In-Space Additive Manufacturing for Planetary Exploration

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Abstract

This poster presents an innovative space mission concept called Nèamh that utilizes In-Space Additive Manufacturing (ISAM) technology for planetary exploration. The proposed mission involves the use of an onboard space fabricator to print an extremely large solar sail once in space, enabling the spacecraft to travel to Mars or other solar-system bodies. Upon arrival, the space fabricator will recycle the solar sail into a large aeroshell to perform an aerocapture within the planet's atmosphere. The aeroshell will then be further recycled into a large high-gain antenna reflector to communicate with Earth, effectively displacing the deep space network communication segment from Earth to the exploration site. This multi-functional concept has the potential to revolutionize space exploration as identified by [1] enabling efficient, cost-effective, and sustainable spacecraft designs for planetary exploration.

Current programmatic developments in the UK and ESA led to the design of a large-scale Space Based Solar Power station (SBSP). This structure aiming to reach a footprint of 100 km² for a length of 5 km and width of 1.7 km will be fully manufactured and assembled in space.

The SBSP station does not represent the technological limitation but what the governments, space agencies, and industries are gearing up to produce by 2040. Keeping those numbers in mind, we can design a feasible mission profile leveraging SBSP manufacturing assets to explore the solar system is a novel frugal and efficient way.

The following sections will explore the dimensioning of each of the design parameters of each phase of a mission aiming to enhance existing Mars exploration program and more specifically reduce the need for super heavy-lift launchers deep space network infrastructures.

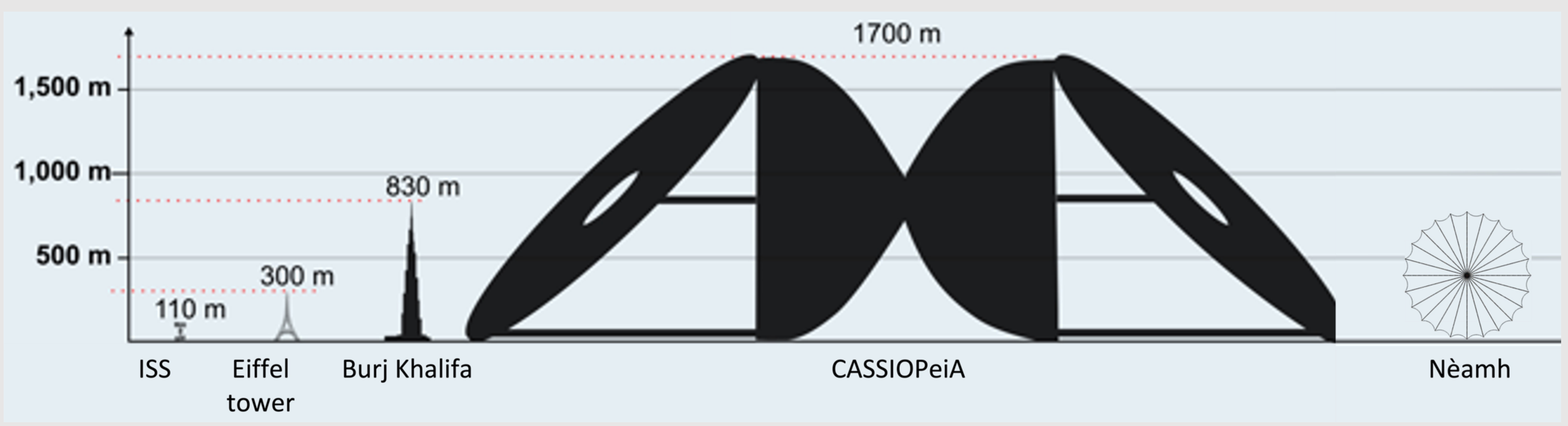

Figure 1: Comparison of CASSIOPeiA and Nèamh solar sail phase based on an existing figure from [2]

Phase 0: System dimensioning

Using the reference case presented in [3], the Nèamh mission concept will be sized to convey 20 tonnes of payload/cargo to Mars starting from a low Earth orbit manufacturing to an orbital science phase around Mars. The ISM fabricator developed at the University of Glasgow has the capability to print structural elements in the vacuum of space and produce extremely long beam in accordance with the proposed substructure of Nèamh (theoretical maximum of 6 km total length for a single fabricator). In addition, the fabricator has the capability to bond in-situ rolls of materials. We are using those capabilities to fabricate and upcycle Nèamh for each phase of the mission. Figure 2 illustrates the three main phases of the mission with artistic renderings. In addition of the 20 tonnes payload, the space fabricator and all the feedstock will weigh 3.62 tonnes.

Phase 1: Solar sail

The performances of Nèamh's solar sail will directly impact phase 2 of the mission as an increased performance of the solar sail (shorter transit time) would impose a harsher aerocapture environment with a faster entry speed. For this reason, we are providing a high-performance solar sail only capable to be achieved with in space manufacturing to reach a $\sigma = 5$ g/m² (without cargo). This will allow us to deliver a payload of 20 tonnes in little over a year with an 800 m sail disk shaped. Indeed, the most complex part of a traditional solar sail mission or spacecrafts using similar technologies (such as James Webb Telescope for its sun shield) is the deployment of the ultra thin foil that will reflect sun light. By fully fabricating the solar sail in space it is possible to use rolls of films as feedstock and layer them without inducing stresses of folding. This provides us with the insurance that no tears will appear due to packing. In addition, it is possible to inspect and repair the sail before its departure and during transit if required (micro meteorite impacts).

Phase 2: Aerocapture

For this phase of the mission, Nèamh must sustain an important thermal and structural loading compared to the solar sail phase of the mission. Few weeks before its arrival in the Martian system, the space fabricator onboard Nèamh will start to upcycle the solar sail component of the system. Instead of an 800 m wide solar sail, the fabricator will produce 24 beams made out of PEEK (Polyether Ether Ketone) bonded to a 1 m wide FTP A6 flexible TPS [4] giving Nèamh a total footprint of 200 m² for 200 m diameter phase 2 configuration. Table 1 presents the main parameters of the resulting aerocapture phase.

As the aeroshell will only be used for aerocapture at high altitude and not entry, thus limiting mechanical loads, we are pursuing efforts to demonstrate the viability of the system for harsher environments. In order to increase capabilities, efforts at the University of Glasgow are investigating carbon nanotube doping of PEEK materials for ISM. This would improve its Young's modulus from 100 Mpa to 0.5-1.5 GPa. The main current challenge for this technology is the recycling/upcycling of the novel polymer blend.

Table 1: Mission Profile key parameters

Periapsys altitude	Maxinal dynamic pressure	Maximal deflection of the aeroshell	Peak surface temperature
80 km	1730 N/m2	18 m	750 K

Phase 3: Deep Space network

One of the drastic advantages of the Nèamh mission concept it's its ability to not rely on the Deep Space Network to conduct its mission and transmit back to Earth its valuable data. With a total diameter of 70 m, it will be possible for X or K-band antenna as small as 3 m diameter to receive high-quality data from Mars. This will drastically increase the scientific return of the mission compared to other mission scenario while not impacting the existing deep space network back on Earth which is already extensively used by solar system exploration missions but will also be saturated by the demanding Artemis program.

Table 2: Data link budget for the phase 3 of Nèamh mission concept

Frequency	Mars transmitter	Earth ground station	Transmitter power	Half Power Beamwidth	Bit rate
8.42 GHz (X-band)	70 m	3 m	100 W	0.69 deg	35 kb/s

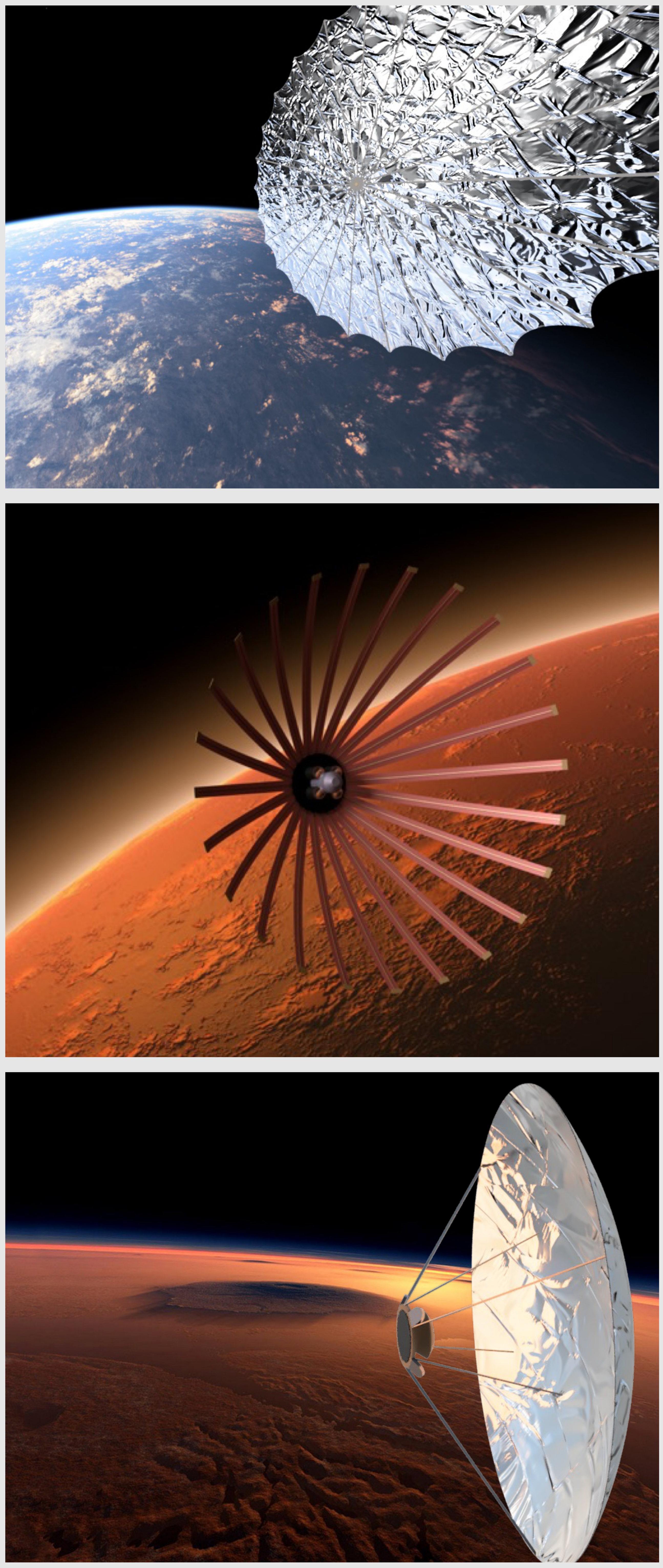

Figure 2: Artistic rendering of the 3 phases of the Nèamh mission concept (top: solar sail, center: aerocapture, bottom: Interplanetary telecommunication relay).

Conclusion

The ISM program at the University of Glasgow is aiming to reach 3d printed structures of size ranging from 10 m to 1 km to tension substrates (antenna, mirror, solar sail). The use of this technology for planetary exploration represents a realistic and advantageous concept for future large payloads even beyond 20 tonnes range. We believe that even without the consideration of mass saving, ISM presents a drastic advantage in resilience (in transit inspection and repair) and mission flexibility (reconfigurability during transit and after atmosphere phase). We are hoping to see new mission scenarios unlocked thanks to this new flexible and reconfigurable capability that will already be developed for ultra large Space Based Solar Power stations.

Acknowledgments

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