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2-4-2 CONCEPT FOR MANNED MISSIONS TO MARS

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In a previous paper, a new scenario for human missions to Mars has been presented. It can be named the 2-4-2 concept. The idea is to minimize IMLEO and the payload on Mars with a crew of only two astronauts. There are two astronauts in each rocket at departure from Earth. They meet on Mars to form a team of four and the pairs are reconstituted for the return (2-4-2). In the previous study it was proposed an assembly in LEO. We propose now a different approach with several small vehicles sent to Mars at the same time. There is no need for LEO assembly and the landers are lighter thus facilitating entry descent and landing on mars.

I. INTRODUCTION

In the last Design Reference Architecture (DRA) for manned missions to Mars from NASA, two major critical phases have been identified [5]. The first is the launching and assembly phase, which requires a large number of launches with an Ares V class launcher and several years operations in LEO before the spacecrafts are sent to Mars. The second critical phase is the descent and landing on the surface of Mars. Braun and Manning also have reported important difficulties for that phase [1]. Because of the payload needed on the surface of Mars, the ballistic coefficient is high and the feasibility of the descent is questionable in terms of technology and timeline. According to NASA, the cumulative risks of the DRA are too high for a manned mission to Mars. In order to reduce the risks, it is important to find solutions to reduce the initial mass in LEO (IMLEO) and to reduce the payload on Mars.

We propose a different scenario that minimizes the two risks described above. It is called the 2-4-2 concept. The basic idea has already been presented [11]. We propose in this paper some improvements and discuss the risks. In Section 2, new elements of the scenario are described. In Section 3, an analysis of the risks is presented.

II. DESCRIPTION OF THE 2-4-2 CONCEPT

Basic idea

The main ideas of the paper have already been published but the scenario had no name [11]. The “2-4-2” concept comes from the number of astronauts at different periods of the mission. There are only 2 astronauts onboard the manned spacecraft. In NASA or ESA reference missions, the number of crew is 6 [5], [6]. 2 astronauts is not the optimum according to skills requirements but it does not increase much the risks of the mission [3], [9]. On the other hand, it is risky to have no backup vehicle on Mars. In order to reduce the risks, the mission is fully duplicated. There are therefore 2 spacecrafts with a crew of 2. At launch and during

transit they are 2. On Mars, the spacecrafts should try to land close to each other. So they are 4 on the surface to explore the red planet. At take off from Mars, they are 2 again. Each Mars ascent vehicle joins an Earth return vehicle and the 2 Earth return vehicles finally return to our planet. This is what is expected if everything goes well. However, 2-4-2 also means 2 for 2: 2 astronauts are ready to help the 2 others in case of an emergency. At every step of the mission, and especially on the surface of Mars, in Mars orbit or in transit, if a problem occurs with a spacecraft, it should be possible to proceed to transshipment onto the other spacecraft. Such a possibility has important impacts in terms of payloads but some mass savings remain.

It is important to recall that Von Braun already proposed a similar scenario. However, in his original concept, Von Braun proposed 12 astronauts and the IMLEO was 1450 metric tons [10]. There are indeed other options in our scenario that differ from Von Braun’s idea and allow important reductions of IMLEO and Mars payload. The main one is the use of in situ local resources to produce propellant for the Mars ascent vehicle.

In Situ Resource Utilization (ISRU)

We suggest bringing all the tools and chemical systems to extract water from the ground and carbon dioxide from the atmosphere to produce CH₄/O₂, which is a good propellant for rockets [15]. In NASA reference missions or in Zubrin Mars Direct scenario, it is proposed to produce propellant automatically by means of a cargo mission sent 2 years in advance [4], [5], [8], [13], [14]. The idea is to have a Mars ascent vehicle ready for launch before the launch of the manned spacecraft. However, such an option adds complexity to the scenario and does not allow using the most appropriate technologies. In the DRA report from NASA, it is clearly explained that the option minimizing Mars payload is the one that exploits as much Mars resources as possible [5]. But that option is

not chosen because of its complexity and risks if it has to be accomplished by robots. The extraction of water from the ground is indeed a complex task for a robot and the reliability is not high. If humans were present, the risk of loosing a robot or the difficulties linked to the deployment and maintenance of the systems would be highly reduced.

Furthermore, important improvements have been made in solar panels technology [12]. According to Cooper et al, new ultra light solar panels have a lower specific energy than nuclear power plants even on the surface of Mars [2]. Obviously, it would be very difficult to deploy and maintain such panels with robots. However, with the help of humans, the deployment would be manageable [12].

The 2-4-2 concept therefore enables optimisation in the utilization of local resources.

Optimisations

Several other optimisations can be proposed around the 2-4-2 architecture.

- First, the same habitat can be used in space and on the surface. Surprisingly, such an idea has not been examined in NASA reference missions, though similar habitat designs have been suggested for transit and on the surface [5]. The reason for that omission is probably that the Mars ascent vehicle would be much heavier if the habitat is used instead of the capsule. However, with a habitat designed for only 2 astronauts and provided that most consumables for the return are left in Mars orbit, the mass penalty is not so important.

- Second, because the specifications are close, the same propulsion system can be used for landing and for take off from Mars. There are therefore mass savings in the reduction of the number of propulsion stages.

- Third, there are small spacecrafts for Mars landing. In the previous paper, it was proposed to land only 2 spacecrafts with a crew of 2 for each and ISRU systems onboard [11]. The reduction in the number of astronauts enables mass savings but ISRU systems are a mass penalty. In order to reduce Earth descent and landing (EDL) risks, it might be interesting to adopt another strategy. ISRU systems can indeed be sent in another spacecraft. The payload would be split into 2 equal parts and the spacecraft would be very light, in the order of 30 tons all included. The ballistic coefficient would be highly reduced, thus enabling a less constrained EDL phase.

- Fourth, what is not necessary on the surface is left in the Earth return vehicle (ERV) waiting in Mars orbit. The ERV is only a propulsion system (service module as in the Apollo program) and an Earth reentry capsule (command module as in the Apollo program). The capsule can be used to store consumables and tools for the return. As in the Apollo moon return scenario, the Mars ascent vehicle joins the ERV. The main difference

is that the habitat coming from the surface of Mars is much bigger than the lunar module. The propulsion system of the Mars ascent vehicle (MAV) is then jettisoned before the rocket engines of the ERV are fired. An illustration is proposed Fig. 1.

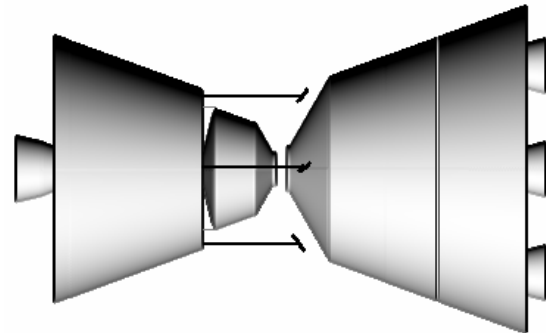


Fig. 1: Junction between the ERV and the MAV. The ERV (left) has 2 parts: a wet propulsion stage and a capsule. The Mars ascent vehicle (right) also has 2 parts: the habitable module and a propulsion stage, which is jettisoned before trans-Earth injection (TEI).

- Finally, another interesting feature is that the ERV, the cargo and the manned spacecraft would have a similar mass. In order to send all the spacecrafts to Mars, the same launcher might be used with a reasonable IMLEO capability. An illustration of the payloads is proposed Fig. 2.



Fig. 2: ERV, manned spacecraft and cargo during Earth-Mars transit. The shape of the vehicles is adapted for aerocapture or/and landing.

II. RISKS ANALYSIS

Risks during the outbound transit phase

The Apollo program was a great success. All astronauts returned safely to Earth. However, during the Apollo 13 mission, a terrible explosion occurred during the transit between LEO and the moon, which caused abort of the mission and endangered the crew. If a similar problem occurred during the transit between Earth and Mars, there would be no abort option to save the crew. In most scenarios, there are abort options while the crew is in LEO, in Mars orbit or on the surface of Mars but not during the transit stage. Is it reasonable to assume that the risks during the transit period are very low? And if not, what can be done to reduce them? We propose to address both questions.

Concerning the risks, the Apollo 13 problem suggests that there are not negligible. However, it is difficult to make an accurate estimation of the risks because many systems are involved and humans have strong capacities to mitigate the problems and repair the defected devices. We propose a qualitative analysis inspired from what has been done for the ISS [7]. What kind of accident may occur during the transit stage that would result in the loss of the crew? Our analysis is summarized in Table 1. In most cases, if the problem is linked with the life support system, the degradation of life conditions is slow. The astronauts could therefore survive several weeks. Let us assume that such a problem occurs. How to implement a rescue mission during that period? Obviously, during the transit stage, it is not possible to stop and come back to Earth. The only solution is to have another rocket on the way to Mars. If that rocket is sent a few hours before or after the other one, it could be possible to make a junction in space and to transship the crew from the unsafe rocket to the safe one. By doing so, an explosion of the oxygen tank as it occurred during Apollo 13 mission would not have a dramatic issue. Now if we allow the transshipment of a crew, what are the consequences on the specifications of the habitable modules? Dramatic problems onboard a space vehicle requiring crew transshipment must be rare. An exceptional restriction of the volume per person is probably acceptable. A critical issue could be to keep the life support system operational if most consumables of the first vehicle are lost. As a consequence, there should be enough consumables for a crew of 4. However, even with a crew of 2, supplementary consumables should be taken onboard to come up with exceptional losses. In the case of transshipment, some consumables might be recovered. It seems therefore reasonable to double the consumables but without additional margins.

Another issue is to allow more astronauts in the Earth entry vehicle at the end of the trip. The capsule should be designed for a crew of 4. However, it can be designed for a crew of 2 plus 250 kg of rocks samples or a crew of 4 plus 50 kg of samples.

Risks assessments

We propose a comparison with NASA architecture [5]. The two major risks that have been identified by NASA are a failure during launch or LEO assembly and a failure during EDL of a lander. Since the number of launches is reduced (6 vs 10) and there is no LEO assembly, our scenario is less risky for that phase. Regarding EDL, the landers of our scenario are much

lighter (3 times less) with shapes adapted for maximum control and reliability. The ballistic coefficient is also smaller, thus minimizing physical and timeline constraints and enabling the use of more simple technologies. EDL risks are therefore much less in our scenario. Other risks exist, see Table 2. Our scenario has important advantages. The good points are the relative simplicity and the ability to perform transshipment during transit. The most important drawback is probably the fact that the ERV is not ready for launch when the astronauts land on Mars. The risk of losing a crew is nevertheless mitigated by two backup solutions. The first one is the transshipment onto the second spacecraft provided that the production of propellant works properly for that one. If it does not work either, we suggest waiting for the next mission, which would bring new ISRU systems. In the DRA scenario, a similar backup solution is proposed if the MAV is not usable. In order to avoid such extreme situations, it is important to prove the feasibility of ISRU systems before the first manned mission. As it is mentioned by many engineers in astronautics [3], the major risk is probably linked to the landing on Mars. We therefore recommend that a dedicated unmanned mission is designed prior to this one to test the landing of a heavy spacecraft and the production of propellant using similar ISRU systems.

III. CONCLUSION

The proposed 2-4-2 concept can be considered as an optimized version of Von Braun's scenario. The idea is to send to Mars at the same time several spacecrafts with a crew of two. The scenario enables several optimizations and minimizes the risks by allowing safe transshipments in case of an emergency. Three important principles emerged:

- The human presence during propellant production enables the most efficient ISRU options.
- Short astronaut numbers enables small spacecrafts thus minimizing EDL complexity and risks.
- Since no LEO assembly is required, the scenario is simple.

Other important problems have not been discussed. Long stays in microgravity have negative impacts on many organs, especially bones, muscles and cardiovascular activity. In order to reduce microgravity effects, it is possible to include in the spacecraft a small centrifuge. Another idea is to have a tether between a habitat lander and a cargo lander and to rotate the system in order to create artificial gravity as it is suggested in Mars Direct [15].

System	Problem	Consequence
Power supply	Partly broken. Not enough power.	Life support system insufficiently powered. Possible consequences: Temperature cooled down, atmosphere not revitalized.
Air composition control system	Out of order, not repairable.	Atmosphere becoming unbreathable (too much CO ₂ , not enough O ₂ , etc.)
Trace contaminants removal system	Out of order or not appropriate for unexpected contaminants	Air poisoned by contaminants. Degradation of astronauts' health.
Water purification system	Poisoned water, system out of order and not repairable or not appropriate for unexpected contamination	Water poisoned by contaminants. Degradation of astronauts' health.
Food conservation and storage	Microbial contamination of food or unexpected packaging degradation	Astronauts starving.
Structure of the habitat	Explosion or meteorite impact or closure leakages	Continuous loss of air. Astronauts might survive during a short period of time in their spacesuit or in a restricted area of the habitat.
Propulsion system	Out of order.	Not able to undertake any maneuver. Rocket going to crash on Mars or to orbit around the sun (with the exception of free return trajectories).
Human	Fatal error or madness of an astronaut. One of the above systems is broken down.	One of the above.

Table 1: Possible dramatic accidents during the transit stage.

Problem	Consequence in DRA scenario	Consequence in our scenario
Crash of manned launcher	6 people dead	2 people dead and mission aborted on Earth or in LEO for the 2 nd spacecraft. The risk of a crash is multiplied by 2. On average, the number of deaths per mission is nevertheless smaller.
Problem during outbound with manned spacecraft	No short term solution. 6 people dead.	Transshipment onto the second spacecraft. Insertion in Mars orbit. Then wait next conjunction for return.
Problem in MO with manned spacecraft	If problem with ERV, abort to Mars and wait for next ERV; if landing impossible, abort to ERV.	Transshipment onto the second spacecraft. Wait next conjunction for return.
Unable to produce propellant using ISRU	Stop mission before sending astronauts.	Try to repair. If not possible, two crews in the same spacecraft at takeoff. If second ISRU also out of order, send appropriate tools to repair.
Long range mobility reduced or unable to join MAV.	Wait next mission.	Wait next mission.
Unable to takeoff from Mars	Wait next mission.	Transshipment. If second spacecraft unable to takeoff, too far or already gone, wait next mission.
Crash of MAV	6 people dead	2 people dead, same as crash of launcher
MAV safe but unable to join ERV	6 people dead	Try transshipment. Otherwise 2 people dead.
ERV unable to leave MO	If possible, wait next mission, otherwise 6 people dead.	Try transshipment. Otherwise 2 people dead.
Problem during inbound	Same as outbound, no short term solution.	Same as outbound, transshipment.

Table 2: Comparison of the risks between the DRA scenario and ours.

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