total</td><td>4483</td></tr>
<tr><td rowspan="4">2nd stage</td><td>Inert mass (including habitat module)</td><td>4907</td></tr>
<tr><td>Propellant: LOX</td><td>0</td></tr>
<tr><td>Propellant: LCH4</td><td>2181</td></tr>
<tr><td>Total</td><td>7089</td></tr>
<tr><td colspan="2">Total MAV</td><td>11571</td></tr>
<tr><td rowspan="3">ISRU</td><td colspan="2">ISRU systems (NASA data)</td><td>945</td></tr>
<tr><td colspan="2">Surface power systems</td><td>4000</td></tr>
<tr><td colspan="2">Deployment systems</td><td>300</td></tr>
<tr><td colspan="3">Structure</td><td>1000</td></tr>
<tr><td colspan="3">TOTAL payload mass</td><td>17817</td></tr>
<tr><td rowspan="8">Aerocapture and EDL systems

(Credit Mark Benton)</td><td colspan="2">Deployable 14 meters diameter rigid heat shield; dual use aerocapture and EDL</td><td>5000</td></tr>
<tr><td colspan="2">TPS and backshell</td><td>1500</td></tr>
<tr><td colspan="2">Avionics and separation structure</td><td>1000</td></tr>
<tr><td colspan="2">RCS dry mass (propulsion system for circularization and descent control)</td><td>500</td></tr>
<tr><td colspan="2">Propellant for RCS propulsion system, circularization burn for Mars orbit insertion, then descent control</td><td>2000</td></tr>
<tr><td colspan="2">Descent stage, propulsion system and landing legs, dry mass</td><td>1000</td></tr>
<tr><td colspan="2">Descent stage, propellant</td><td>5000</td></tr>
<tr><td colspan="2">Margins (to obtain 50% total mass)</td><td>1817</td></tr>
<tr><td colspan="3">TOTAL EDL SYSTEMS (50% of total)</td><td>17817</td></tr>
<tr><td colspan="3">TOTAL</td><td>35634</td></tr>
</table>

Appendix 2: 2nd interplanetary vehicle: Consumables to the surface

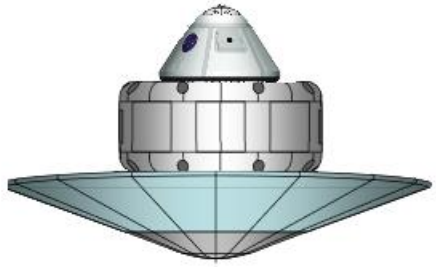
	t	**Mass in kg**
Payload to the surface: Cargo vehicle.  (Credit Mark Benton)	500 days food and water for 3 astronauts	8000
	Other consumables	2000
	Power systems	2000
	Rovers and rovers consumables	2000
	Scientific tools	2000
	Structure	1000
	TOTAL payload mass	**17000**
Aerocapture and EDL systems  (Credit Mark Benton)	Deployable 14 meters diameter rigid heat shield; dual use aerocapture and EDL	5000
	TPS and backshell	1500
	Avionics and separation structure	1000
	RCS dry mass (propulsion system for circularization and descent control)	500
	Propellant for RCS propulsion system, circularization burn for Mars orbit insertion, then descent control	2000
	Descent stage, propulsion system and landing legs, dry mass	1000
	Descent stage, propellant	5000
	Margins (to obtain 50% total mass)	1000
	TOTAL EDL SYSTEMS (50% of total)	**17000**
	TOTAL	**34000**

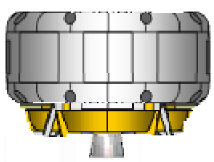
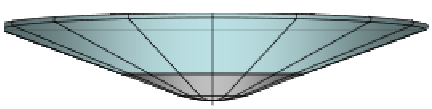
Appendix 3: ERV, part 1



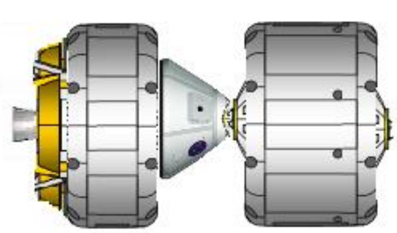
		Mass in kg
Payload to Mars orbit: ERV habitable module  (Credit Mark Benton)	Habitable module 3 astronauts 600 days life support (NASA data)	**23496**
Aerocapture and RCS systems  (Credit Mark Benton)	Deployable 14 meters diameter rigid heat shield	5000
	TPS and backshell	1500
	Avionics and separation structure	1000
	Propulsion for post-aerocapture burn, attitude control and Mars orbit rendezvous, RCS dry mass	500
	Propulsion for post-aerocapture burn, attitude control and Mars orbit rendezvous, RCS propellant	3000
	Margins	1000
	TOTAL AEROCAPTURE SYSTEMS	**12000**
TOTAL		**35496**

Appendix 4: ERV, part 2

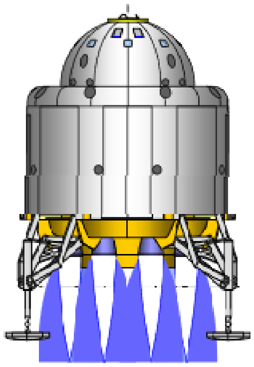
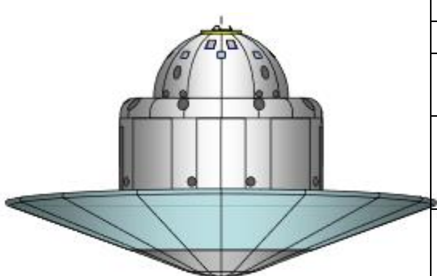


		Mass in kg
Payload to Mars orbit: Earth reentry capsule. 	Capsule	5000
	Capsule consumables	1000
	Structure, fixations to propulsion stage and separation mechanisms	1000
	Total Earth reentry capsule	**7000**
Payload to Mars orbit: ERV propulsion system, Delta V: 1.5 km/s  (Credit Mark Benton)	Propulsion stage dry mass	2000
	Propulsion stage, propellant CH_4+O_2 Total propellant mass fraction : 38%	13700
	Total propulsion stage	**15700**
Aerocapture and RCS systems  (Credit Mark Benton)	Deployable 14 meters diameter rigid heat shield	5000
	TPS and backshell	1500
	Avionics and separation structure	1000
	Propulsion for post-aerocapture burn, attitude control and Mars orbit rendezvous, RCS dry mass	500
	Propulsion for post-aerocapture burn, attitude control and Mars orbit rendezvous, RCS propellant	3000
	Margins	1000
	TOTAL AEROCAPTURE SYSTEMS	**12000**
TOTAL		**34700**

After Mars orbit insertion, the heatshield is jettisoned and a rendezvous is programmed between ERV part 1 and ERV part 2 to assemble the full ERV. Another docking system is available on the right for the Mars ascent vehicle.



Appendix 5: 5th interplanetary vehicle: crewed spaceship to the surface

		Mass in kg
Payload to the surface: Mars habitat.  (Credit Mark Benton)	Habitable module 3 astronauts 250 days life support	17691
TOTAL payload mass		**17691**
Aerocapture and EDL systems	Deployable 14 meters diameter rigid heat shield; dual use aerocapture and EDL	5000
	TPS and backshell	1500
	Avionics and separation structure	1000
	RCS dry mass (propulsion system for circularization and descent control)	500
	Propellant for RCS propulsion system, circularization burn for Mars orbit insertion, then descent control	2000
	Descent stage, propulsion system and landing legs, dry mass	1000
(Credit Mark Benton)	Descent stage, propellant	5000
	Margins (to obtain 50% total mass)	1691
TOTAL EDL SYSTEMS (50% of total)		**17691**
TOTAL		**35382**