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Mars Sample Return: Entry Descent And Landing Analyses For Architecture Assessment Study

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Abstract

This paper presents the Earth return Entry Descent and Landing (EDL) analysis carried out to support the Mars Sample Return Architecture Assessment Study, lead by DEIMOS Space under ESA contract. Mars Sample Return (MSR) is a proposed joint collaborative mission between ESA and NASA, with the goal of bringing back to Earth several surface samples from the Red Planet. The objective of the study was to evaluate the mission feasibility and its sensitivity to the most critical design drivers to select the best candidates for the mission and system design. Extensive mission analysis activities were carried out to verify the fulfillment of the mission goals. The EDL mission analysis, based on a robust methodology for the design of the EDL phase in case of high energy entry scenarios, included Entry Corridor analysis for different Earth return scenarios and preliminary EDL mission performance assessment. The results of the analysis allowed to identify the feasible solutions among the proposed architecture, and confirmed at preliminary analysis level the viability of the mission objectives, focusing in particular on the EDL mission of the return capsule.

Keywords: *Mission Analysis, Entry Descent and Landing, Entry Corridor, Mars Sample Return*

1. Introduction

Mars Sample Return is a proposed joint collaborative mission between ESA and NASA, with the goal of bringing back to Earth several surface samples from the Red Planet. The mission is considered a major step toward a future Mars human exploration, because it will help further increasing the understanding of the characteristics of Mars and will allow testing some critical technologies necessary for a successful crewed return mission. Such complex objective envisages several mission phases, from the Earth-Mars transfer to the Mars orbital phase, the descent and landing on the Martian surface, the ascent from the Red Planet, the inbound leg towards Earth and the entry in the terrestrial atmosphere followed by the landing on our planet of the Earth Re-entry Capsule (ERC) containing the astrobiological sample.

Different architecture options have been evaluated along time, and the current baseline concept involves the coordination of three spacecrafts launched between 2020 and 2026 (see Fig 1):

- M2020, under development by NASA, will deliver a rover on the Red Planet surface to sample Mars terrain and atmosphere and to then cache the samples' tubes in dedicated depot(s).
- The Sample Return Lander (SRL), led by NASA, is comprised of three elements: a surface platform and a Mars Ascent Vehicle (MAV), both provided by NASA, and a Sample Fetch Rover (SFR) equipped with a robotic arm, provided by ESA (see Fig 2). Once deployed to the surface, the SFR will traverse toward the depot(s), collect the sample tubes, and return to the lander platform. The sample tubes will then be transferred by the SFR into an Orbiting Sample (OS) containment element making use of the robotic arm, and loaded on-board the MAV. Finally, the MAV will launch the OS into Mars orbit.
- The Earth Return Orbiter (ERO), led by ESA, will detect, rendezvous with, and capture the OS, before biosealing it and transferring it safely to the Earth Re-entry Capsule (ERC), provided by NASA, that will be released by ERO on an Earth entry trajectory.

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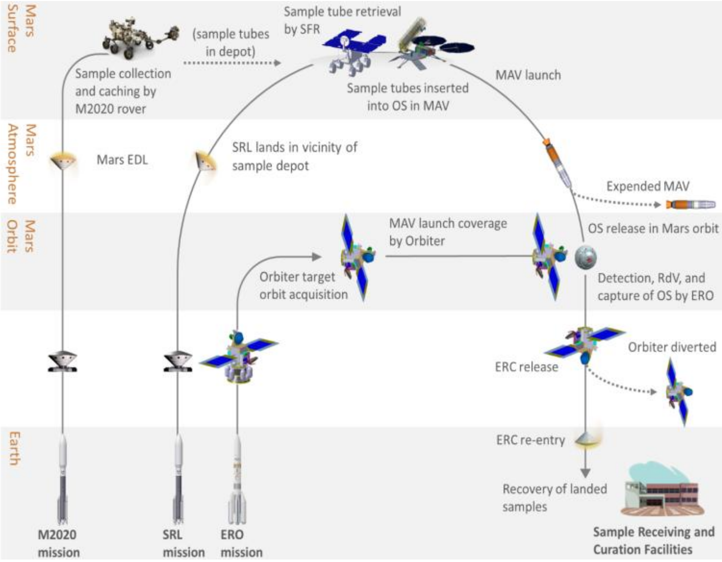

Fig 1. Mars Sample Return Concept (Credits: NASA)

Fig 2. SRL Concept (Credits: NASA/JPL-Caltech)

The study, coordinated by ESA, has been carried out by an industrial consortium composed by DEIMOS Space S.L.U. as prime contractor and responsible for the mission design, Lockheed Martin UK Ampthill for the system design, mass budget and risk analysis and MDA Corporation for the payload mechanisms.

The objective of the study was to evaluate the mission feasibility and its sensitivity to the most critical design drivers to select the best candidates for the mission and system design. During the MSR Architecture Assessment Study (MSRAAS) several mission configurations have been analyzed, and several trade-offs of all the mission design parameters were conducted, including the combination of candidate propulsion systems (1 chemical and 4 electrical) together with the consideration of all possible staging scenarios, the evaluation of different Mars orbit acquisition strategies (including aero-braking), and the assessment of different candidate Earth landing sites for the return capsule. Extensive mission analysis activities were carried out to verify the fulfillment of the mission goals.

This paper presents the main results of the activity, focusing in particular on the Entry Descent and Landing (EDL) mission analysis, based on a robust methodology for the design of the EDL phase in case of high energy entry scenarios developed in DEIMOS [1]. Local Entry Corridor (LEC) analysis of different Earth return scenarios has been carried out, to evaluate the capability of the ERC to fulfill the mission objectives and at the same time assure its integrity by respecting the aerothermodynamic constraints. Once the most promising solutions were identified, a preliminary EDL mission performance assessment was carried out, to estimate the entry trajectory dispersions and the position dispersion at the landing site.

2. High Energy EDL Mission Analysis Overview

In the most recent years, space exploration missions from worldwide agencies dramatically increased, or are on route to, the knowledge of the solar system, collecting information about comets, asteroids, proto planets in the asteroid belt, and dwarf planets in the Kuiper belt. Nevertheless, only in a few cases these missions were able to successfully bring back to Earth samples of solar wind particles (Genesis, NASA, partially successful), comet and cosmic dust particles (Stardust, NASA), and asteroid material (Hayabusa, JAXA). A sample return (SR) mission represents an extremely challenging task due to the increase in complexity of the overall mission and system design, and, in particular, to the need of assuring a safe return to Earth of a sample container, coming from an interplanetary orbit at very high energy. With respect to the relatively low energy entries, nowadays regularly operated from LEO for instance, high energy entries are more taxing and difficult to manage: the excess of energy needs to be dissipated by the entry vehicle without incurring in an excess of heat load into the vehicle: the design of the vehicle aeroshape, the thermal protection system, and the entry trajectory are highly constrained by the arrival conditions.

The Atmospheric Flight Competence Centre (AFCC) of DEIMOS has been working for the last 15 years in the area of Mission Analysis for atmospheric flight, leading and supporting the Mission Engineering and Flight Mechanics for several studies and projects, covering different scenarios, from hypersonic and space transportation to exploration, with a wide range of vehicles (from capsules to space planes), environments (Earth, Mars, Titan), and flight phases (ascent, coasting, and entry, descent, and landing -EDL) [2]. The methodologies and atmospheric flight design tools developed within the AFCC have been flight validated by the IXV mission in 2015 [3] and by the ExoMars16 mission [4], landed on Mars on October 19th, 2016.

Leveraging on this experience, a design approach was developed in the AFCC of DEIMOS for the Mission Analysis of the EDL phase of high energy return missions [1]. The objective was to define and implement a method to allow the robust design of the Entry Descent and Landing phase in case of high energy entry scenarios, assuring that the entry vehicle is able to fulfill the mission objectives and at the same time assuring its integrity by respecting the aerothermodynamic constraints. To achieve this goal, three building blocks are needed: the entry vehicle (aerodynamics, Mass, Centre of Gravity and Inertia, control surfaces – if any), the environment (density, temperature, winds), and the initial conditions (time, position, velocity, attitude), plus the events, if any (e.g. triggering of new phases and GNC modes). The process is presented in Fig 3: it is a complex mission engineering process involving different actors and analyses at different levels, with tight links with interplanetary MA and re-entry capsule system design. The complete process starts with an analysis of the aerodynamics of the re-entry vehicle and an assessment of its flying qualities (FQ: trim, stability and controllability indicators). Through a parametric analysis of the FQ, coupled with thermo-mechanical constraints, an optimization of the Centre of Gravity location is performed. Based on the initial conditions (usually part of an end-to-end interplanetary trajectory optimization and landing site targeting process) an analysis of the environment is performed for the expected range of entry conditions. The above steps are necessary to set up a trajectory simulation of the entry vehicle. With proper Worst Cases combinations of the variability expected along the trajectory it is possible to perform an Entry Corridor analysis, Local or Global, depending on the degrees of freedom considered, to support system trade-off and design. Based on these results, sizing trajectories are identified, usually on the steep or shallow entry corridor bounds, to derive specifications for relevant subsystems (e.g. for the detailed thermal characterization and Thermal Protection System design that is critical for high energy return missions). Finally, a reference trajectory is designed within the entry corridor, and the mission performance and margins are assessed through Monte Carlo analysis. Additionally, visibility analysis of the reference and dispersed trajectories could be carried out to support the ground station definition and operations.

This methodology can be fully or partially implemented to address the re-entry problem in different scenarios, and adapt to the analysis needed. In the past, applications of this design approach included exploration missions (ExoMars 2016 [5]), sample return studies (Phootprint, Phobos SR [6], Lunar Polar SR [1]), and advanced exploration concepts (MARSPLAY, MARSNext, MREP [1]).

To support the Mars Sample Return Architecture Assessment Study, the following activities were carried out:

- Environmental analysis: to derive the atmospheric variability (atmospheric properties and winds) associated to the considered landing sites and the epoch of arrival.
- AEDB analysis: to characterize the aerodynamic database and analyze the capsule aerodynamic properties in continuum and free molecular flow (FMF) regimes.
- LEC analysis: to analyze the variability expected along the entry trajectory and the sensitivity as function of system, environmental and mission critical design parameters.
- Reference Trajectory and performance assessment: trajectory definition and trajectory performance in nominal and dispersed conditions, focusing on the characterization of the entry aerothermodynamic performance and the landing dispersions by means of sensitivity and Monte Carlo analyses.

The results obtained by the application of this methodology to the MSR Architecture Assessment Study are presented in section 4, after a brief overview of the main MSRAAS achievements is provided in section 3 to put in context the EDL analysis.

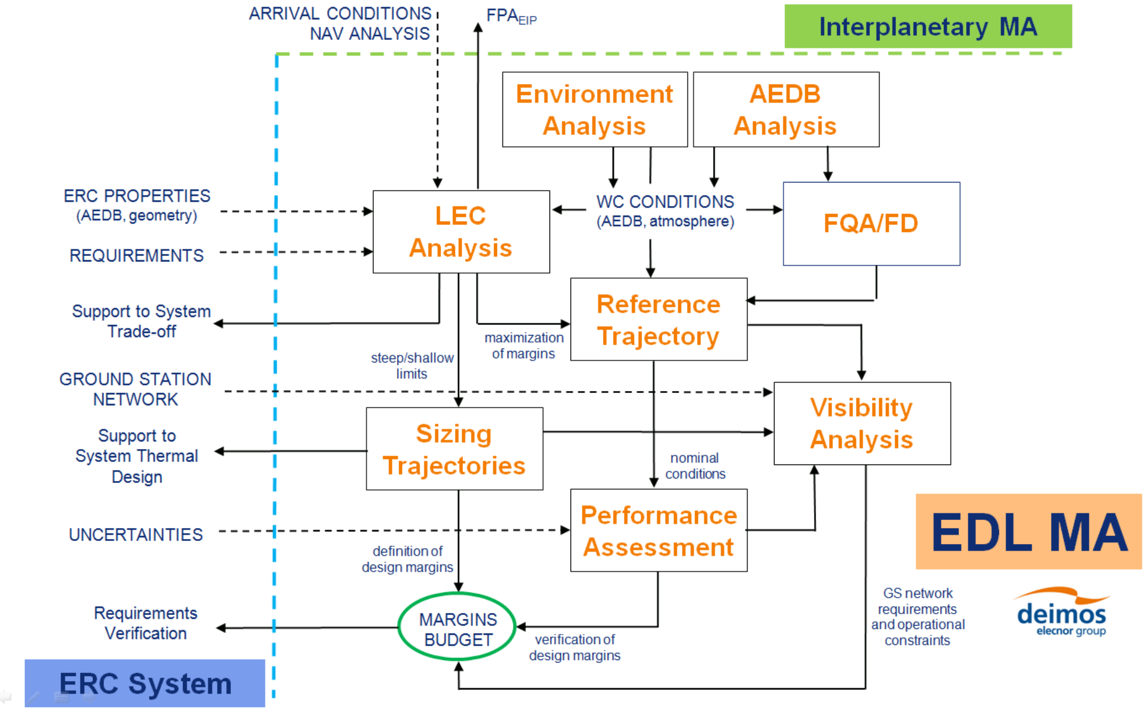

Fig 3. DEIMOS High Energy Return Mission EDL Design Methodology

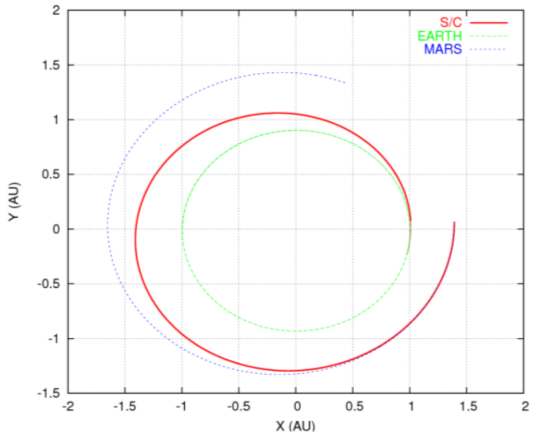

Fig 4. Example of outbound EP trajectory

Table 1. CP inbound trajectories detail

LANDING SITE	Utah	Woomera
Escape year	2028	2028
DSM	No	No
Arrival constraint	No	Yes
Mars escape date	11/09/2028	23/09/2028
Hyp. escape V (km/s)	2.54	3.231
TEI (w/o GL) (m/s)	716.1	1129.88
Earth arrival date	03/06/2029	22/06/2029
Hyp. arrival V (km/s)	5.587	5.459
Arrival declination (deg)	-3.774	-30.000
Delta-V w/o GL (m/s)	716.1	1129.9
Duration (day)	265.1	271.7

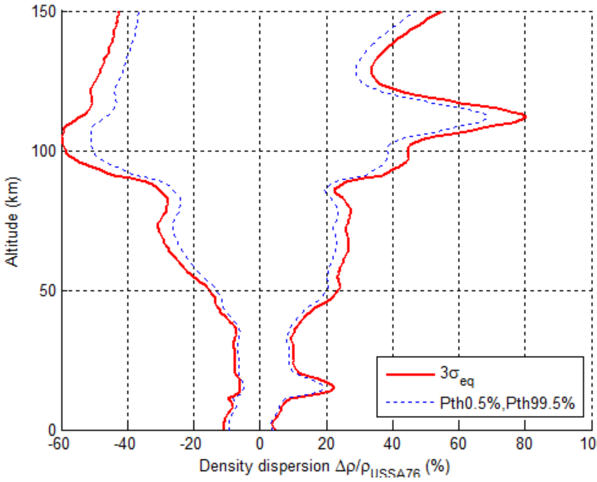

Fig 5. Density dispersion, Woomera scenarios

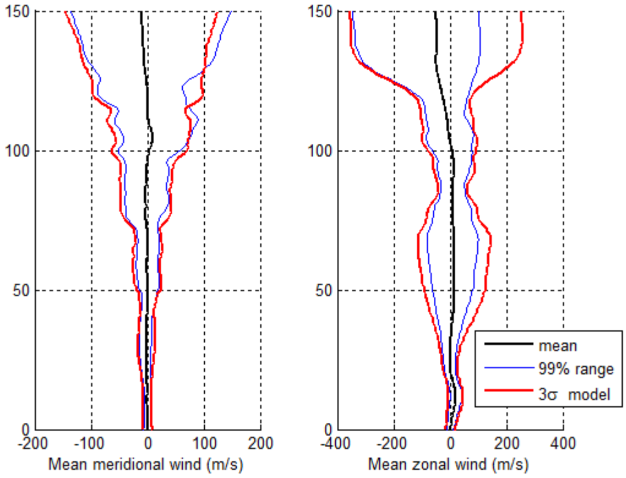

Fig 6. Winds variability, Utah scenarios

3. Mars Sample Return: Architecture Assessment Study overview

During the MSR Architecture Assessment Study (MSRAAS) several mission configurations have been analyzed at architectural level, to take into account the possibility of using different propulsion systems for different maneuvers and to evaluate the impact of various sequences of staging event. The goal was to minimize the spacecraft wet mass at launch while meeting the tight timeline requirements to return the samples back to Earth before the end of 2029 and matching the OS availability for rendezvous (RdV) in Low Mars Orbit (LMO) after May the 1st 2028.

As any sample return mission [6], MSR encompasses high design complexity derived from the numerous phases to be accomplished. Due to the significant impact on the mass margin, one of the most critical aspects is the propulsion system selection, for which different options could be considered [7]: Chemical propulsion (CP) for all maneuvers, Electrical propulsion (EP) for all maneuvers considering 4 different EP engines, or a mixed propulsion system making use of different engines for the different maneuvers. This yielded to a total of 66 spacecraft scenarios to assess. Moreover for each scenario eight different staging options were considered leading to a total of 528 spacecraft permutations to be studied. These configurations were be analyzed primarily at mass budget and timeline level to evaluate their feasibility.

The mission analysis has been of capital importance during the MSRAAS activity to define the detailed mission timelines [7], highly influenced by the propulsion system capabilities, and to evaluate the mission feasibility in the proposed time frame. Its main objective was to optimize the main mission maneuvers:

- MOI: Mars Orbit Insertion after the interplanetary cruise
- TOA: Target Orbit Acquisition to reach LMO
- DOA: Departure Orbit Acquisition to raise LMO
- TEI: Trans-Earth Injection to leave Mars orbit

One of the critical aspects of any interplanetary mission is the trajectories selection to fulfill its goals while minimizing the spacecraft propellant mass. All the optimizations have been conducted with LOTNAV [8], a tool developed for ESA to allow systematic analyses of trajectory optimization, navigation and guidance of interplanetary probes utilizing both chemical and low-thrust propulsion.

Interplanetary trajectory solutions covering all phases and maneuvers have been obtained for the configuration solutions under evaluation. An example of the outbound trajectories obtained for electric propulsion systems is depicted in Fig 4. The inbound trajectories targeted two landing sites (Utah and Woomera) and are constrained by the return date in 2029. Table 1 reports the details of the inbound trajectories optimized for Chemical propulsion solutions.

4. Mars Sample Return: EDL analyses

The EDL analyses have been carried out to support the MSRAAS and address the feasibility of the architectural concepts under evaluation focusing on the last part of the mission, that is the re-entry of the Earth Return Capsule into the Earth's atmosphere.

4.1. Environmental analyses

The USSA 1976 atmospheric model is commonly used in re-entry analysis, providing representative profiles of the mean atmospheric properties as a function of the altitude. To account for the variability in terms of landing site and epoch, an equivalent model based on NRLMSISE-00 was derived.

This equivalent model is based on the statistical analysis of the NRLMSISE-00 variability, where different contributions are considered:

- Location: an area around the baseline landing sites (Woomera and Utah) is considered, defined as the reference coordinates ± 10 deg in longitude and latitude (±1100 km), to account the atmospheric variability as function of latitude and longitude.
- Date: full arrival variability, all year long, day and night (365 days/24 hours), to take into account the variability with respect to the epoch and the local time.

- Solar activity and geomagnetic activity, according to ECSS recommendations, to take into account the variability as function of the solar activity.
- Uncertainties of the model itself, to take into account possible model errors.

Two Monte Carlo campaigns (based on 25000 shots each) were run, one for each considered landing site, providing a conservative global envelope of the expected atmospheric variability. For the EDL analysis a 3-sigma model of the atmospheric density as a function of the altitude was extracted (see Fig 5).

The same logic was used to define the wind perturbations with respect to the nominal HWM14 profiles. Fig 6 shows the wind dispersion profiles for the Utah landing site.

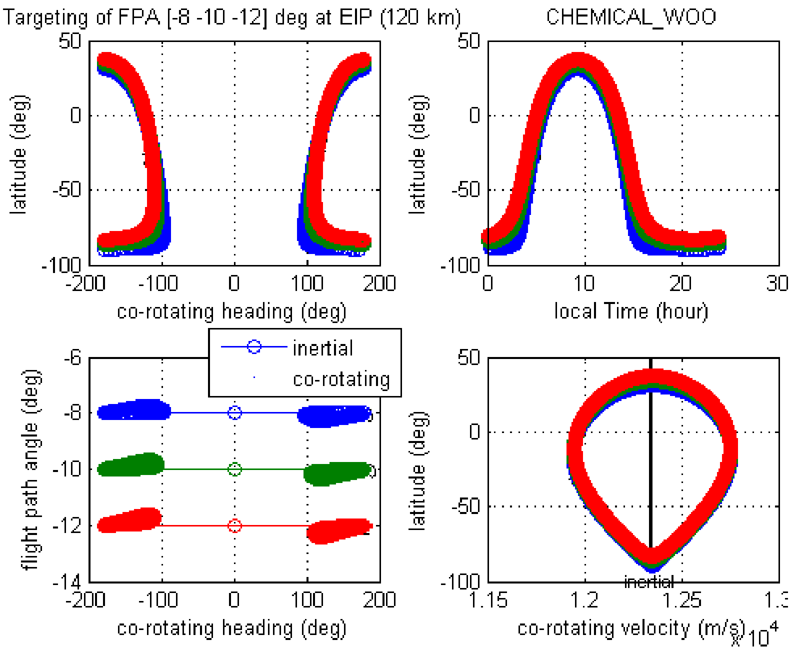

Fig 7. Inbound analysis for Woomera Chemical return scenario: EIP arrival conditions

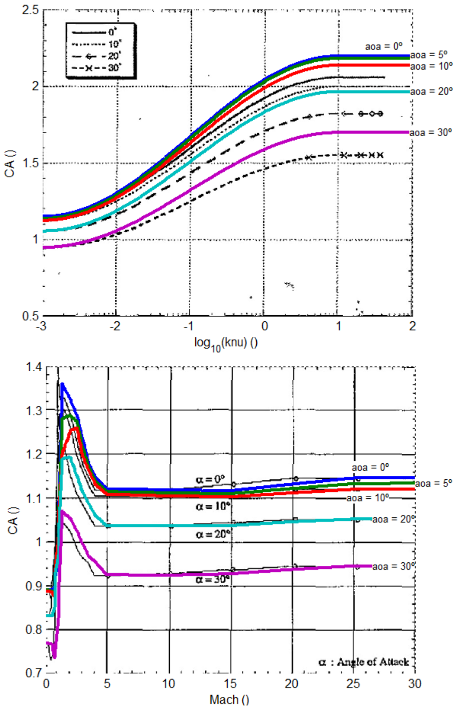

Fig 8. Derived Hayabusa aerodynamics

Table 2. Arrival conditions for the considered return scenarios

	Woomera C	Woomera E	Utah C	Utah E
Inertial velocity (km/s)	12.35	11.87	12.41	11.80
Heading (deg)	115	115	180 (WC)	180 (WC)
Co-rotating velocity (km/s)	11.97	11.49	12.40	11.79

Table 3. Constraints for LEC analysis

Parameter	Units	Value
Maximum load factor	g	80
Maximum total heat flux	MW/m2	14
Maximum total heat load	MJ/m2	300
Maximum stagnation pressure	kPa	80
Skip-out indicator	-	-
Margin wrt correlated pstag/heatflux*	%	0

(*) 0% margin means trajectory touches the pstag/heat flux boundary line

4.2. Local Entry Corridor analyses

The Local Entry Corridor (LEC) analyses were carried out for the Utah and Woomera landing sites considering two possible return scenarios, Chemical (C) and Electric (E) propulsion. These 2-D LEC analyses are based on multiple trajectories simulations covering a parametric variation of the co-rotating flight path angle at the EIP, and the ballistic coefficient (β), defined as:

$$\beta = mass/(Cd \cdot Sref)$$

The variation of the ballistic coefficient can be used for design purposes given that for a particular vehicle shape (*Cd*, drag coefficient), different vehicle size (*Sref*, reference surface) and mass can be assessed. Furthermore, for a given vehicle size, the maximum mass that allows a safe entry can be derived.

In order to have a full coverage of the possible arrival conditions all the applicable scenarios are taken into account for LEC analysis, even if the final selection of the baseline and backup reference will be done considering the final return solutions identified by mission analysis. This approach is justified by the necessity to be conservative given this stage of the analysis, and at the same time guarantee the overall consistency of the design. In particular, Table 2 reports the initial conditions considered, based on a subset of fixed inertial velocity/entry heading angle pairs, extracted from the arrival scenarios under consideration. For the Woomera landing site, the entry heading angle is constrained to be close to 115 deg in order to comply with the Woomera Test Range safety regulations. On the contrary, for the Utah landing site the worst case is assumed, that is 180 deg for a prograde entry. For each case the conditions at EIP are computed, as a function of the entry FPA. Fig 7 shows the conditions at the EIP for the Woomera Chemical scenario: the targeting has been carried out to reach the latitude of the Woomera Test Range (about 31 deg south) with a heading angle of 115 deg, resulting in a co-rotating velocity at the EIP of 11.97 km/s. Table 2 reports the results obtained for all the scenarios considered.

The entry corridor is defined with respect to a set of constraints and figures of merits defined for the EDL phase (See Table 3). Active constraints are those parameters affecting the aero-thermal and mechanical integrity of the entry vehicle, such as the maximum load factor, heat load, heat flux and stagnation pressure. Margins on the convective and radiative heat fluxes are considered to be conservative e against modeling uncertainties. A skip-out indicator is also taken into account to allow quantifying the margin with respect to any undesired rebound and assure the entry is properly achieved.

For the MSRAAS, the reference ERC configuration was based on a geometric up-scaling of an HAYABUSA-shaped capsule. Hayabusa is a 45-degree half-angle blunted cone capsule characterized by a hypersonic continuum drag coefficient of 1.15. Free Molecular flow effects as well as uncertainties are modeled (see Fig 8). The reference configuration has diameter of 1.66 m and height of 0.91 m, with a reference nose radius of about half of the capsule diameter. According to the methodology presented, the LEC analysis is based on a worst case approach including ±3σ uncertainties on the aerodynamic and the atmospheric properties, and on the entry condition in terms of EIP dispersions.

The LEC analysis results allowed the analysis of the feasibility of the different arrival solutions, indicating that:

- Entry corridors exist for all cases. For the Woomera Chemical and Electric scenarios, and for the Utah Electric scenario the corridor limits are defined on the shallow side by the skip out indicator, and on the steep side by the maximum stagnation pressure constraint. For the Utah Chemical scenario the maximum heat flux becomes the active constraint, due to the very high co-rotating velocity at the EIP. The Entry Corridor opens up considerably in case of lower entry velocities.
- Arrival solutions based on architecture with electric propulsion present in general more favorable conditions and wider entry corridors than the solutions based on chemical propulsion, therefore, and strictly form the point of view of the entry analysis, electric propulsion solutions are the best options.

- Limits on the ERC design are identified for the different scenarios. Assuming the reference geometric configuration, the an entry corridor solution is available up to a ballistic coefficient ranging from 83 kg/m2 in the worst case (Utah Chemical) to 130 kg/m2 (Woomera Electric). This is translated into limits on the maximum ERC mass ranging from 207 kg in the worst case to 324 kg in the best case.

From preliminary ERC design carried out by MDA, a mass breakdown was obtained, including design margins, with a total mass of 256 kg, leading to a reference ballistic coefficient of 102.6 kg/m2. This means that a valid Entry Corridor exists for the Woomera Chemical, Woomera Electric and Utah Electric scenario, while no Entry Corridor exists in case of Utah Chemical. The upper figure in Fig 9 shows the LEC for the Woomera Electric scenario: each curve represents a constraint and the grey region is the feasible region in terms of flight path angle at EIP and ballistic coefficient. The EC size, for the reference ballistic coefficient, is around 1º, for flight path angles between -9.14º and -8.14º. A less wide corridor is obtained for the Utah Electric scenario (0.53º), see Fig 9 in the lower side, while a similar value is guaranteed for the Woomera Chemical scenario (0.67º).

As anticipated, the LEC analysis indicated that no Entry Corridor exists in the Utah Chemical scenario for the baseline ERC configuration. A reduction of the ballistic coefficient should be needed in order to have or increase the entry corridor. This could be done considering either lower re-entry masses, or a modification of the geometry configuration. A sensitivity analysis on the ERC geometric configuration was carried out, to assess the dependency of entry corridor size on the capsule geometry, while keeping the mass value, and the aeroshape solution, see Fig 11. In this case, a higher nose radius would lead to lower heat fluxes, for a given combination of entry flight path angle and ballistic coefficient, that would open the corridor (see also the contour plots of the heat flux as a function of the entry flight path angle and ballistic coefficient shown in Fig 10).

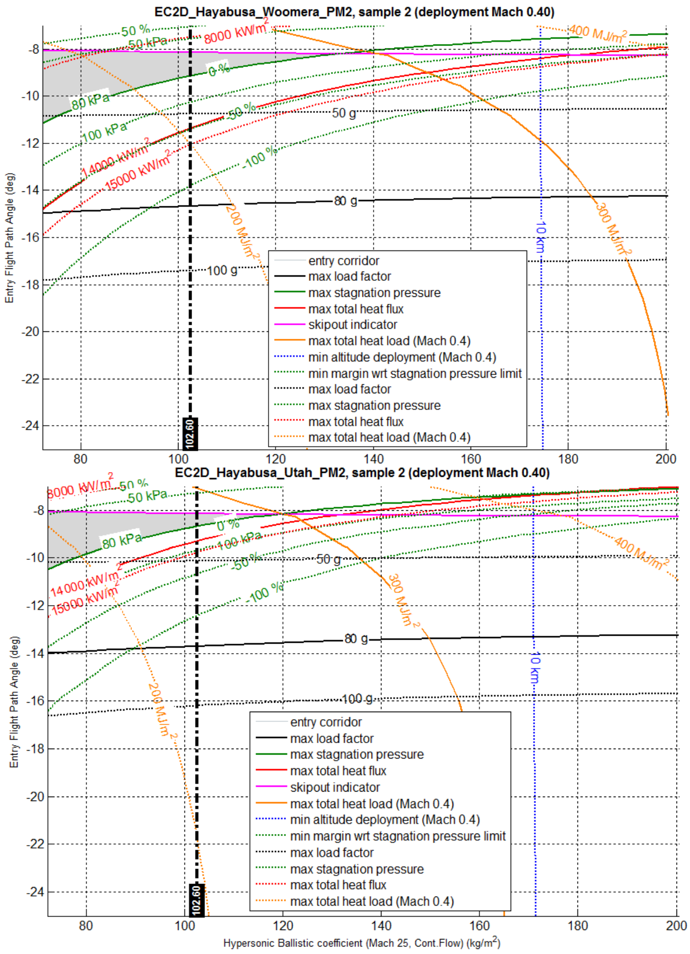

Fig 9. LEC results for Woomera E (up) and Utah E (down)

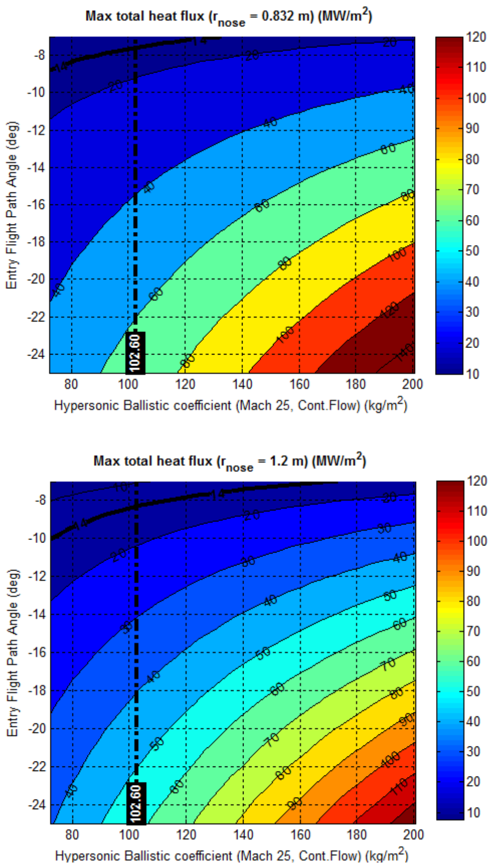

Fig 10. Sensitivity of heat flux w.r.t. Ballistic coefficient, FPA at EIP, and nose radius, Utah C scenario

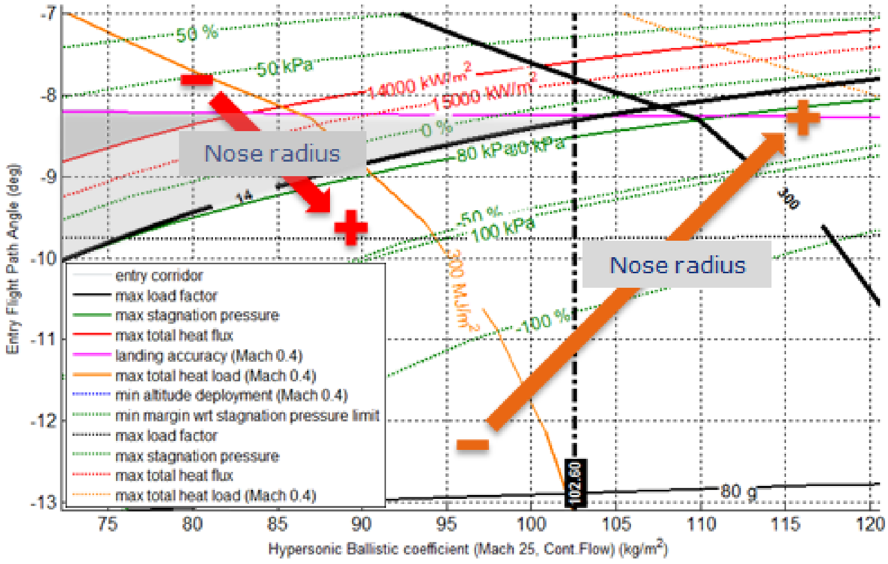

Fig 11. Sensitivity of Entry Corridor width w.r.t. the nose radius , Utah C scenario

4.3. Trajectory performance analyses

An EDL Trajectory Analysis was performed to preliminary assess the entry trajectory performance. The analysis focused on the mission scenarios with return trajectories to Utah, considered the baseline landing site for the candidate mission solution. The LEC analysis demonstrated how, for the mission constraints assumed and the considered capsule baseline solution, an entry corridor exists only in the case of electrical return. Nevertheless, both the mission constraints and the capsule design have to be consolidated in the future, therefore the EDL trajectory analysis was carried out also for the chemical scenario in order to provide the main trajectory performance and study the associated variability, in particular with respect to the LEC analysis predictions.

The definition of the EDL reference trajectories is based on the Local Entry Corridor results in terms of FPA targeting at EIP, given the reference arrival condition. The objective is to try to maximize the margins (see Fig 12). The EDL reference is defined from the Entry Interface Point until touchdown. As a baseline design, no parachute is foreseen to slow down during the descent phase, therefore the impact velocity is an important parameter to assess the robustness of the structural design of the ERC and the sample container. A 3DOF Monte Carlo Analysis was carried out. Initial conditions, environmental parameters, aerodynamic properties, and the mass of the ERC have been perturbed in order to assess the entry trajectory performance once uncertainties are considered.

For the Electric return scenario, the results show that a landing at Utah Test Range (UTTR) is fully feasible and does not present any constraint violation (Fig 14 shows the heat flux versus stagnation pressure profiles during entry for the nominal and dispersed trajectories). Furthermore, the entry trajectory dispersions guarantee considerable margins with respect to the assumed constraints, validating the approach used for the design of the entry reference trajectory and confirming the predictions of the LEC analysis. Performance in terms of position and velocity dispersion at touchdown show that a landing accuracy below 40 km is achievable. Even if fine targeting of the UTTR has not been performed, the touchdown position dispersion is within the UTTR area (see Fig 13). Fine trajectory tuning and impact point targeting will move the landing ellipsoid within the UTTR. On the contrary, the current ERC design (mass and geometry), results in a terminal velocity at touchdown between 43 and 49 m/s (see Table 4). To reduce this velocity it would be necessary to decrease the ballistic coefficient of the ERC.

The results show how the chemical return scenario for a landing at UTTR presents the violation of the heat flux and total heat load limits currently considered, as anticipated by the LEC analysis, for the targeted FPA at EIP, see Fig 15. Nevertheless, performance in terms of position and velocity dispersion at touchdown are in line with the performance obtained for the electrical return scenario (see Table 4).

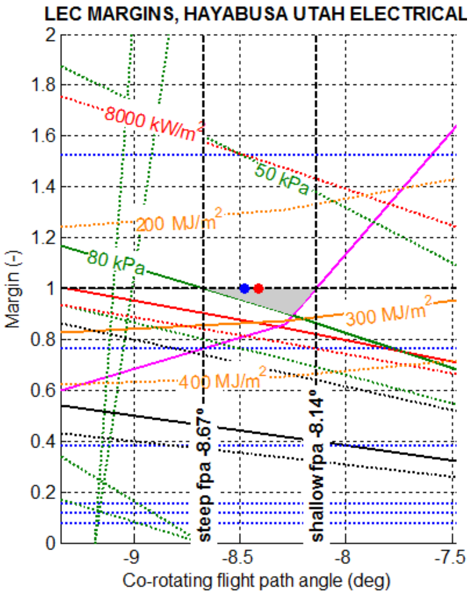

Fig 12. Targeting of reference entry conditions w.r.t. Utah E Entry Corridor

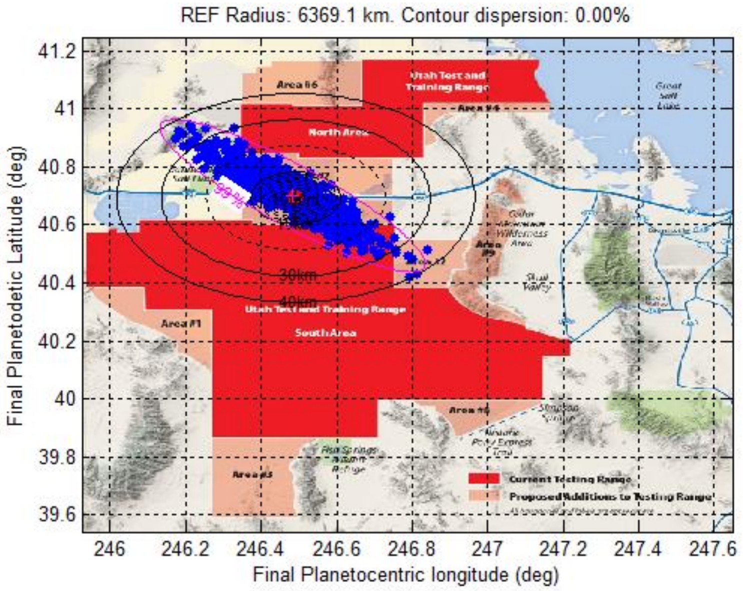

Fig 13. Footprint at touchdown w.r.t. Utah Test Range, Utah E scenario

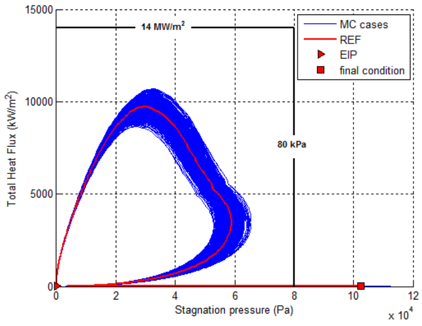

Fig 14. Heat flux versus stagnation pressure variability, Utah E scenario

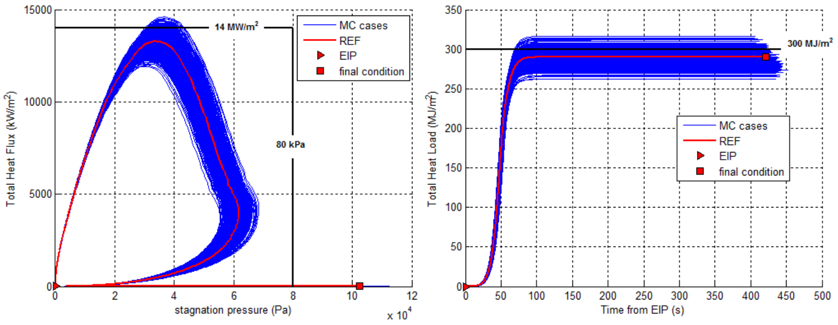

Fig 15. Heat flux versus stagnation pressure and total heat load variability, Utah C scenario

Table 4. Touchdown velocity variability for the Utah Electric and Chemical return scenarios

Parameter	REF	Mean	99% range (90% CL)	
ELECTRIC				
Time from EIP (s)	421.25	423.10	398.24	446.13
Co-rotating velocity (m/s)	46.20	46.34	43.23	49.72
Vertical velocity (m/s)	-46.19	-45.95	-49.23	-43.10
CHEMICAL				
Time from EIP (s)	421.50	423.46	398.74	446.38
Co-rotating velocity (m/s)	46.21	46.33	43.27	49.80
Vertical velocity (m/s)	-46.20	-45.95	-49.22	-43.10

5. Conclusions

A Mission Analysis design process for the Entry Descent and Landing mission analysis of exploration and sample return missions has been implemented in DEIMOS and presented. This process involves all the disciplines required for the design of an entry vehicle, and provides support to the thermal and System design. This methodology has been applied to the Mars Sample Return Architecture Assessment Study to support the evaluation of the mission feasibility and its sensitivity to the most critical design drivers, focusing on the EDL phase of the mission, to select the best candidates for the mission and system design.

Local Entry Corridor (LEC) analysis of different Earth return scenarios were carried out, to evaluate the capability of the ERC to fulfill the mission objectives and at the same time assure its integrity by respecting the aerothermodynamic constraints. LEC analysis showed that, for the reference ERC design, return trajectories targeting landing in Woomera will assure the existence of an entry corridor in all cases, while if landing in Utah is targeted, an available Entry Corridor exists only in the electrical scenario. Therefore, an ERC design revision is recommended to open up the corridor for chemical return to Utah, or, in alternative, a constraints relaxation is needed.

E2E reference trajectories are defined targeting FPA at EIP to assure margins with respect to the entry corridor. A preliminary trajectory performance assessment confirmed that, considering representative uncertainties/dispersions, a feasible solution exists for the Utah electrical scenario, with margins with respect to the aero-thermodynamic constraints, while a return with chemical propulsion would result in a constraints violation during entry in case of non nominal conditions. The prediction of the LEC analysis are thus confirmed by the performance assessment. Furthermore, the preliminary landing footprint is compatible with landing at UTTR.

The results presented in this paper further demonstrate the validity of the approach, and the maturity and robustness of key procedures and tools of the presented design methodology that DEIMOS has been developing.

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