HEARTED: the Hyper-velocity EArth Re-entry TEchnology Demonstrator mission of ESA

L. Ferracina [1], J. Bertrand [2], G. Pinaud [2], P. Tran [2], M. Regnier [2], S.Chandesris [2], I. Sakraker [3], H. Weihs [3], M. Sudars [4], V. Mareschi [4], A. Ferri [4], G. De Zaiacomo [5]

Abstract

Worldwide experience on Earth high speed re-entry (>10 km/s) is available to USA, Japan and Russia whereas the European background does not exceed the 8 km/s typical of a Low Earth Orbit (LEO) re-entries. Although ESA was/is considering various missions requiring Earth re-entries at speeds up to 13 km/s (such as Marco Polo, Mars Sample Return - MSR, Phobos Sample Return, Polar Lunar Sample Return) no mission, so far, has been adopted for implementation; very often the lack of the necessary background on Earth high speed re-entry played and essential role on the decision

To fill such a knowledge gap, ESA is presently considering implementing the Hyper-velocity EArth Re-entry TEchnology Demonstrator (HEARTED) mission.

This paper will report the status of the feasibility study of the HEARTED mission covering phases 0 and A concluded within the Agency Technology Development Element programme.

Keywords: *High-Speed Missions and Vehicles, Thermal Protection Systems, Entry Descent and Landing, crushable structures, parachutes.*

Nomenclature

AGS – ArianeGroup SAS
ARD - Atmospheric Re-entry Demonstrator
ATV -Automated Transfer Vehicle
EDL - Entry Descent and Landing
EIP – Entry Interface Point
ERC - Earth Re-entry Capsule
ESA – European Space Agency
EXPERT - European eXPErimental Re-entry Test-bed
HEARTED - Hyper-velocity EArth Re-entry TEchnology Demonstrator
IRDT - Inflatable Re-entry and Descent Technology
IXV - Intermediate eXperimental Vehicle
LEO - Low Earth Orbit
OM – Orbital Module
SUEM - Spin-Up and Ejection Mechanism
TAS - Thales Alenia Space
TPS - Thermal Protection Systems

[1] *ESA-ESTEC, Keplerlaan 1 2200 AG Noordwijk ZH the Netherlands, Luca.Ferracina@esa.int*
[2] *ArianeGroup SAS, Rue du General Niox, 33166 Saint Médard en Jalles | France, jerome.bertrand@ariane.group*
[3] *DLR, Stuttgart, Germany, Isil.Sakraker@dlr.de*
[4] *Thales Alenia Space Strada Antica di Collegno, 253 10146, Torino, Italy, martins.sudars@thalesaleniaspace.com*
[5] *DEIMOS Space S.L.U., Ronda de Poniente 19, Tres Cantos, 28760, Spain, gabriele.dezaiacomo@deimos-space.com*

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1. Introduction: why a new demonstration mission

Worldwide experience on Earth high speed re-entry (>10 km/s) is available to USA (Stardust, Genesis), Japan (Hayabusa) and Russia (Lunar-16) whereas the European background does not exceed the 8 km/s typical of a Low Earth Orbit (LEO) re-entries. Such an important but limited knowledge has been gained through many years and different mission/projects as the Atmospheric Re-entry Demonstrator (ARD), Inflatable Re-entry and Descent Technology (IRDT), European eXPErimental Re-entry Test-bed (EXPERT), Intermediate eXperimental Vehicle (IXV), and Automated Transfer Vehicle (ATV – destructive re-entry) Earth re-entries, and the Huygens (Titan) and Beagle 2, ExoMars (Mars) planetary re-entries.

Although ESA was/is considering various missions requiring Earth re-entries at speeds up to 13 km/s (such as Marco Polo, Mars Sample Return - MSR, Phobos Sample Return, Polar Lunar Sample Return) no mission, so far, has been adopted for implementation: very often the lack of the necessary background on Earth high speed re-entry played and essential role on the decision.

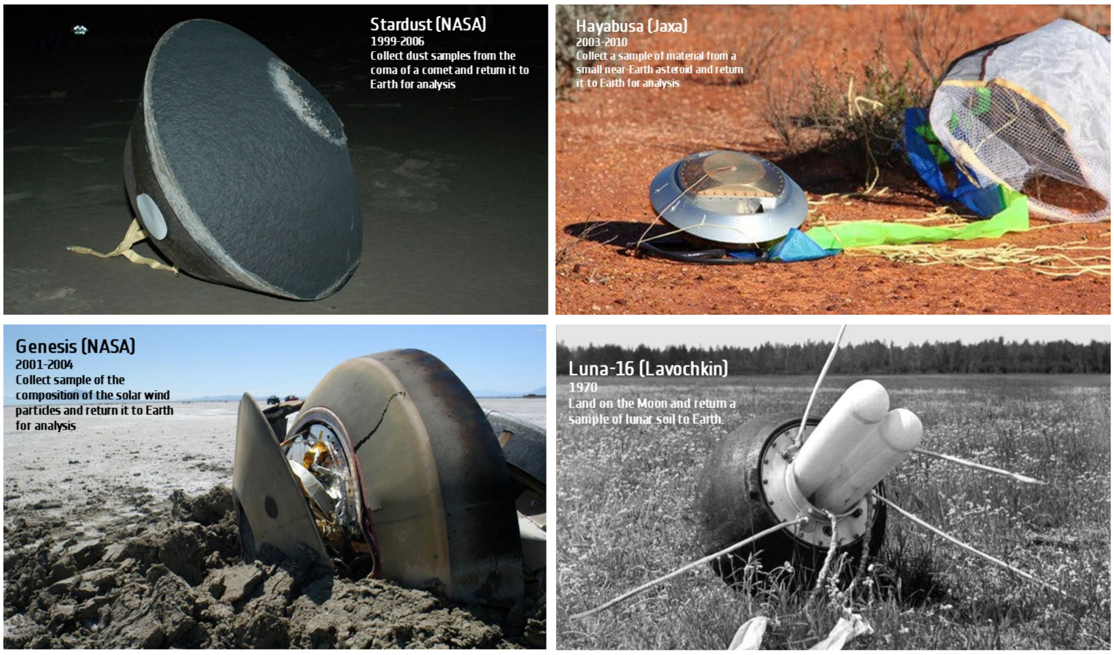

Figure 1: Experience on Earth high speed re-entry in USA (Stardust – Top Left; Genesis – Bottom Left), Japan (Hayabusa – Top Right) and Russia (Luna-16 – Bottom Left)

Good quality data are not available and no ground facility is capable to reproduce the relevant environment suitable for the qualification of most of the critical subsystems (e.g. TPS, EDL).
To fill such a knowledge gap, ESA is presently considering implementing the Hyper-velocity EArth Re-entry TEchnology Demonstrator (HEARTED) mission

Clearly, such a mission will be immediately useful for Science, Robotic Exploration and Human Space Flight Missions constituting a pathfinder for any European sample return mission providing credible alternatives for international cooperation.

Such a mission would inevitably speed-up the maturation of critical technologies for:
- materials for Thermal Protection Systems (TPS),
- Entry Descent and Landing (EDL),
- flight and recovery systems,

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- crushable structures and/or parachutes,
- sensors for harsh environments.

Moreover, a mission like HEARTED would

- speed-up the development and reduces cost (and cost uncertainties) of development of future sample return capsules,
- reduce risks for sample return and high-speed entry missions,
- increase scientific knowledge (aerothermodynamics);
- help to maintain (industrial) expertise.

Depending on the HEARTED mission configuration selected, ESA & Europe have also the opportunity to demonstrate extensive capabilities for space operations, which may involve:

- Launch capability and booster recovery, Orbital transfer capability
- Deorbiting towards a precise landing area on ground (eg aiming for a precise Latitude / Longitude on ground)
- Launcher Re-entry capability
- Multi-mission capability

Finally, it is worth noticing the crosslink contribution that such a mission could have on other programs as CleanSpace (Design for Demise) surveillance of space (hypervelocity impact) and civil security (hypervelocity entry).

2. The HEARTED industrial studies

As response to the presented situation, ESA has initiated two industrial parallel activities for the technology assessment of HEARTED covering Phase 0 (Feasibility of the HEARTED Mission) and Phase A (Analysis of the HEARTED Mission and Identification of the Needs).

The two parallel contracts were led by ArianeGroup (AGS) and Thales Alenia Space (TAS) with the support of DLR and Deimos respectively.

Starting from the high level mission requirements provided by the Agency, a series of preliminary scenarios have been selected, analyzed and traded-off in order to identify the system level requirements and to select an architecture solution capable to operate in line with the expectations. A design-to-cost approach has been followed to remain within the available financial envelope.

Special attentions has been paid to:

1. The Earth Re-entry Capsule (ERC) aero-shape and more particularly its AEDB, that must guarantee sufficient drag and stability performances along the entry, descent and landing trajectory phases;
2. The TPS technologies to protect payload from a very harsh environment during reentry.
3. The high-speed re-entry aerothermodynamics environment characterization and measurement (with thermal/pressure plugs, radiometers spectrometers…). The demonstration mission shall be able to replicate at best key physical phenomena which are encountered during pre-entry phase (mainly regarding stability), re-entry phase (regarding aerodynamic stability, convective and radiative heat flux, thermochemistry erosion at the TPS level), and descent and landing phase.
4. The descent and landing systems for the final deceleration;
5. The recovery system and associated ground logistic that allow a fast and robust recovery of the capsule and payload. To facilitate the data retrieval, a mission scenario with land/ice landing should be preferred with water landing to be pursued only as alternatives in case of unfeasibility of the first option.

Finally, HEARTED design shall make the maximum reuse of the solutions, Hardware and Software, technologies, processes, and materials identified in several previous studies funded by the Agency.

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2.1. AGS solution

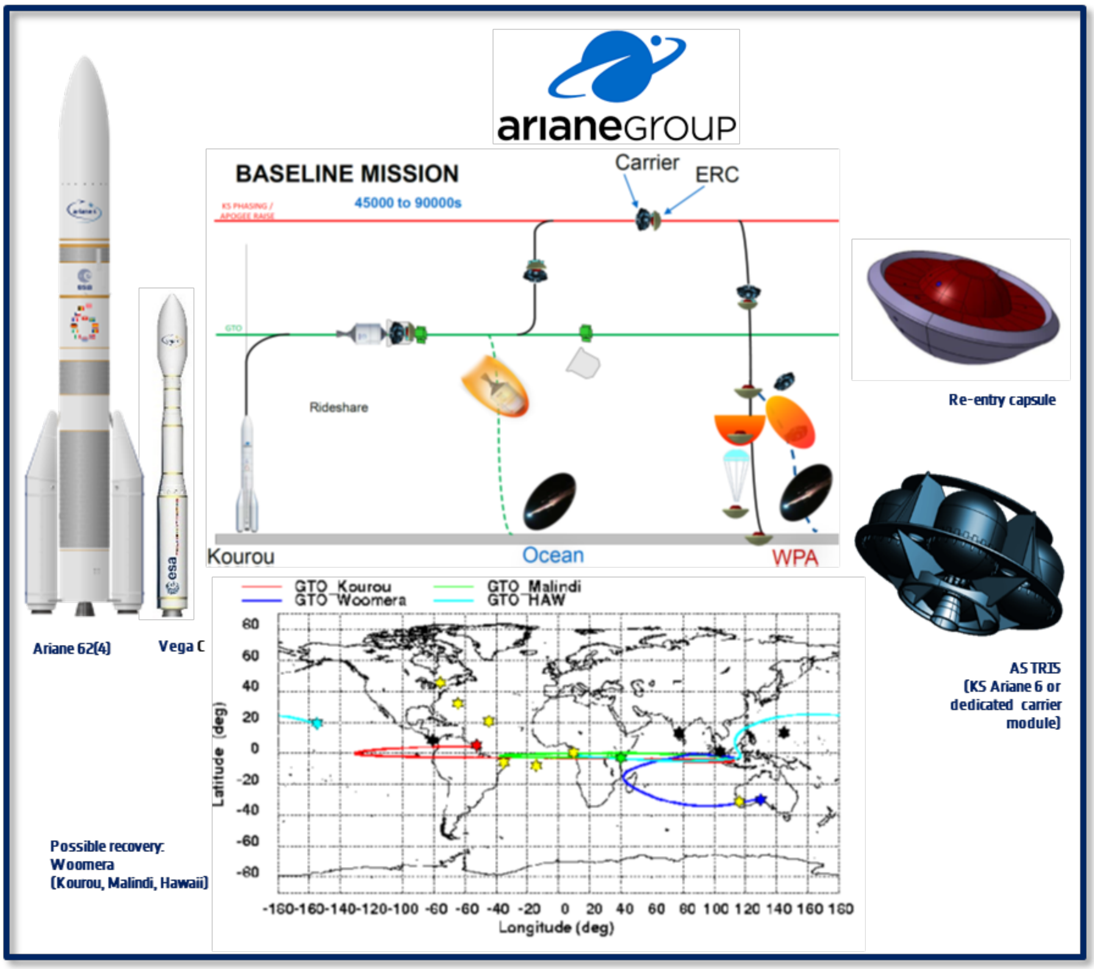

Fig 2: AGS solution

The use of various launchers such as VEGA-C, Ariane 6, Soyuz (and even being a passenger of SLS/Orion) were considered and a feasibility analysis of several missions, including LEO, MTO, or GTO trajectories were traded. The investigation concluded with the selection of a shared Ariane 62 as the baseline mission scenario (with Vega-C considered as back-up). Launching from Kourou on a LEO mission and landing in Woomera it is possible to achieve the necessary entry conditions (11.5 km/s).

The vehicle segment finally proposed consists of the following elements:

- Earth Re-entry Capsule (ERC) that will re-enter, carry/operate the instrumentation, land and will be recovered. The ERC configuration would target a diameter between 600 and 800 mm that will result from a global optimization between the launcher capabilities, the mission profile, the technological/scientific mandatory objectives and the global cost of the HEARTED mission.
- A Carrier that will accelerate the ERC to the required high-velocity conditions at Entry Interphase Point (EIP). ASTRIS Kick Stage of Ariane 6 is considered as the baseline, while a dedicated Carrier developed inside HEARTED project is retained as a back-up solution.
- A SUEM (Spin-Up and Ejection Mechanism) that will spin and separate the ERC from the Carrier prior re-entry.

Two TPS architecture have been proposed base respectively on ASTERM and NAXECO.

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2.2. TAS solution

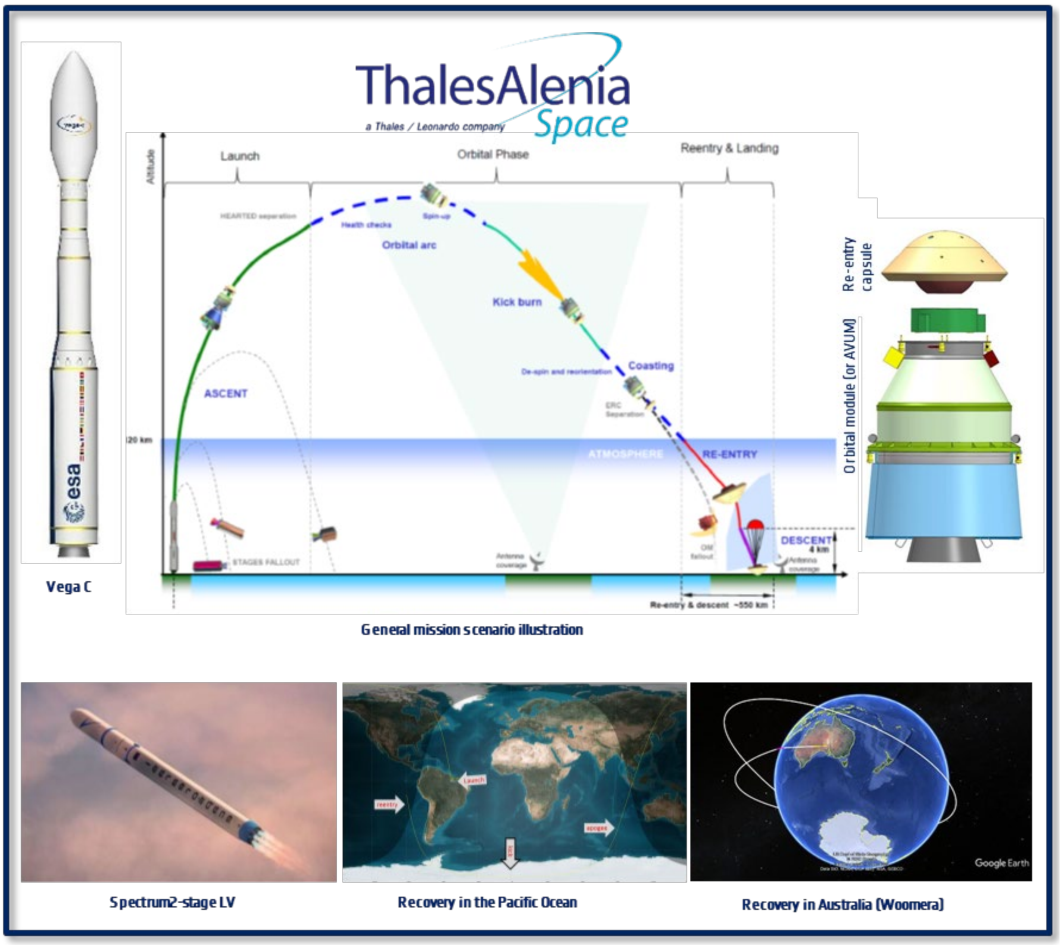

Fig 3: TAS solution

Similarly to AGS solution, the HEARTED System proposed by TAS is composed by an Orbiter Module (OM) and an Earth Return Capsule (ERC).

The OM, mainly composed of the propulsion stage and relevant accessories, is devoted to accelerate the Re-entry Vehicle; the ERC is the element sustaining the atmospheric re-entry phase and equipped with the Instruments to fulfil the mission objectives.

For cost and programmatic reasons, the Kick Motor of the OM propulsion system, in the TAS proposal will be either the STAR 27H or STAR37FM from Northrop Grumman. However, if European solution will be available in time, the trade-off will be re-opened.

Finally, although smaller launchers (like Launcher One - Virgin, Spectrum - ISAR) have been considered the selected baseline foreseen a dedicated launch with Vega C from Kourou on a LEO mission that, after one and a half orbit, lands in Woomera (with an entry velocity of 11.7 km/s).

2.3. Open points

Both teams have contacted all the relevant launcher authorities (Ariane Space, ISAR AEROSPACE, Virgin Orbit) and initiated a detailed discussion of the different mission options (Vega-C, Ariane 62(4), SPECTRUM, Launcher ONE) in order to consolidate the selected mission scenarios.

At the same time the studies indicated the urgency to consolidate (the need of) the orbital module/kick stage (dedicated, ASTRIS, AVUM) where the required characteristics are directly linked to the launcher capabilities.

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Finally the landing selection (Woomera preferred option) need to be confirmed: although preliminary contact has been already made and no show-stoppers have been indicated, formal authorization shall be obtained by the Australian authorities.

3. The next phase

A preliminary development logic was proposed as part of the Phase0/A study to provide the Agency with a general features regarding both project development plan costs and schedule aspects.

At the time of writing, the continuation of the activities foreseen an additional study to consolidate the requirement (already running) while the Phase B shall wait approval at Ministerial Conference by end 2022 to be kick-off mid-2023. Presently the HEARTED full implementation is expected to be initiated only after the approval at Ministerial Conference beginning 2025, with the Phase C/D kick-off by beginning 2025.

Finally, Phase E, with the HEARTED Mission Launch, is scheduled by end-2027 / early 2028 immediately followed by the recovery and post-flight analyses.

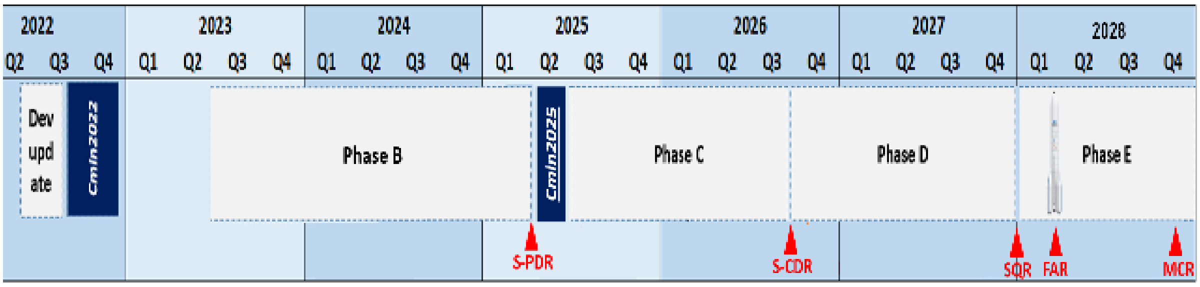

Figure 4: Tentative schedule development

4. Conclusions

The HEARTED project represents a unique opportunity for Europe to gain experience on a strategic capability as the high speed Earth re-entry. HEARTED represents an important development for Science, Robotic Exploration and Human Space Flight Missions constituting a pathfinder for any European sample return mission providing credible alternatives for international cooperation.

Two parallel industrial activities have been successfully concluded covering Phase 0 and Phase of the project. A mission architecture and a system conceptual design have been determined. Critical points have been identified and the next phase is being prepared. Some open points have been indicated and a plan has been defined to tackle them as a matter of urgency. The available technology readiness (TRL) has been assessed and critical procurement highlighted. Accessibility of Woomera as the preferred option for landing has been preliminary investigated and confirmation will be requested to the Australian authorities.

Consolidation of the baseline mission is ongoing while Phase B initiation is waiting for approval at Ministerial Conference by end 2022.

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