# DEVELOP GLOBAL SAFETY SYNERGIES FOR LONG-RANGE HUMAN SPACE EXPLORATION, WITH FOCUS ON LAUNCH SYSTEMS

**Aline Decadi**

*He Space Operations BV at European Space Agency, 52 Rue Jacques Hillairet, Paris, France*
*Email: Aline.Decadi@esa.int*

## ABSTRACT

The agencies participating in the *International space Exploration Coordination Group* (ISECG) demonstrate a natural synergy for defining and implementing meaningful steps towards advanced human spaceflight. Within the exploration mission themes of the *Global Exploration Roadmap* (GER) [1], crew transportation and operation capabilities are driven by key requirements based on human and robotic mission partnership. They require an acceptable level of safety associated with the risks inherent to live, travel and work in space. This paper pursues the goal to investigate the safety orientations to be targeted by the space agencies, and addresses the main decision factors for implementing global safety rules regarding the space transportation vehicles.

## 1. INTRODUCTION

Human space exploration will proceed in a step-wise manner, extending proven capabilities to achieve more complex goals while enabling new discoveries with each step. The widespread recognition of the updated *Global Exploration Roadmap* (GER) released in August 2013 [2], provides a common reference, which is then useful for the work of individual space agencies to advance mission concepts and to study associated capabilities.

The GER emphasizes the near-term initiatives in implementing the common international strategy:

1) Full utilisation of the International Space Station (ISS) to prepare for exploration,
2) Continuing efforts to expand on synergies between human and robotics missions,
3) “Proving ground” missions in the lunar vicinity in order to develop capabilities and techniques leading to a sustainable human exploration on the surface of Mars.

ISECG focuses on a continuing definition and elaboration of a common long-term strategy making clear that there is a role for any nation willing to contribute. ISECG also evaluates concepts and opportunities as humans prepare the next steps in a sustainable long-term program of exploration. Human-assisted robotic mission concepts are receiving increased attention by participating agencies within ISECG because they appear to provide opportunities for leveraging the unique capabilities of human exploration to achieve multiple objectives. Work remains to fully quantify and assess this benefit, but several ongoing studies seek to provide data to complete such an assessment. Recent studies in particular, one led by ESA and one led by NASA/JPL [3] are ongoing and shared within ISECG. Results from their analysis will be used in the next iteration of the Global Exploration Roadmap. They provide descriptions of architecture elements through mission campaigns and operational concepts. These studies cover the main categories:

- Prepare human exploration of the lunar surface
- Enable scientific and exploration knowledge gain
- Provide opportunities to advance science mission bringing back benefit on Earth (e.g. Mars sample return scenarios).

Whatever are the different exploration scenarios, the key capabilities related to multi-destination space transportation are [2]:

- Launch vehicle that has the capability to deliver cargo or crew beyond low-Earth orbit. Initial capability evolves with advanced boosters and an upper stage to enable increasingly complex missions with further evolution to support crewed Mars missions (e.g. various launch scenarios including a split launch on Soyuz / Ariane (assembly at the cislunar habitat) or co-manifested launch on Space Launch Vehicle (SLS) Block IB, or Next Generation Space Launch Vehicle (NGSLV))
- Crew (transportation) vehicle capable of delivering a crew to exploration destination and back to Earth (e.g. Multi-purpose Crew Vehicle (MPCV), Orion)
- Cargo logistics vehicles capable of resupplying orbital infrastructures in lunar vicinity with pressurized and unpressurized payloads
- Small Cargo Lander capable of delivering robotics and cargo on the lunar surface to meet lunar exploration objectives (e.g. automated (potentially tele-operated), total wet mass of 10 Tons, multiple missions)
- Crewed Lunar Lander capable of delivering crew and cargo to the lunar surface (may be reusable, and is composed of two or more stages)

- Mars Ascent Vehicle (MAV) capable of transporting crews from the surface to Mars orbit
- Mars Lander (Liquid Oxygen/ Methane Cryogenic Propulsion System) such as a re-usable lander
- Mars orbiter
- Evolvable deep Space Habitat, in-space habitat with relevant subsystems for the purpose of advancing capabilities and systems requiring access to a deep space environment.

These major transportation capabilities for future exploration architectures have different functions to ensure:

- Transport the crew/ cargo (main phases are launch, approach around Mars and landing)
- Propulsion
- Navigation
- Power
- Environmental control and life support
- Communication

These functions are triggered by safety objectives that are developed hereafter.

How does the safety principles apply to the functions related to spaceflight capabilities of the future exploration architectures?

The following chapters present:

- The safety methodology, i.e. objectives and assessment process for mitigation of unacceptable failure conditions (based on Recommended Practices and Lessons Learnt)
- Illustrations of the implementation of the safety assessment on the future exploration transportation capabilities (based on a screening of their main functions)
- The synergies resulting from these Recommended Practices and their use for the elaboration of a global safety standard for space exploration.

## 2. SAFETY OBJECTIVES

Safety is a major argument on which the agencies commit to secure to crew a safe return to Earth. The objective of Safety is to bring failure probability down to an acceptable level, especially regarding critical functions, which have catastrophic failure conditions. Nevertheless, Safety is confronted to other criteria such as acceptability of budget, schedule and completeness of operational objectives. Safety optimisation is often compared to elements that have different order of magnitude. How combine the residual probability of accident with the overall programme development cost? Several approaches can be addressed in parallel, e.g. with regards to other issues, the use the lessons learnt from previous space flights heritage (e.g. Apollo, ISS, space shuttle), or other hazardous endeavours (e.g. explorations, sporting feat).

The main disadvantaging factors regarding to mission safety when experimenting space exploration to Mars are [6]:

- Mission duration that has an impact on the failure probability of equipment, as well as on crew health (physical and mental)
- Distance associated to confinement during the journey leading to impossibility of receiving help from Earth
- Complexity of the mission, e.g. the number of critical phases/ operations, and number of vehicles to consecutively operate at each mission phase
- Extreme environments (in space and on surface).

The elaboration of safety rules is based on the fundamental principles:

- Redundancy at each level of the mission architecture with regards to degraded cases, with at least one backup lane or unit
- Spare policy, e.g. by splitting the launch dates of cargo and crew vehicles in order to provide additional spare equipment to crew in place to mitigate potential hardware failure cases
- High level of maintainability of systems (e.g. in terms of modularity, ability to repair)
- Simplicity of the mission architecture by limiting the number of modules, phases or critical maneuvers
- Deployment of a maximum of infrastructures on ground (via cargo missions) before sending the crew
- Foreseeing sufficient quantity of supplies in order to wait for the next crew assistance, if required.

This decision-making process for the implementation of the most appropriate safety barriers is based on hazard analysis to be performed in order to propose the best mitigation actions, associated to trade-off and compromise (mainly programmatic such as development uncertainties and cost). Indeed this trade-off makes sense to define the realistic safety needs. Otherwise, results of “safety at all prices” would potentially lead to:

- Redound any element on-board that could lead to such a heavy launch system that the mission would be technically compromised
- Launch dozens of cargo vehicles before sending any crew, such as the mission becomes economically unrealistic.