Proof of Mars Hopper Concept Technologies

Executive Summary

DTI EXPORT CONTROL RATING: 9E001, 9A006(a)
Rated by: Liz Tucker

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1 STUDY INTRODUCTION

Proof of Mars Hopper Concept Technologies was an eight-month study funded by ESA's General Studies Programme from ECSAT in Harwell. The study has focussed on increasing the TRL of key technologies required for the Mars Hopper concept, which were:

- **In Situ Resource Utilisation (ISRU)** subsystem to collect and store CO2 from the atmosphere and deliver it to the propulsion system. Locally generated propellant doe snot require transportation to Mars providing a huge mass saving
- **Thermal, Power and Propulsion subsystem** that provides constant electrical energy to the platform and the thermal rocket engine. Special thermal technologies are also considered to handle large amounts of heat generated
- **Landing subsystem**. The platform must make repeated landings, a requirement new to Mars platform landing gear.

The Mars Hopper vehicle served as a medium for a consistent set of ISRU, thermal, power and propulsion and landing system technologies to be developed in an aligned and consistent manner. However their application to the wider exploration and space domain was an important factor considered in parallel, and possibilities for terrestrial spin out for developed subsystem technologies and concepts were also considered

As a result of work prior to the study, mission requirements were derived. These were a turnaround time of a week, hop range of 1 km, carry a payload of 17 kg, total traverse of 200 km, wet mass of 430 kg and landing on slopes of 20^{o}. These served as a starting point for technology developments.

To aid development and add robustness to subsystem requirements, two reference 'science cases' are outlined. These were based on possible Mars mission scenarios where the Hopper capability would be beneficial. Case 1 was aimed at Hypanis Valles/Xanthe Terra region originally considered for MSL, showing evidence for ancient fluvial action. 200 km traverse with 3 km elevation range. Case 2 was to an Amazonian aged (< 2.5 Ga) 50 km diameter, complex impact crater located in the Elysium Region. 20 km traverse, could form part of larger mission. Fe/Mg – phyllosilicates to be present in this crater, produced by either an impact-induced hydrothermal system or through exposure of underlying, ancient phyllosilicate-bearing rocks which were exposed by the impact.

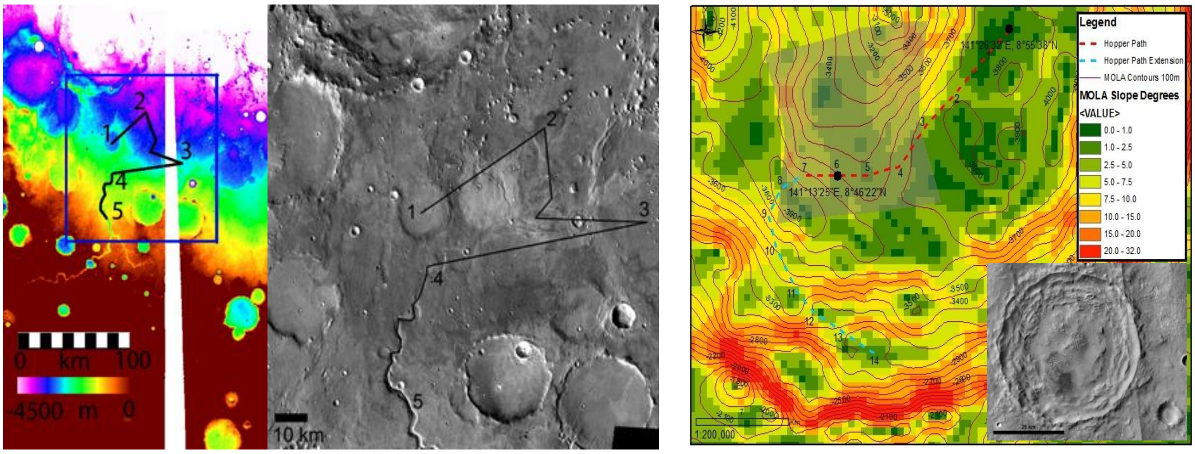

Figure 1-1 Science reference case 1 (left) and case 2 (right)

2 TECHNOLOGY SELECTION

In-Situ Resource Utilisation Subsystem – ISRU

The ISRU system generates liquefied CO_2 from the atmosphere, cleaning it of dust and contaminants.It is critical that dust is removed from the system prior to compression, and this is achieved with a staged barrier filter design with gas 'blowback' to clear the filters. This was selected due to its high TRL, mechanical simplicity and low risk. The gas blowback is fed from the first stage compressor.

Water must also be removed prior to CO_2 liquefaction as it will freeze. This is achieved using a twin chamber pressure swing adsorption system with a mass of 2 kg and is after the second compressor stage. The PSA system would switch between chambers once a day, using the diurnal environment cycle minimising resource requirements. Contaminant gases are removed using a polymeric permeation membrane which separates gas species by flow rate through the membrane. The simple and passive technology has a minimal impact on the system

Liquefaction is achieved using a three-stage mechanical compression system. To achieve the required flow rate a 34 kg, 212 W system is proposed, supplying 4 MPa CO_2 to the tanks at 280 K. Mechanical compressors have space heritage and have a good balance of required power and mass.

CO_2 is stored using saturated liquid/vapour VaPak tanks which allow 92% fill fraction to be utilised with a small pressure drop.

Thermal, Power and Propulsion Subsystem

Electrical power is supplied to the platform using two 50 W_e ^{241}Am RTG units with a total mass of 67 kg. Such units provide ~1.8 W/kg RTGs and are preferred over SRGs due to their inherent simplicity, lower failure risk and higher TRL with in Europe. Americium fuel is used to be aligned with European NPS roadmaps and current developments. A single encapsulated heat source design is proposed.

To dissipate the 1700 W of thermal energy from the RTGs, a mechanically pumped loop system is proposed to transport heat to a large 8 m^2 radiator. The system is based on Alphasat but re-optimised for minimum pump power (approximately 10 W) rather than system mass.The motor design has been updated to use ^{241}Am RPS modules and to provide the required performance. Motor insulations technologies essential for maintaining performance were traded and available European solid insulation technologies were preferred (such as MicroTherm and Min K 1800). The motor mass was estimated at 100 kg, providing an average Isp of 128 s and 7.5 kN thrust.

A cold gas RCS system was proposed to provide vehicle pitch-over on launch, using cold CO_2. An approximate performance of 60 s Isp and 300 N thrust is predicted, with thrusters arranged in 4 sets providing three axis control authority.

Landing Subsystem

An eddy-current based magnetic damping system was proposed to absorb vehicle loads on landing. Such a technology is highly stable against environment temperature and pressure variations and mechanically simple. An assembly combining a Titanium spring and set of concentric NdFeB magnets was defined based on detailed magnetic FEM analysis.A 3 legged cantilever leg configuration was initially proposed, using dampers on the primary struts only for minimum mass. This maximises clearance against rocks whilst achieving a 20-30^o slope tolerance when landing in the worst case, whilst utilising the inherent static stability of a tripod configuration.

Proof of Mars Hopper Concept Technologies

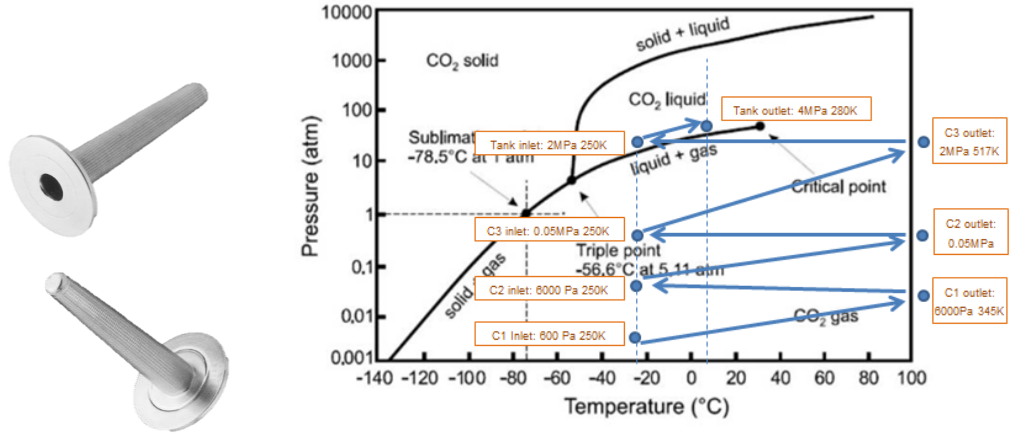

Figure 2-1 Candidate barrier filters (left) and proposed mechanical compression chain (right)

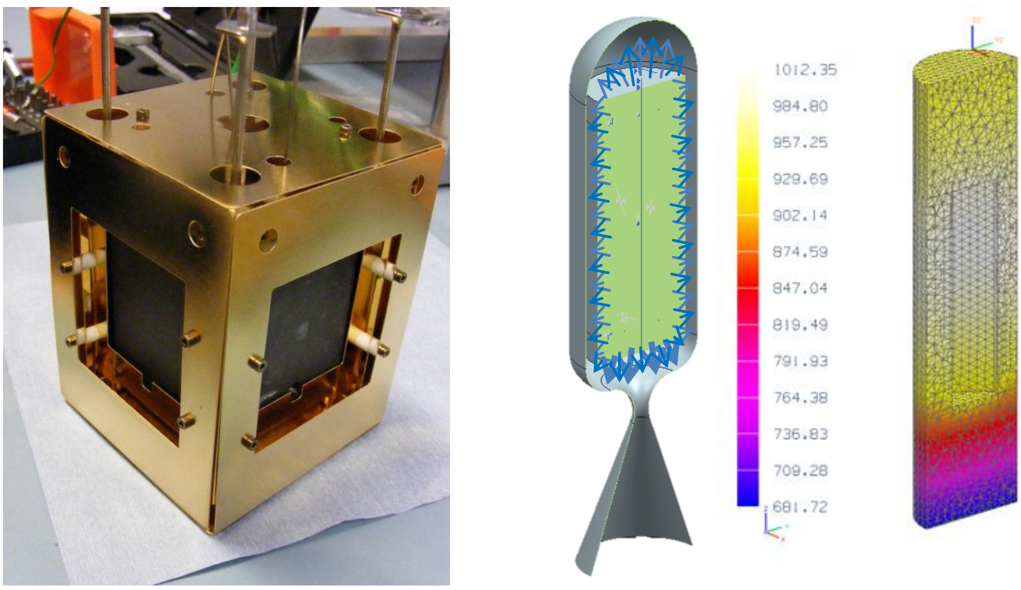

Figure 2-2 Prototype European RTG (left) and motor configuration and temperature (right)

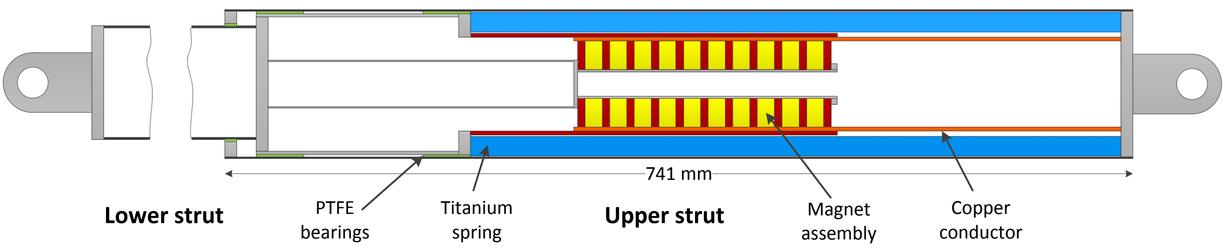

Figure 2-3 Cut-away of proposed magnetic damper assembly

3 VEHICLE DESIGN UPDATE

Vehicle Update

Concurrent working sessions were used to iterate the vehicle design with the goal of meeting the key performance of a 1 km hop range, compatibility with a Soyuz launch mass envelope and 1 week turnaround between hops. As a result, subsystems were resized and aligned. The conclusions were that a significant increase in the volume of CO_2 was needed due to reduction in engine performance (due to move to ^{241}Am fuel and realistic encapsulation), and increased subsystem masses. Higher ISRU power demand coupled with reduced availability (move to European RTG technology from US ASRG) also reduces CO_2 production rate. Consequently 167 kg of CO_2 is required. The ISRU system has been optimised to be able to operate continuously during the day and night. The total vehicle dry mass is 1006 kg, requiring an Ariane 5 launch. The average available power from the RTGs is 114 W_e.

Figure 3-1 shows the proposed Mars Hopper configuration. The upper structure is dominated by the large octagonal radiator structure of 11.34 m^2 required to dissipate 1700 W of RTG waste heat. The radiator has a central cut-out to accommodate the main engine (blue) which has a direct view to space for thermal control. The radiator has cut-outs for accommodation of the RTGs (also have a view to the sky) and the RCS thrusters (purple)

The main octagonal platform houses the platform equipment and is offset from the radiator octagon to allow better accommodation of the RCS, RTGs and landing legs. A move to 4 legs was made to provide better dynamic landing stability in the face of an increased CoG. The landing legs are slanted at 45 degrees (best compromise between vertical and horizontal landings) and fold inwards to fit within the aeroshell.

To reach the surface from orbit, the vehicle uses a dedicated bipropellant descent stage which is accommodated on the underside of the platform. This is jettisoned on initial landing.

Vehicle Performance

Figure 3-2 overleaf shows the optimised Hopper trajectory for maximum range. Whilst utilising the maximum Ariane 5 launch mass, a hop distance of 600 m is achieved. The plot shows the effect of launch ‘pitch over’ required to reorientate the vehicle after lift-off to allow a horizontal traverse. The vehicle can also ascent and descend 1.15 km and 1.25 km respectively. To generate the required fuel mass the ISRU system requires 29 days continuous operation. An additional 7 days of science is proposed as a minimum.

The landing system configuration will accommodate landings onto a slope of approximately 27 degrees at a horizontal velocity of 1 m/s in the worst case landing scenario. Additionally, rocks up to 50 cm in height can be negotiated.

Alternative hopper concepts were investigated. A bipropellant alternative (no ISRU or radioisotope engine) provides a total range of 6 km in 5 hops (or 22 km in 1 hop). If European Stirling technology is projected with an optimistic performance, the additional power and lower mass increases the hop range to 1070 m for the same dwell time. By removing the radioisotope engine and using a cold gas CO_2 thruster (no engine mass) the hop performance is severely compromised.

In comparison with current roving vehicles the average mission traverse speed and slope tolerance of the hopper is comparable to Curiosity, however the hopper is able to travel as the crow flies and cross difficult hazards that a rover cannot (cliffs, craters, boulder fields)

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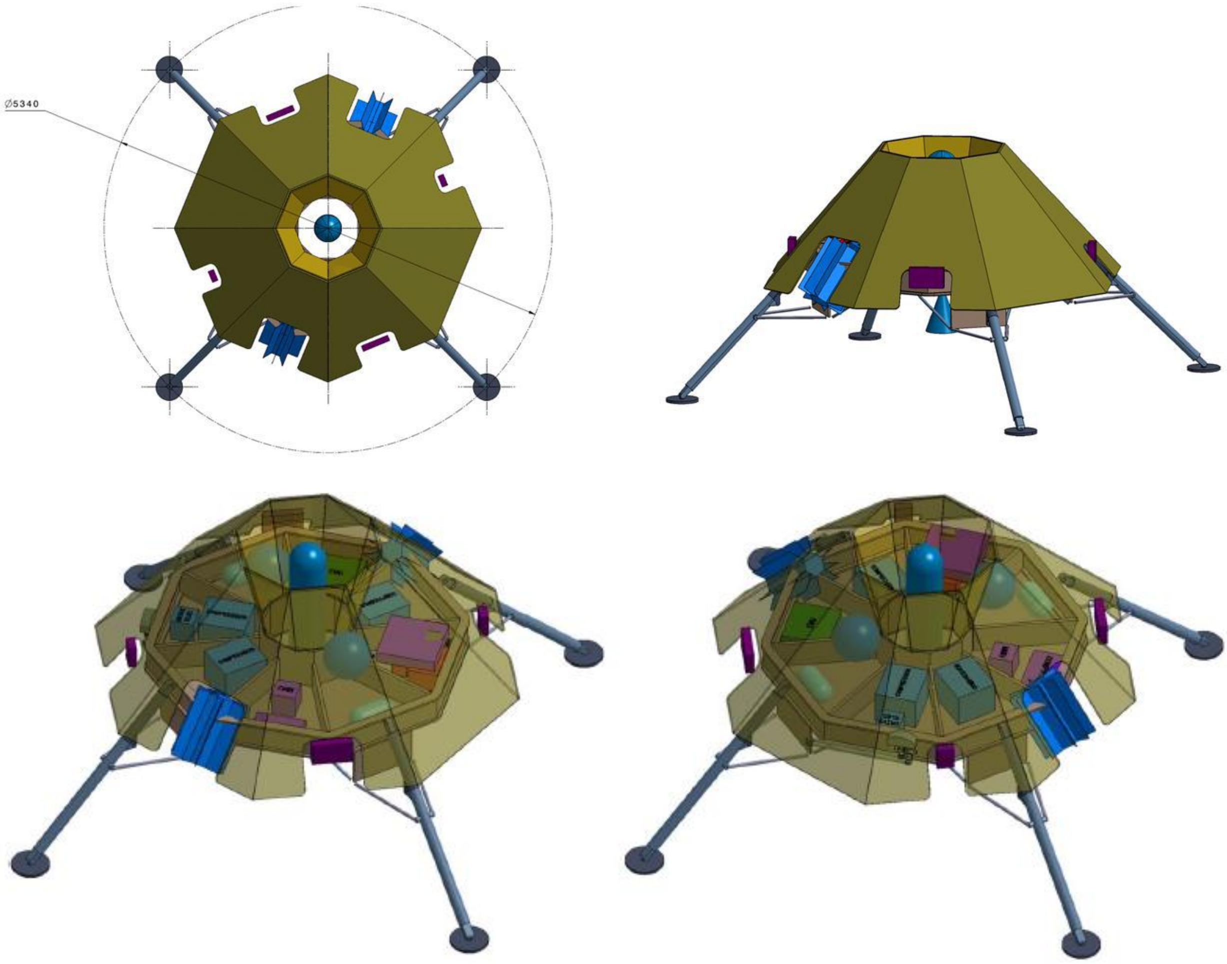

Figure 3-1 Mars Hopper Configuration

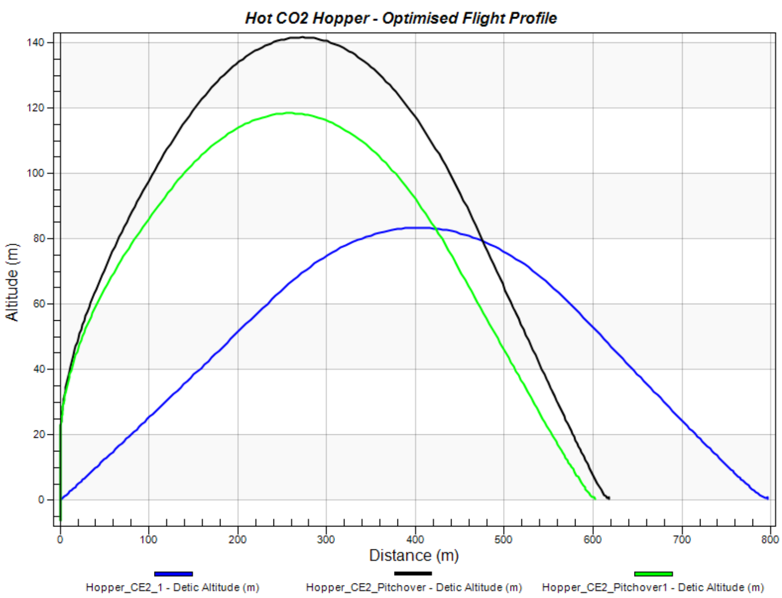

Figure 3-2 Predicted Mars Hopper hop traverse performance

4 TECHNOLOGY ROADMAPPING

In-Situ Resource Utilisation Subsystem – ISRU

Currently, atmospheric processing technologies are of interest for human spaceflight (CO_2 scrubbing) but prefer alternative technologies. Looking to the future, ISRU will become increasingly important for Mars exploration (propellant/oxidiser production, habitation).

The main technology challenges identified were firstly the first stage compressor and dust removal system, as dust must be removed to a high level and compression in the Martian atmosphere is a considerable challenge. Secondly purification materials (sorbs, membranes) must be demonstrated and optimised for the Martian atmosphere. Tank technologies and fuel distribution are also identified.

In the near term, a combined dust removal and first stage compressor 'gas duster' technology could be developed and utilised on Mars missions to clean solar array dust, instrument windows etc. This could be demonstrated on INSPIRE. Into the further future general gas compression technologies will find multiple uses in manned trips to Mars and beyond.

The main roadmapping activities reflet this, where compression, dust filtering and purification technologies are recommended to be developed to TRL 5 in a staged fashion in the near future.

Thermal, Power and Propulsion Subsystem

European space nuclear power developments started in 2008 and targeted both disrupted developments and European independence and competitiveness. Currently there are activities covering isotope extraction and encapsulation and RHU, RTG and SRG development.

Must spin in potential is identified, including spark plasma sintering, bespoke TEG materials, nickel super alloys and chemical isotope separation technologies. The main impact is future mission enablement and cost reduction, along with terrestrial applications (oil wells) and knowledge expansion

In the future, advancement in a European isotope production facility is proposed building on on-going activities leading to production in 2018. Safety case elaboration will continue (lasting a decade) with encapsulation technologies reaching TRL 4 in 2018. RHU, RTG and SRG technology developments should continue (with RHU leading) to reach TRL 5 by 2020.

A major conclusion is that current RPS momentum and investment must be maintained with further mission studies to explore constraints and requirements, and parallel RTG and SRG developments.

A range of pumped fluid cooling loops have been studied in Europe, for example for Alphabus. Further development activity would focus on optimisation for minimum power usage. The roadmap reflects this, starting from TRL 2 in 2018

Landing Subsystem

Active magnetic damping systems are being considered for aircraft, moving to all electric systems. Magnetic dampers could also be valuable for aircraft operating in extreme environments or where maintenance is challenging (military). Mass is also a challenge in this sector. Therefore terrestrial developments should be monitored in the future. Considering exploration in the near term, docking with non-cooperative objects (debris removal) could benefit from magnetic damping technology and in the further future manned planetary roving vehicles would require similar (possibly active) technology.