GLOBAL ENTRY CORRIDOR: ACCURATE TOOL FOR LANDING SITE SELECTION IN PLANETARY EXPLORATION

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ABSTRACT

This paper deals with the Global Entry Corridor (GEC), a tool for the evaluation on a planetary scale of the performances of interplanetary exploration probes during the critical atmospheric entry phase.
Since the GEC allows for the generation of planetary maps of mission performances and since mission scientific objectives can also be summarised in interesting planet areas, feasible and interesting landing sites can be easily identified as multi-layers combinations of different filtering maps by this tool.
Practical applications of the GEC to the identification of interesting landing sites in two European Space Agency (ESA) Mars exploration projects are presented: Exomars and Mars Next.

1. INTRODUCTION

Probes for interplanetary exploration are always optimum solutions in terms of cost, designed to safely achieve the mission objectives.
Given the uncertainties intrinsic in an exploration mission, probes must be robust enough to compensate with margins the expected variability of the environmental conditions they are going to face. Robustness implies flexibility but planetary probes cannot be designed to cover any potential mission since extra margins imply extra costs.
Margins are formalized by a set of engineering constraints, so that mission performances are limited and objectives can be successfully reached only in reduced conditions.
It is not possible to land a planetary probe in any point of the desired target planet. Typically there are regions that are not compliant with the engineering requirements and regions that are less interesting from a scientific point of view.
Evaluating mission performances on a planetary scale is a complex task solved by the Global Entry Corridor, a tool that becomes the natural platform for integrating filtered areas according to both scientific objectives and engineering constraints.
One of the output provided by the tool are the planet regions where the mission landing site can be placed guaranteeing safe achievement of the mission objectives.

2. GLOBAL ENTRY CORRIDOR

When the planet is surrounded by an atmosphere, one of the key drivers of an interplanetary exploration mission is to survive the critical entry phase. Many constraints limit the flyable conditions and the entry corridor is the classic concept typically implemented to analyse the design margins.
While the Local Entry Corridor (LEC) analysis provides the corridor limits for a given single set of boundary conditions, the GEC introduces flexibility in these boundary conditions, extending the concept to wider dimensions, see [1].
The GEC is an extension of the LEC to a planetary or regional level taking into account the specific characteristics of each site (topography, atmosphere, arrival conditions...).
Each of the LEC on which the GEC is based (by varying the problem boundary conditions) relies on accurate multiple simulations runs of the entry phase under worst case conditions, guaranteeing appropriate safety margins to the accomplishment of the mission minimum performances. In addition, conditions at the Entry Interface Point (EIP) are linked to the interplanetary transfer from Earth, thus guaranteeing coverage of the complete mission. Variability in the target landing site, in the mission epoch, in the arrival scenario or in the vehicle properties are just few of the options available.
When variable landing sites are considered, entry corridor in any point of the planet can be evaluated and longitude-latitude maps of mission performances can be produced by this tool.
GEC application to the selection of the mission landing sites is based on the natural combination of filtering maps as shown in the following paragraphs.

3. FILTERING MAPS

As an example of the of the criteria for the selection of candidate landing sites, in the frame of the ESA Exomars Mission the following filtering conditions have been considered:
- Terrain filtering:
    - Latitude band
    - Terrain slope

- Maximum landing site topographic altitude
- Landing site footprint: shape and size

- Scientific objective [2]:
  - Phyllosilicates and hydrated minerals rich areas

Scientific objectives have been obtained starting from open information available to public, thus they do not represent any mission requirement officially applicable. Anyway the chosen constraint is in line with the mission objectives and its application is well representative of future scientific constraints nowadays still to be consolidated.
An equivalent set of terrain filtering criteria has been considered also for the Mars Next project.

Fig.1 shows the planetary map of filtered landing site according to terrain filtering conditions only.

Fig.2 shows the planetary map of filtered landing site according to scientific objectives only.

Fig.3 shows the combination of terrain filtering and scientific objectives: six areas on the planet have been identified for Exomars, before any entry corridor limitation is applied: GEC maps are introduced in the next paragraph.

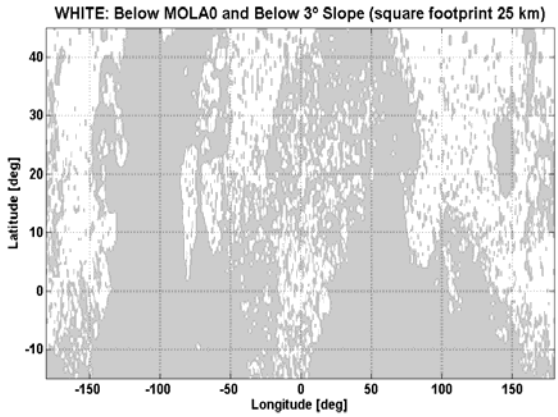

Fig. 1. Terrain filtering.

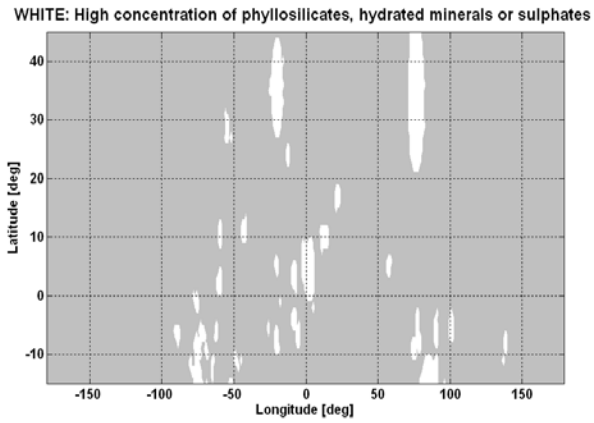

Fig. 2. Exomars example of scientific objectives.

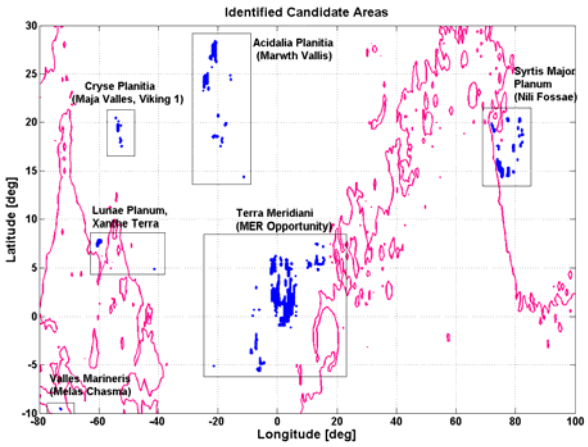

Fig. 3. Exomars candidate landing areas.

Fig.4 shows a zoom on the Terra Meridiani area, plotting the candidate landing areas on a 3D surface reproducing the Mars planet topography.

Fig.5 shows the effect of different landing footprint dimensions on the same Terra Meridiani area. Clearly, as the footprint shape reduces, the candidate area increases.

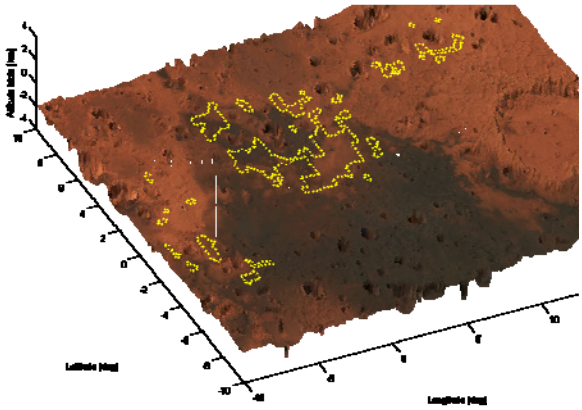

Fig. 4. Terra Meridiani: candidate landing areas (Exomars).

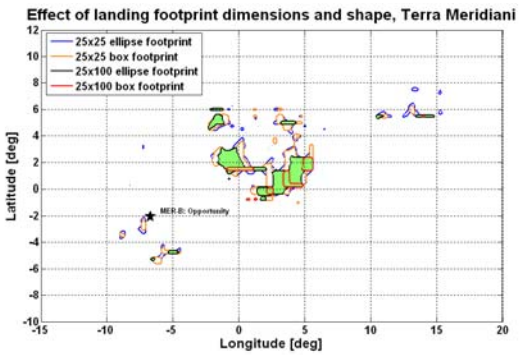

Fig. 5. Terra Meridiani: effect of footprint on landing areas (Exomars).

4. GEC MAPS

In the frame of the Exomars and Mars Next projects the following entry corridor limits have been considered:

- Heat flux
- Dynamic pressure
- Load factor
- Landing accuracy
- Heat load
- Altitude at first parachute deployment

Given the GEC variability on the boundary conditions (landing site coordinates among others), one of the graphical outputs of the GEC are contour maps that provide an accurate planetary overview of selected performances. For ballistic entry probes, like Exomars and Mars Next, the most synthetic view of the entry phase is given by the flight path angle (FPA) entry corridor width at the Entry Interface Point (EIP).

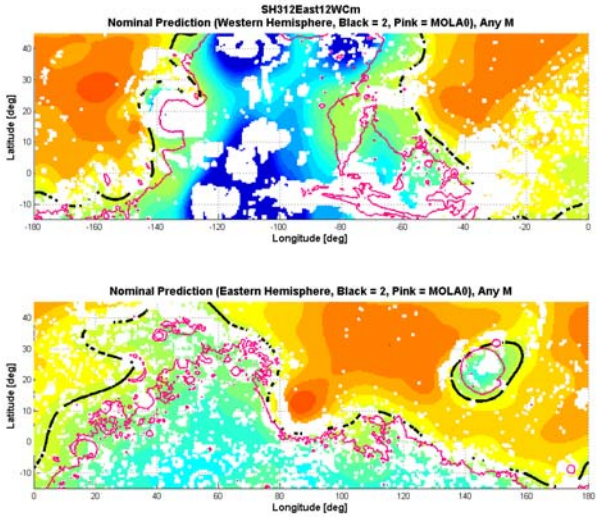

Fig. 6. Exomars GEC Map

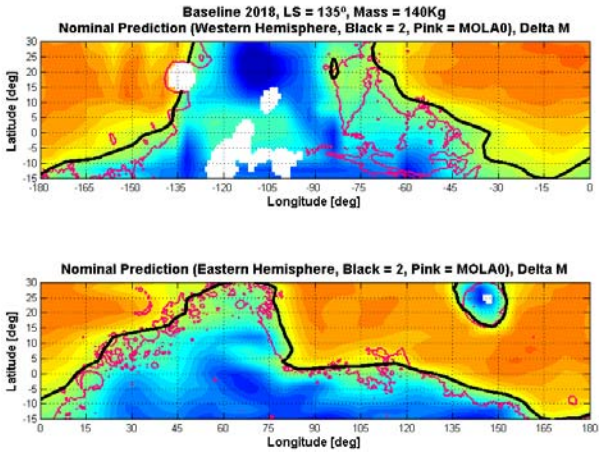

Fig. 7. Mars Next GEC Map.

Fig.6 shows the planetary map of FPA entry corridor width at the EIP for the Exomars project.

Fig.7 shows the planetary map of FPA entry corridor width at the EIP for the Mars Next project.

In both contoured maps, positive entry corridors are associated to yellow-red shadings while negative entry corridors to green-blue shadings. White regions are related to specific additional mission filtering.
Black contours are set at FPA corridor width equal to 2 degrees and represent the minimum performance required to the mission. Regions compliant with this constraint are safely reachable even in worst case conditions.

When related to the Mars topography, these maps reveal a strong correlation between the landing site altitude and the entry corridor, driven by the minimum altitude at the first parachute deployment. This is a typical sizing constraint for ballistic entries on Mars, given the relative thin atmosphere on this planet.

5. LANDING SITE SELECTION

Provided the GEC maps, the selection of the landing site is easily completed at a planetary level by the combination of the several filtering maps presented so far. The multi-layers overlap of constraints results in the identification of all the planet areas that are compatible with the mission constraints and also appealing from a scientific point of view.

Fig.8 shows the combination of terrain filtering, scientific objectives and GEC corridor limits for Exomars. Green areas are the landing sites identified as possible candidates for the mission given the assumptions set. The GEC corridor filtering eliminates those not safely reachable by the planetary probe.

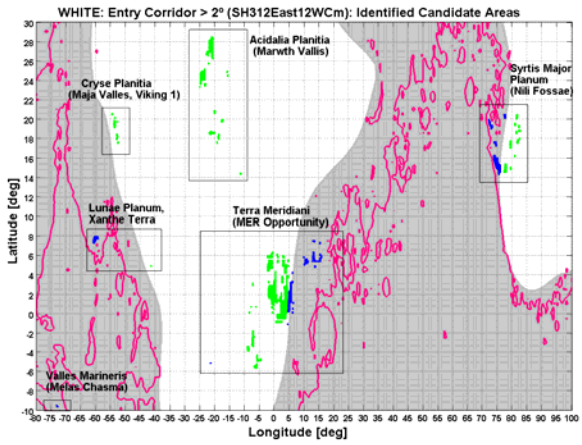

Fig. 8. Exomars candidate landing sites (green).

Fig.9 is focused on the Terra Meridiani candidate region for Exomars, overlapping the FPA corridor contour map of Fig.6 with the areas identified in Fig.3.

Fig.10 provides the evolution of progressively including new constraints to the landing site selection process on another Exomars mission scenario (top: GEC corridor, middle: Terrain Constraint added, bottom: Scientific objectives added; black area correspond to constraints satisfaction)

As shown in Fig.11, the tool is also capable to provide statistical analysis of the landing site areas identify to further support system trade-offs: as an example, Fig.11 provides the percentage distribution of landing site altitudes for the mission scenario of Fig.10. The black line corresponds to middle case of Fig.10, the red one to bottom case of Fig.10.

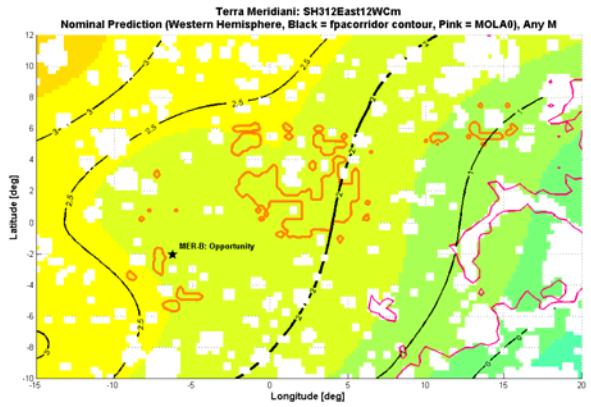

Fig. 9. Exomars GEC Map and Candidate areas.

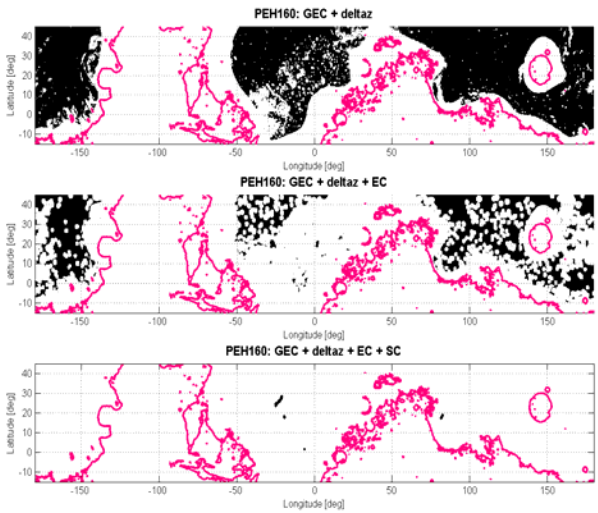

Fig. 10. Exomars GEC progressive filtering.

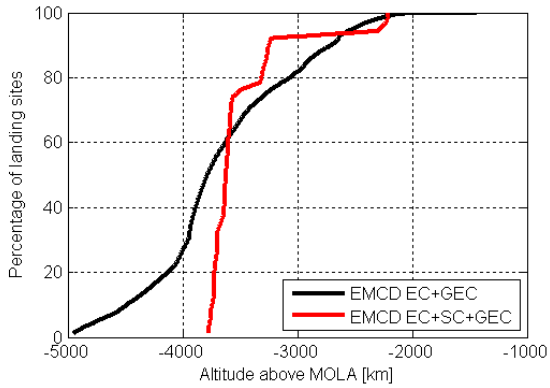

Fig. 11. GEC statistical analysis of landing areas.

6. CONCLUSIONS

An efficient and easy approach to the identification of landing sites in planetary exploration has been presented with practical results from the European Exomars and Mars Next projects.
The Global Entry Corridor is the key tool used to obtain these results by combination of multi-layered maps at planetary level. This tool relies on the critical advantage of including in the landing filtering process the performances maps of the entry phase at planetary level.
The GEC analyses provide a fast answer to the design team in terms of landing site feasibility and performances. It is applicable both to early design phases and to advanced design phases, as proven in the application to Mars Next and Exomars projects.
Local finer analysis can then be focused on the selected interesting and feasible areas identified by the GEC, drastically reducing the efforts to converge towards an optimum landing site identification.

7. REFERENCES

1. Haya R., Bonetti D. et al. Exomars Mission Analysis and Design – Entry Descent and Landing, 17th AAS/AIAA Space Flight Mechanics Meeting, 2007 Sedona, Arizona.
2. Bibring et al. Global Mineralogical and Aqueous Mars History Derived from OMEGA/Mars Express Data. *Science*. VOL 312, April 2006.