Cooperation and Dialogical Modeling for Human Space Exploration of Mars

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Abstract
Designing an Human Space Autonomous system for Mars exploration, need a framework for understanding the relations between safe Trajectories and the requirements for propulsion systems design, in particular to prevent and reduce risks for the astronauts during the transit phases Earth-Mars-Earth. This paper proposes an approach for modelling Human-Organisation-Environment lead by the safety point of view. Our perspective is that the propulsion system needs to exhibit some aptitudes at each step of the mission. Its structure must be able to evolve in front of some unforeseen situations during the flight. Before and during the design stage, different paths of modeling are possible. Our paper proposes a new approach for modeling that allows to merge different hypothesis in link with a subjective approach for risks. Cooperation is required at the early stage of the project and the quality of the result is fundamentally inseparable from the problem formulation perceived from different points of view.
Keywords: Human space exploration, dialogical modeling, propulsion system, cooperation, autonomous

1 Introduction

To launch a scientific international Manned mission in our solar system leads us to ask new questions linked with the evolution of Humanity and its technologies. Mankind evolution is at the center of the Mars exploration mission with political, scientific and technological aspects. Our research initialized in 2003 concerns the conditions of a safe design that firstly protect Man and its humanity by giving him its free place at the heart of an audacious scientific exploration mission [1]. A safe design for Mars mission implies a collective networked intelligence for success. To place Man at the core of the project leads us to consider a design process Human and inter-cultural oriented. The design process must also be organized to generate a reliable and safe technical system for the team of explorer. The difficulty is to conceive an open, self-learning and reliable system[1]able to self-adapt in dangerous and unforeseen situations during the flight and

[1] The modes of proof for design an open, self-learning and reliable systems are on different register : 1. Human system → Representation, 2. Technical system → Models, 3. Information system → Calculation and Logic

stay on Mars. We consider that the exploration entity is a real aware newborn child stemming from mother Earth. With a fine and evolutionary consciousness of its internal states and with a multi-scale perception of its external environment, the Human Exploration system is like a cognitive entity both wide ranges of anticipatory actions [2]. Perceptions of new dangers in different unknown, to forecast environment is a great stake for the success of the mission.

2 Epistemology applied to Human space exploration

The research has allowed us to identify two main aspects useful for the success of a such complex project led in international cooperation :

- At the fundamental level, the question is : How to improve safety of an open system ? This implies a new paradigm for understanding complexity. System sciences is a possible path to accompany the transition between the « old » materialist paradigm and a new one.
- At the practical level, the question is to accompany the transition between an engineering which is oriented by competition to an engineering that takes into account the safety of a world-wide project. This evolution is in link with a real cooperative engineering process based on inter cultural fecundity in human relations.

These epistemological researches with fundamental and applied characters are crucial, because they establish the base of a reassurance of a safe and demonstrable process for design proposed in a thesis supported in the University of Technology of Compiègne in 2008 [3]. The stake is to take into consideration during design the risks according to the point of view of the crew to be protected. This methodological proposition aims to overpass the system engineering techniques today applied for the development of the technologies for robotics exploration of the solar system.

3 Reliability and presence of the Man on board

Place Man at the center of the exploration on Mars push us to go beyond a simple recombination of the knowledge already stabilized by the successive experiments of space flights (for 60 years). Since the beginning of the spatial era, the notion of reliability (life-time of a component or a system) is a top concern for designers and builders of technologies. In the case of a Mars mission, reliability and maintainability are the object of systematic studies for example in connection with a type of propulsion chosen on the basis of a trajectory familly. The attentive study of technologies finalized in laboratory and tested in circumterrestre space show to space agencies the necessity of refocusing the research efforts to think better the connections between Human-Health-Technology-Environment and especially for Manned mission to Mars (long distance and long-term) [4].

For example for a manned mission to Mars, several trajectories are possible, they result nevertheless from a combination of objectives, constraints and criteria bound to the presence of healthy women and men on board [5]. For long mission about 1000 days using conjunction trajectories,the following aspects are crucial to insure the success of the mission :

- The duration of the journey
- The rate of exposure to solar radiations
- Weak or zero gravity
- Individual and collective stress
- The cost of the technological solution
- Unknown phenomena

4 Safe design and analytical approach limit

For a safe design, the difficulty consists in seeing that the success or the failure of the mission depends on the choice of the logical structure of the technical system (every technology carries its own dangers for his creator). The way of organizing functional sets of the exploration system has a very large influence on the design process. This drove us to demonstrate that the various functions of the exploration system are an answer to a need which has (at least) two opposing faces: Reliability and safety [6].

At the first level of analysis, we identified 22 insecable elements which participate in the success of the mission. Their activities support the life or the survival of the astronauts during a part or all the entire duration of the mission.

The defect, the failure or the accident which appears on one of these 22 elements generate directly the failure of the mission. This first approach which is very analytical allows to consider the possibility of a well know breakdown, This approach is the classical way to improve safety by a (probabilistic) calculated approach of the redundancy. This strategy is useful for well tested technologies and makes possible the choice of the best structure for assembling components and\or un-repairable system. In a classic initiative, the point of departure consists in considering the eventuality of an accident created by different causes :

- An individual or collective human error (actor and actors' system)
- A defect, a failure of a component or a system (component and system of components)
- A breakdown of the communication and information system (unit of information and information system)

For every identified failure, it is necessary to find some ways to save the astronauts and to insure their a "safe" return. This approach is under tightened by the use of treelike oriented approach (Fault trees and Event trees). The problem with this analytical approach is that the exploration system possesses a very high number of heterogeneous components. These create a risk that is enhanced with the multiple forms or configurations of the exploration system might take during its life cycle. These configurations are unpredictable because of the complexity of the organization and the use of a large and various range of technologies [7]. The combination of the dangerous configurations becomes very quickly uncountable. On the one hand, the construction of scenarios of realistic accidents becomes rather rapidly unthinkable, on the other hand, the technical system moves in an environment potentially unknown (it is an exploration) and we can not hope to identify all the new dangers and all the potentially dangerous interactions which are going to appear at the interface of the system and its environment (before and after the mission).

5 Towards a modeling insuring the transition from simple to complex

Towards the current spatial systems, the exploration disposal to be conceived is autonomous and piloted. The technical system is at the service of the embedded team. This motive implies a design which integrates a specification of needs made by the astronauts around a shared reference between the designers and the manufacturers. We have to consider during design the systematic reassurance of all the phases of the mission. We can not tolerate the choice of a logical and calculated architecture which would depend on one or some unique critical components. It is a necessity to use systemic tools in front of reductionistic methods. Although undeniably successful they have very real limitations especially for complex system in unknown environment. We can see this by disastrous consequences shown by a serial of high technology accident cases.

It is thus a necessity to integrate the definition of the specifications of the exploration system into a very wide perspective centered on the idea to think first of all about the "viability" (of the support system for exploration) and to make potentially actionable " Human safety " during all the time of the mission. Our works resulted in the implementation of a practice of the modeling of a man-organization-environment [M-O-E]. The purpose is to improve the management of the socio-technical risks before the development stage of the technical system of exploration. This practice of modeling [M-O-O] is in break with the classical normative methods considers that the project of exploration is a combination of the individual project of each actors and not a heavy preestablished organization that fix almost totally the project of the actors. We have considered the interest to realize an interactive specification of requirements which takes care about the sensibility and the creativity of all the authors of the project in their variety of experiences. At first, the description of a mission of reference allowed us to show the interest to consider a definition of the system of exploration as a composition of a system of actors, a technical system and an information system [8]. The transition from the definition of a mission of reference to the modeling of a system [H-O-E] passes by several plans of modeling. Each stage is scaled from the least complex to the most complex (from deterministic to the most chaotic levels).

This distinction of levels aims to avoid the design of an open system in a closed one. We consider that every paths of modeling is compounded by a "complex unit " shape by at least two parts that are irreducible one from the other (couples). The couples represent the progression of the knowledge which are necessary to realize the Martian mission.

For the Mars manned mission, the first challenge is to transport a quantity of material on Mars (couple n°1: Trajectory-propulsion). The second stage is to be able to maintain alive Man in a favorable environment for life (couple n°2: Man-life). The third step is to be equipped with scientific disposal for the Mars surface exploration (n°3: Mars-exploration). And finally we can consider the possibility of implanting a long-lasting home on the fourth planet of the solar system (couple n°4: Mars-civilization).

These four couples are guides accomplishing the definition, the modeling and the simulation of the system of exploration. This dialogical (couples): trajectory-systems of propulsion, man-ways of life, Mars-systems of exploration, Martians-Mars-civilization are the expressions of an open modeling which does not reduce the immaterial aspect to a material system.

The initiative for driving the modeling project with 4 couples allows us to aggregate heterogeneous requirements and be able to face the combinatorial explosion of the uncountable dangerous configurations. The main advantage is to answer to the high need of integration of the the technical system that will support the mission. A part of the « complex unit » represents the need to satisfy and the other part is an answer which takes a technological shape. The validation of a classical technology is made by statistics (and stochastic) methods and for the innovative parts we should use maturity models [9].

This way of proceeding allows to discern carefully the hierarchy of needs to satisfy according to an ordinal evaluation (inter-subjectivity) then, it is possible to launch some objective studies on critical aspect lead by pre-evaluation of risks. The advantage of this initiative is that it allows to be free from a certain extent and evolution of technologies.

6 Coupling and interaction, the example of the first couple trajectory-propulsion

We consider that the coupling between the points of view of the actors is a way of long-lasting solution to improve the reliability of the design process (cooperation) [10]. We were interested first of all by the couple trajectory-propulsion to validate and demonstrate the relevance of our approach of safe design in technology. Classically the design of technologies is driven by an excessive technical specialization which tends to maintain a strict independence between the functions to be conceive. According to this perspective, the designer-manufacturer looks at first for a better reliability of the system of propulsion with a sizing fixed according to a trajectory familly. But the presence of Man on board led us to investigate the interdependences between the need of propulsion at every moment of the journey and a series of safe trajectories for the crew.

In the classical perspective, the tendency is to consider that a single actor (for example a consortium of motorist) is capable to solve the problem by modeling in a single field of knowledge. But the safety of the astronauts passes by a shared recognition of all the dimensions of the problem. It means the causes and conditions for coupling the need of trajectory and the adequate propulsion (reliability and safety)

At the level of the global project, the challenge is to orchestrate the cooperation between several agencies, organizations and individuals. The first step is to introduce and to develop cooperation between the trajectorist, the motorist, the astronaut, and the space agency. This was made with the definition of a reference mission qualified on the foreground of modeling (couple n°1 - Trajectory-propulsion - > Register of deterministic mathematical modeling).

The implied actors are gathered for a common pooling of experiences to conceive a system of safe interplanetary transport for the crew. The implementation of our methodological proposition has demonstrated the importance of taking at least three points of view to think well the relation between the need of trajectories and the system of propulsion to be specified. The team establish together a common project. This avoids at once a division of the project driven by independent functions. We need a better efficiency of the propulsion, but also a better safety of the trajectory thought in connection with the function of propulsion.

The meaning of cooperation is to increase the possibilities of reassuring the mission for the astronauts. The coupling reduces the conditions of possible failures, because the failure becomes more difficult for two or for three actors from the moment they become conscious of the causes and the conditions of a real dynamic of cooperation [11]. By forming the couple trajectory-propulsion we saw a big fertility for possible solutions in case of danger.

7 Subjective approach of the risks and the dynamics of the cooperation

It is the subjective approach of the risks that allows to lead the actors to understand the conditions of success and failure for coupling the point of views. The identification of the feelings, the dilemma, the contradictions, the conflicts and the paradoxes allows to stabilize the process of cooperation. The place of the best coupling is made there where we anticipate the most relational skids possible between the actors in their subjectivity in front of risks. The objective of the initiative displayed on the first couple initialize and develop the cooperation between the trajectorist, the motorist, the astronaut. This work establishes a prototype for reassuring the process of a demonstrable safe design.

The approach realized in natural language results in a classification of the importance of the risks. For example, we show below feelings that is perceive by the various points of view before their inter-subjective evaluation by the actors of the future design process.

<u>Aspect trajectory</u>

Astronaut :

- To have an embedded model to calculate in real time trajectories [Positive Feeling, Attract]
- Unique trajectory [Negative feeling, Fear]

Trajectorist :

- To take in considerations the astronauts for the trajectories calculation [Positive Feeling, Attract]
- Some trajectories that don't take care of Man in the system [Negative feeling, Temptation]

Motorist :
- To be able to change the trajectory for return [Positive Feeling, Attract]
- Design mistakes [Negative feeling, Fear]

The first identification of the risks by the inter-subjective dialog allows us to discriminate their relative importance according to the point of view of each actors and the collective, but this initiative especially allows to put some order in the structure of visible disorder of all the causes which can contribute to the failure of the mission according to the actors involved together in the success.

This stage of revelation is inescapable, because it allows the constitution of a real individual and collective responsibility which ends "naturally", that is to say without constraint driven by a central power. It is also a guide to launch more objectives studies. This safety studies are well centered on the most important factors that can reassure the mission of the transport system according to an ethical perspective.

If we want to develop a trust strategy between the astronaut, motorist and tractorist, we can make a virtual coupling (by free will) of their gains. This coupling which is perceived and decided by the actors is an expression of the trust level that one actor allow to the other. This kind of reasoning can stabilize the cooperation process with some conditions that are in link with what the actors accept to realize in common. The intensity of the feeling dilemma depend on the coupling / un-coupling that the actors accept to do “in their mind”. Such a structure : Unity of interaction allows creating a language representation in which the actors can express three types of feeling: Attraction, Fear, Temptation (A, F, T). In themselves and in their relations with other people.

The AFT, is a new language representation which is very useful for the actors because they can tell the possible feeling in a dilemma situation. With a simplistic calculation, we can show that the positive coupling of the gains can permit to reduce fear and temptation and to increase Attraction. This can create the stabilization of the cooperation process. In a few words, we can make a link between actor’s motivations in an interaction situation and the feeling of Fear, Attraction and Temptation [12].

8 Redeployment towards the objective studies and the comparison of modelings

The transition towards the objective studies to be led from the design materializes when we look at the transverse reconstruction which the group realizes through the choice of the inescapable topics which connect their different perceptions from a common problem [13].

For example, we show the topics identified by the group. This example shows the difference which gradually drove the launch of the objective studies from aspects perceived as crucial. The proposed initiative is a guide to start the various studies of safety at the very early stage of design.

Project (Astronaut, Trajectorist, Motorist)---> Topics 1. Propulsion, 2. Piloting, 3. Psychological stress 4. Couple Trajectory-propulsion, 5. Connection between space agencies, -. Human-machine coupling.

The specifications bound to the topic 4. Couple Trajectory-propulsion were developed by the group on the basis of a structure of dilemma from the collection of the Fears, Attractions, Temptations.

The first results of the confrontation of the various points of view drove the project group to finalize simple mathematical models to understand the criteria which connect the possible trajectories and the specifications of an adequate propulsion. It is at first the dialog between the various points of view reveled by a dilemma structure that brought us to envisage a system of an hybrid pilotable propulsion capable of solving potentially dangerous situations. This assume our initial objective to reduce the risks of loss of the crew during interplanetary flight by increasing interaction and cooperation at the early stage of the design.

9 Conclusion - Hypothesis and reference mission

The hypothesis retained for the modelings of the safety of the couple trajectory-propulsion is based on a new family of trajectories. The reference trajectory correspond to a duration of transit between Earth and Mars of nine months, this one being able to be reduced to three months for a supplementary spending to moderate energy; D (DV) = 3,98 - 3,40 = 0,58 Km/s. This choice of trajectories is based on technological and economic criteria. It corresponds to a minimization of the mass in low orbit. This mass is a good indicator of the cost of a mission. The use of this type of trajectory leads to a profile of mission of 950 days with flight durations of 2 x 6 months.

Behind the transportation system, our reference scenario is based on a derived version of the Mars Direct scenario devised by Robert Zubrin and David Baker, that combines innovative s and current technology to land a small crew on Mars. This scenario is innovative for its human oriented approach and the use of in situ resource utilisation. It also relies on multiple vehicles for improved redundancy and autonomy. Launch windows to Mars opens up approximately every two years, when Earth and Mars are in the correct orientation relative to each other. The scenario consists of one launch in the first year and two launches during every launch window after the first, which keeps humans on Mars almost constantly.

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