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A European Launcher for Manned Mars Missions

From Lionel Ferra, Mars Society Germany


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-2002-

A German translation was published in our 8th Newsletter . Eine deutsche Übersetzung ist im 8. Newsletter erschienen.

INTRO
Prior studies of human exploration of Mars have tended to focus on spacecraft and flight, rather than on what the low-cost launcher conception ought to be. The scale of the launcher architecture is fundamentally determined by the mass of the payload that will be landed on the Martian surface. The nominal design mass for individual packages to be injected in a Mars Transfer Orbit within reasonable concept and costs is 35-40 tons for a crew habitat (sized for 4-5 people) which must be transferred on a high-energy. We propose to analyze a possible Mars Mission Architecture and pre-study of a launcher in the frame of a European Manned Mars Mission. This paper presents a summary of the EMM (European Mars Mission) and its associated launcher.
The main items of a European Mars Mission are:

- Take up a long term manned space challenge within Europe with European systems.
- Challenge the traditional technical obstacles associated with sending humans to Mars.
- Identify relevant technology development and investment opportunities.
- Define a set of tasks of value for humans to perform on Mars and provide the tools to carry out the tasks.
- Support the humans with highly reliable systems.
- Provide a risk environment that will maximize the probability of accomplishing mission objectives.
- Provide both the capability and the rationale to continue the surface exploration beyond the first mission.

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RISK
Several related but also separable aspects of risk are associated with a Mars mission must be considered in designing a European Mars Mission (EMM). Mission activities will inevitably be hazardous because they are conducted far from home in extreme environments. However, proper design and operational protocols can reduce the hazards. Before a Mars exploration program is approved, it will be necessary to decide whether the elements of risk to the enterprise can be reduced to a level consistent with the European investment in resources and human lives.

SPLIT
The split mission approach has been adopted for the EMM because it allows mission elements to be broken into manageable pieces rather than trying to integrate all necessary hardware elements for a single, massive launch. For this mission, ?manageable? was defined to mean pieces that can be launched directly from Earth and sent to Mars, using launch vehicles of A5M class, without assembly in LEO, only a possible crew rendezvous in LEO is foreseen to reduced costs. A key attribute of the split mission strategy is that it allows cargo to be sent to Mars without a crew, during the same launch opportunity or even one or more opportunities prior to the crew?s departure. This creates a situation where cargo can be transferred on low energy, longer transit time trajectory, and only the crews must be sent on a high-energy, fast-transit trajectory. By using a low energy transfer, the same transportation system can deliver more payloads to the surface of Mars at the expense of longer flight times. Spacing the launches needed to support a mission across two launch windows allows much of the infrastructure to be pre-positioned and checked out prior to committing crews to their mission. When combined with the decision to focus all Mars surface infrastructure at a single site, this approach allows for an improved capability to overcome uncertainties and outright failures encountered by the crews. Launches of duplicate hardware elements, such as ERV?s, on subsequent missions provide either backup for the earlier launches or growth of capability on the surface.
The hardware elements launched as part of the split mission approach must come together on the surface of Mars, which will require both accurate landing and mobility of major elements (Mobil Habitat) on the surface to allow them to be connected or moved into close proximity.

Splitting the launch of mission elements allows the propellant production capability to be emplaced, checked out, and operated prior to committing the crew to launch from Earth. In addition to spacecraft propulsion, this production capability on Mars can provide fuel for surface transportation, reactants for fuel cells, and backup caches of consumables (water, oxygen, and gases) for the life support system. All of these features allow for smaller amounts of consumable material to be launched from Earth and contributes to the goal of learning how to live on Mars.

CAPTURE
Mars orbit capture and the majority of the Mars descent maneuver will be performed using a single biconic aero shell. The decision to perform the Mars orbit capture maneuver aerodynamically is based on the fact that an aero shell will be required to perform the Mars descent maneuver no matter what method is used to capture into orbit about Mars, and current technology can develop an aero shell with a mass that is equal to or less than the propulsion system required for capture. Thus, the EMM strategy assumes the development of a single aero shell that can be used for both Mars orbit capture and descent maneuvers.

ELEMENTS
The EMM mission design is based on previous American and Soviet studies. The architecture of the mission defines 4 main element types:

HABITAT
The crew is transported to Mars in a habitat that is identical to the surface habitat/ laboratory deployed robotically on first cargo mission. Designing the habitat so that it can be used during transit and on the surface results in a number of advantages to the overall mission.
The possible duplicating habitats on the surface provide redundancy during the longest phase of the mission and reduce the risk to the crew. By landing in a fully functional habitat, the crew does not have to transfer from a ?space-only? habitat to the surface habitat immediately after landing. This approach also allows the development of only one habitat system instead of two or more unique, specialized systems.
The Mars transit/surface habitat will contain the required consumables for the Mars transit and surface duration of approximately 800 days

(approximately half a year for transit and 600 days on the surface).

MAV (Mars Ascent Vehicle)

When the surface mission has been completed, the crew must rendezvous with the orbiting ERV. This phase of the mission is accomplished by the MAV, which consists of an ascent propulsion system and the crew ascent capsule.
The MAV is delivered to the Mars surface atop a cargo descent stage. The ascent propulsion system is delivered with its propellant tanks empty. However, the same descent stage also delivers a nuclear power source (or solar cells), a propellant manufacturing plant, and several tanks of hydrogen to be used as feedstock for making the required ascent propellant. This approach is chosen because the mass of the power source, manufacturing plant, and seed hydrogen is less than the mass of the propellant required by the ascent stage to reach orbit. The crew rides into orbit in the crew ascent capsule. This pressurized vehicle can accommodate the crew of three-five, their EVA suits, and the samples gathered during the expedition and from experiments conducted in the surface habitat/laboratory.
Life support systems are designed for the relatively short flight to the waiting ERV. This ascent capsule does not have a heat shield, as it is not intended for re-entering the atmosphere of Earth or Mars. Once the rendezvous has been completed and all crew, equipment, and samples have been transferred to the ERV, the MAV is jettisoned.

(*)In Situ Resource Utilization for EMM provides two basic resources: propellants for the MAV and cached reserves for the Life Support Systems. Using indigenous resources to satisfy these needs instead of transporting resources from Earth reduces launch mass and thus mission cost.

ERV (Earth Return Vehicle)

Returning the crew from Mars orbit to Earth is accomplished by the ERV which is composed of the propulsion stage, the Earth-return transit habitat, and re-entry capsule (ERC). The ERV is delivered to Mars orbit with the propulsion stage fully fuelled, and it loiters there for nearly 4 years before being used by the crew returning to Earth. For the return to Earth, the crew will jettison the MAV and proceeds to the appropriate departure procedure to leave the parking orbit.
The propulsion system for the ERV is sized for the velocity change needed to insert the Earth return habitat and the Earth Re-entry Capsule from the highly elliptical parking orbit at Mars to the fast-transit return trajectory to Earth. As with the TMI stage, the energetically demanding return trajectory was used to size this system for a half-year return.

SOYUZ Vehicle

The Soyuz vehicle is a classical Soyuz TM capsule launched from Baikonur or Kourou with the crew of 3. Two Soyuz flights may be required if the designed mission is based on crew of 5. This Soyuz vehicle will proceed to a LEO rendezvous with the Transithab, which loitered unmanned in Low Earth Orbit.
After the one or two rendezvous completed, the Soyuz will be jettisoned to the Earth and the crew operates the required maneuvers to leave the LEO to a Trans Mars Orbit injection in the Transit Habitat.

SEQUENCE

1)The first launch delivers a fully fueled ERV to Mars orbit. The crew will rendezvous with this stage and return to Earth after completion of their surface exploration.

2)The second launch delivers a vehicle to the Mars surface which is comprised of an unfueled MAV1, a propellant production module, a nuclear power plant (or solar cells to be deployed), liquid hydrogen (to be used as a reactant to produce the ascent vehicle propellant), and approximately 20 tons of additional payload to the surface.
After this vehicle lands on the surface:
Case 1: nuclear reactor
The nuclear reactor will be autonomously deployed approximately 1 kilometer from the ascent vehicle Case 2: solar cells will be autonomously deployed

And, in any case, the propellant production facility (using hydrogen brought from Earth and carbon dioxide from the Mars atmosphere) will begin to produce the nearly tons of oxygen and methane that will be required in the MAV1 or MAV2 to launch the crew to Mars orbit. This production will be completed within approximately a year? several months before the first crew?s scheduled departure from Earth.

3)The third launch is an optional launch, which can deliver a second MAV either as backup for the first crew team or as nominal MAV for the next crew. It delivers a vehicle to the Mars surface which is comprised of an unfueled MAV2, a propellant production module, a second nuclear power plant (or solar cells), liquid hydrogen as back-up of the second cargo flight. The second nuclear power plant (or solar cells) will be autonomously deployed near the first plant (w.r.t. the first unfolded solar cells). Each plant or solar generator will provide sufficient power for the entire mature surface outpost, thereby providing complete redundancy within the power function.

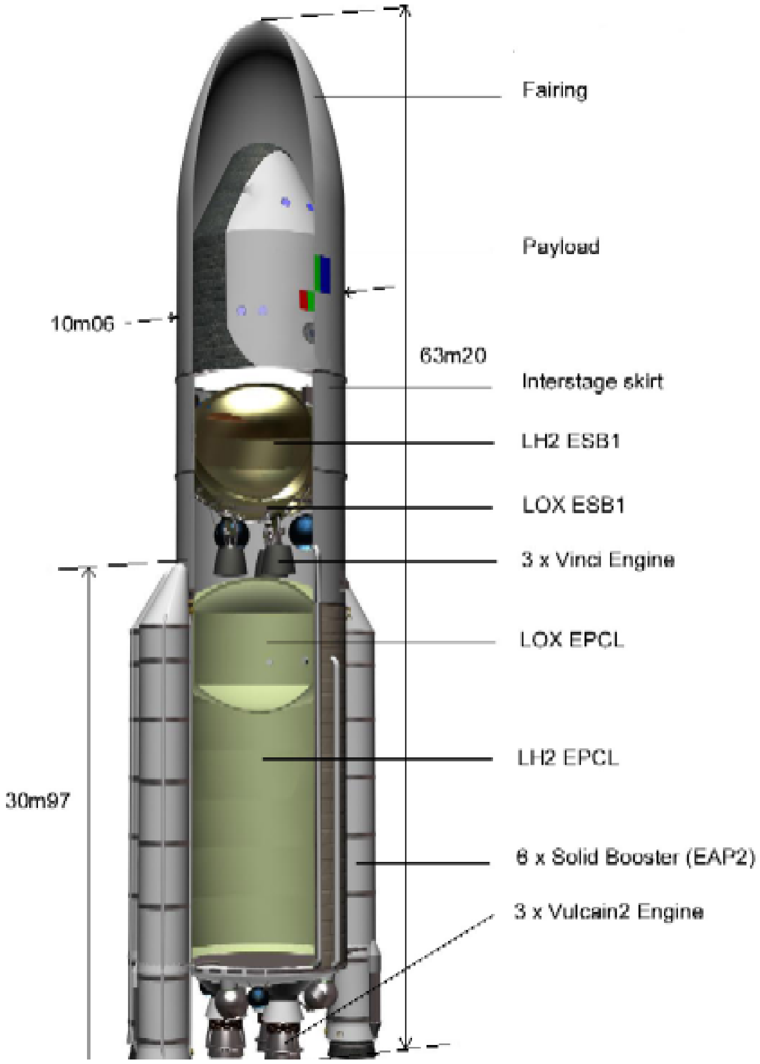
4)The forth launch opportunity is also a optional launch, will deliver a third lander to the Mars surface; it will be comprised of a surface habitat/laboratory, nonperishable consumables for a safe haven. It will descend to the surface and land near the first vehicle.

5)The last launch delivers the main habitat, which will be used throughout the mission as transfer habitat. It is composed of one single large module shaped to allow an aerocapture in the Martian atmosphere. If the launcher (see appendix) is qualified for manned mission, the transhab will be directly inserted in TMI with the crew. Else the launcher injects this empty module in LEO as parking orbit. After completion of this phase and checksum of all functional units on-board, the crew will lift-off and proceeds to the rendezvous aboard one or two Soyuz launches and proceeds to the final Trans Mars Injection.

THE LAUNCHER

All the cargo flights (MAV1 or MAV2, Transit Habitat or Habitat, ERV) will be put into orbit by a single common heavy lift booster derived from existing Ariane 5 elements. The vehicle architecture is the key of the EMM to make a manned mars mission possible within current European budgets and current developed technologies.

The architecture is close to the nominal design of Ariane 5, whereby the size of relevant element is increased to achieve mission objective in term of mass and performances.



EPCL
The main cryogenic stage (EPCL Etage de Propulsion Cryogénique Large), or core stage, primarily comprises a large aluminum alloy tank, a thrust frame that transmits the engine?s thrust to the stage, and a forward skirt (JAVE), which interfaces with the upper composite and transmits the thrust from the six giant solid boosters.
The tank comprises two compartments containing 633 tons of very low temperature cryogenic propellants. The cryogenic engines can be steered in two axes for flight control, via the engines actuation unit. They deliver about 410 tons of thrust.
The core stage operates continuously for 660 seconds, providing most of the kinetic energy needed to place a payload in orbit or in TMI. When it shuts down, the launcher is at an altitude of 130 to 420 kilometers, depending on the mission. This stage is not placed into orbit, but falls back naturally into the sea.

EAP2
Each of the six solid boosters contains some 253 tons of solid propellant. These are the largest solid rocket motors ever built in Europe.
The motor comprises a casing made of seven steel cylindrical sections, and a nozzle mounted on a flexible bearing, that can be steered up to 6 degrees by the nozzle actuation unit. The propellant is loaded in three segments.
Each MPS solid rocket motor delivers thrust ranging from about 552 tons at lift-off to a maximum of 600 tons (1,320,000 lb.).
The six solid boosters are ignited a few seconds after ignition of the main cryogenic stage, to make sure that the main three engines are operating correctly.

With a combined thrust of 3,600 tons the six solid boosters provide some 90% of the total lift-off thrust. They burn for about 128 seconds. After burnout, they are separated from the main stage by a pyrotechnic system at an altitude of 55 to 70 kilometers (depending on the mission). They continue on a trajectory peaking at 80 to 140 kilometers, then deploy parachutes and fall back into the sea about 150 kilometers from the launch base. They may be regularly recovered for inspection and analysis as well as what is done with Ariane5.

ESCB1
The extended cryogenic upper stage completes the orbital injection of the payload into the targeted orbit (LEO or TMI), and ensures payload separation and orientation. The propellant stage comprises two tanks containing up to 67.5 tons of LOX and LH2 plus 3 VINCI cryogenic engine: restartable engine and nozzle with extendible exit cone and delivers specific vacuum impulse of 455 s. Nozzles are gimbaled in two axes for thrust vector control.
This stage can proceed to either a LEO payload insertion or a TMI payload injection (cargo mission).

Versions data sheet

Launcher Costs
With regard to the development of completely new heavy launcher system, the A5M launcher reuses several parts of Ariane 5 Evolution:

- Overall system design (2 stages plus strap boosters)
- The Strap Boosters (EAP2)
- The main cryogenic architecture but resized
- The first stage engine type (Vulcain 2)
- The second stage restartable cryogenic ESCB type
- The GNC logic
- Several existing facilities can be kept or easily re-adapted to the size of the launcher (assembly hall, transportation systems...)

Thus, development costs aiming toward the full realization of the A5M launcher is less than 2 Md. Euro and the cost per launch is evaluated to be similar to three times the actual cost of an Ariane 5 launch: 250-300 M. Euro / launch.

CONCLUSION
A very heavy launch vehicle based on Ariane 5 elements to perform a European Manned Mars Mission is technically and economically feasible. This launcher is defined to put into orbit or send to direct trajectory heavy payloads to Mars. Prior studies of manned Mars Mission needed a huge technical progress or required too large launchers; those were always abandoned because of the costs or mainly because of

insurmountable technological hurdles.
This EMM associated with the A5M launcher are doable within 10 years development, its budget can be limited to 10-15 billion Euro (2 billion Development for the launcher, 2 billion max for all launches and 6 to 11 billion Development for the overall mission design, deployment and operations.)

Graph schedule

Launcher datasheet

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