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The LETUCA protocol, Operational manual

Damien L'Haridon, Anne-Lise Marchand, Laurent Chaudron, Yves Gourinat

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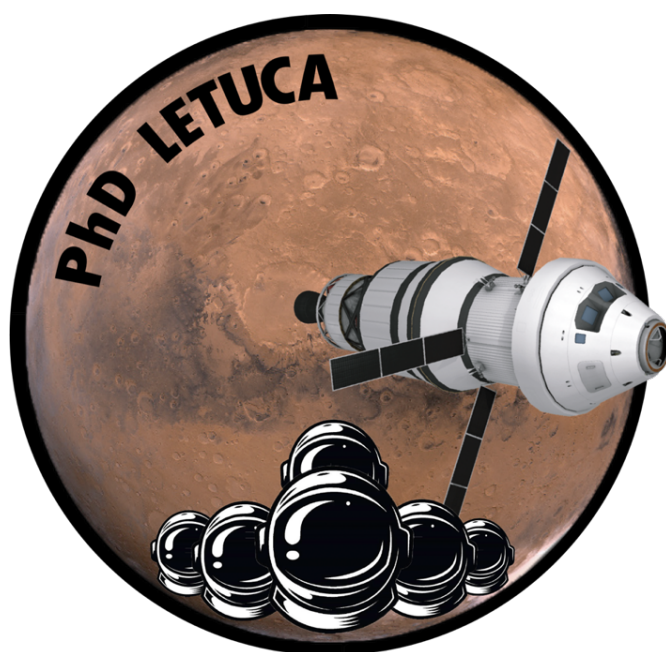
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THE LETUCA PROTOCOL

OPERATIONAL MANUAL



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FOREWORD

This report is linked to the completion of the thesis of Damien L'Haridon (2019) dealing with optimized collective decisions in extreme and operational environments and their application to unknown situations during human space flights. Laurent CHAUDRON, Yves GOURINAT (ISAE-SUPAERO) and Anne-Lise MARCHAND (CReA) directed the work of Damien L'Haridon (2019). In order to test the hypotheses about teamwork and to gather data, a protocol including an operational performance measurement method was created. This protocol is called LETUCA for Longitudinal Evaluation of Teams via Unknown and Collective Activities. It is composed of twelve exercises submitted to participants organized in a team so as to make them interact.

This report presents the twelve exercises with all the elements and details of the protocol LETUCA necessary for a free use in other works.

Being directly linked with the doctorate of L'Haridon (2019), the present report employs numerous elements without citing each time the PhD dissertation. The goal is to facilitate the reading of this document, please read L'Haridon (2019) for further details and the progress achieved thanks to the protocol LETUCA.

ABSTRACT OF THE DOCTORATE OF L'HARIDON (2019)

Unknown situations, i.e. neither expected nor experienced, may happen during aerospace missions; notably, like in the case of the Apollo 13 mission. Then, the crew of the first manned flight to Mars will probably treat unknown situations (Orasanu, 2005) in this potentially constrained, volatile, and extreme environment whilst being isolated from ground control support due to communication delays. Yet, a crew cannot be trained to treat all situations, including the unknown situations (Noe, Dachner, Saxton et Keeton, 2011). The present research work deals with the **improvement of the operational and collective performance while coping with an unknown situation during a manned space flight toward Mars.**

The studied literature (McLennan, Holgate, Omodei et Wearing, 2006; Noe et al., 2011) indicates that a team sharing experiences increases its skill. However, either this literature is focused on a precise activity or it does not discriminate the different types of experience. Moreover, the training of a team to react to an unknown situation is not discussed in this literature. Potentially influenced by experience sharing at collective level, the metacognition is a recognized lever to improve performance during problem resolutions. Metacognition is defined as cognition about cognition (Flavell, 1979) and is modeled into different reasoning steps during problem resolutions. Nonetheless, no link is established between on one side the follow-up of these steps or their possible mixture (i.e. metacognitive clearness) and, on the other side, the increase of the collective operational performance during problem resolutions.

To deal with these problematics, a specific protocol (LETUCA) was build and applied for twenty months. Three stable teams coped with twelve problems designed for this study or adapted from the literature. The first one shared a maximum of experiences; the second one was formed with teammates living the same experiences, but mainly separately from each other. The third team did not live specific experience. These three teams are characterized according to the lived experiences' qualities relative to a fictive training to the unknown. These qualities are determined by professionals that may face collectively unknown situations.

The obtained results support the existence of a relation between the sharing of quality and diversity experiences and the collective operational performance during unknown problem resolutions. The study of metacognition enables to specify this relation: no link is established between the operational performance and the tracking or not of the selected metacognitive model. However, a relation is confirmed between high metacognitive clearness values and the increase of the operational performance. Finally, the results enable the construction of an empirical model of collective metacognition during problem resolution.

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GLOSSARY

CERP'AIR: Psychological studies and research center (in French, Centre études et de recherches psychologiques Air)

ISS: International Space Station

LETUCA: Longitudinal Evaluation of Teams via Unknown and Collective Activities

GENERAL INTRODUCTION

The present protocol is called LETUCA for: Longitudinal Evaluation of Teams via Unknown and Collective Activities. Twelve collective exercises accessible for non-specialized participants compose the LETUCA protocol. One is directly integrated from the literature, seven are adapted from the literature, and four are created for the LETUCA protocol. This protocol is designed by L'Haridon (2019) in order to collect data in the framework of his PhD, performed under the supervision of the ISAE-SUPAERO, the ONERA and the Research Center of the French air force Academy. The goal of this PhD is to study the evolutions and to enhance the teams' operational performance (L'Haridon, 2019) while coping with unknown failures¹ in the context of human space flights and more specifically toward Mars. Nonetheless, the LETUCA protocol can be reused beyond this work and particularly for researches founded on the Grounded Theory method (Strauss and Glaser, 1967) which aim for "gathering and analyzing data to generate middle-range theory" (Charmaz and Henwood, 2008). Moreover, few exercises in the literature deal with performance measurements. Then, the goal of this method is to provide the research community with all the necessary elements to reproduce the LETUCA protocol or make it evolve.

According to the goal of the PhD of L'Haridon (2019), the LETUCA protocol is designed to trigger situations for which participants can work like space crews and more broadly like operational teams. However, potential participants are not requested to follow any space training; then, they can only have a low level of knowledge and skills about space flight exploration. Thus, the LETUCA protocol is designed to be a low-fidelity simulation. Nonetheless, in keeping with Weaver and al. (2010), the low-fidelity simulations "can be high in cognitive fidelity" for initial trainings of an activity. So, despite this low-fidelity simulation, numerous characteristics of human space flights and operational contexts can be integrated into the LETUCA protocol, even if the scenario of an exercise is not space-related. Particularly, the exercises of the LETUCA protocol demand, of the participating teammates, skills needed to solve problems, the respect of assigned functions and the treatment of information given to each function.

The working environment is set as identical as possible for all the teams. Then, all the participants base their interactions and in fine their decision on a common initial state. Thus, the operational performance results should only differ according to each teamwork. To obtain identical working environment for all the teams during problem resolutions, the LETUCA protocol can be organized in laboratory environments so that the researcher can control a maximum number of parameters.

As defined, the LETUCA protocol must enable the measurement of the operational performance of participating teams. Once these operational performance data are gathered, they need to be treated. Indeed, the data can be measured with different natures, in fine time, points or the two in a single exercise. Then, mathematical treatments must be defined. In addition, the LETUCA protocol was designed to enable a comparison of all the operational performances one another. Thus, despite the specificities of each exercise, a complete comparison must be executed thanks to a last mathematical treatment, called the "General relativity".

Nonetheless, the interest of the LETUCA protocol is not limited to the operational performance measurement. Indeed, video and audio recordings can be performed during the problem

¹ An unknown situation is defined as previously neither expected nor experienced (L Haridon, Chaudron, Marchand, and Gourinat, 2017).

resolutions. While teammates are working on exercises, the interactions can be used to study verbal and nonverbal exchanges.

PART I: THE PROTOCOL LETUCA

Introduction

Teams are ubiquitous. Whether we are talking about software development, Olympic hockey, disease outbreak response, or urban warfare, teams represent the critical unit that “gets things done” in today’s world. (Marks, 2006, p.1)

Several definitions of teams exist in the literature (for instance Salas, Dickinson, Converse, and Tannenbaum, 1992; Katzenbach and Smith, 1993; Anzieu and Martin, 1968). Dealing with space flight crews performing a mission toward Mars, the definition of L’Haridon (2019) is selected for the design of the protocol LETUCA and is based on:

- A restrained ensemble of two persons or more,
- That can feel emotional, affective and solidary attachments, that can become intensive among the members,
- That interact dynamically, interdependently, and with resilience,
- Via norms, beliefs, and signals that may become specific to this team,
- Toward a common goal, and
- All teammates have been assigned specific purpose or functions
- In order to be performant.

Researches about teamwork can demand the observation of teams while they are solving problems (for instance: L Haridon, Chaudron, Marchand, and Gourinat, 2017). In operational environments, unknown problems might happen, they are defined as neither expected nor experienced (L Haridon et al., 2017). These events could threaten the safety of an operational mission because of the lack of knowledge or solutions to solve them. L’Haridon (2019) provides a list of thirteen operational events and one probable considered as unknown. The protocol LETUCA, for Longitudinal Evaluation of Teams via Unknown and Collective Activities (L’Haridon, 2019), provides tools to complete researches about teamwork and especially about unknown problems resolutions. Twelve collective exercises compose the protocol LETUCA and seven of which are unknown problems. The twelve exercises

- last less than thirty minutes
- are executed without any training previously performed by the participants
- necessitate office equipment².

The measurement of the capacity of teams to solve or not a problem enables to evaluate the quality of the related training, relevance of methods, equipment, and select teammates for operational missions. This capacity of teams to solve or not a problem can be measured via the operational performance. Defined by L’Haridon (2019), the operational performance measures the achievement degree according to an assigned task. To test the hypotheses of L’Haridon (2019), each exercise of the protocol LETUCA is designed to measure the operational performance.

² The needed equipment is described for each exercise in the Part II.

Chapter 1: Generalities of the LETUCA protocol

The LETUCA protocol and its twelve exercises were designed and used within the framework of the PhD of L'Haridon (2019). They were employed to test the performance and the metacognition of three stable teams for twenty months. During this period, the teammates of each team lived together or not diverse and quality experiences. Thus, the LETUCA protocol enabled to measure the evolution of the performance and the metacognition depending on common or individual experiences. Over this twenty-month period, one exercise was organized every fifty days in the order presented in the Part II of this method. Nonetheless, the LETUCA protocol can be considered as twelve independent collective exercises. One exercise every fifty days over a twenty-month period were sufficient to test the retained hypotheses (L'Haridon, 2019); so, the number of exercises composing the protocol LETUCA was limited to twelve. This number also permitted to maintain diversified enough scenarios; then, the possibilities to transfer resolution methods from one exercise to another were limited. Indeed, no standardized ways to treat two or more problems were produced, each exercise having its single method of treatment. Familiarization and lack of surprise were avoided from the conception and/or selection of the exercises: the performance measurement, the context, the reasoning, etc. vary.

In addition to a single treatment method per exercise, the exercises of the LETUCA protocol are divided into two categories as suggested by Baiwir and Delhez (2004) and Breuker (1994). Indeed, these authors suggested a parameter to distinguish problems, they “can be characterized by their (minimal) solutions, i.e. their generic conclusions.” (Breuker, 1994). The exercises of the LETUCA protocol have different goals; thus, it is possible to discriminate one problem from another. Some have goals consisting in gathering results without any relationship among one another. They are called gathering exercises. Other problems demand the construction of one or several interdependent results. This second category is called construction exercises.

Moreover, due to environmental constraints³ needed to execute the protocol LETUCA, all the exercises had to meet the following specificities and were designed accordingly:

- exercises duration below thirty minutes,
- difficulty level high enough so as to spread out performance results all along the associated scale,
- difficulty level low enough so as not to create too much difficult exercises for non-specialists,
- no initial knowledge is demanded.

Three different origins were needed to design twelve diversified enough exercises meeting the previous constraints:

- four exercises were completely created for the LETUCA protocol,
- seven exercises were adapted to meet the specificities of the LETUCA protocol, and
- one was directly extracted from the literature.

The order presented in the Part II of the LETUCA protocol method was designed to alternate difficulties, unknown problems, interfaces, types of scenario, etc. in order to test the hypotheses of L'Haridon (2019). This order should be adapted according to future research problems.

³ The participants to the PhD of L'Haridon (2019) had busy schedules, an absence of space training, and diversified backgrounds.

1. LETUCA: a protocol designed to make teams solve unknown problems

As already used by Prichard, Bizo, and Stratford (2011), problem solving, decision making, and planning highlight team skills during collective exercises. The definition of the problem to solve, the way a team might find out a solution, and the selection of relevant information are examples of tasks demanded by the LETUCA protocol.

Since the LETUCA protocol is designed to make teams cope with unknown problems, L Haridon et al. (2017) analyzed unknown problems lived in real and operational conditions. These authors (2017) defined an unknown situation as “neither expected nor experienced”. It also means that a crew facing an unknown problem knows the context but has no procedure to solve this abnormal event initially. Indeed, operational crews are aware of their position, the status of the vehicle (aircraft, spacecraft for instance), the remaining time to complete the mission, the available equipment, etc. However, as soon as an unknown problem happens, crews have nothing to follow because the problem is “neither expected nor experienced” (L Haridon et al., 2017). The translation of this situation into the LETUCA protocol consists to inform the teams of a context but without any guidelines. So, the participants in the LETUCA protocol do not know initially how to proceed.

Nonetheless, to make teams work on problems without giving any guidelines includes a risk: the teams might not understand the problem to solve and could not proceed as expected by the researcher. In that case, the experience is not as valuable as a good understanding of the task to perform. Indeed, the goal of the LETUCA protocol is to discriminate performance levels according to a common task. If one team works on the prepared problem and another one on an off-topic problem, the performance scale will respectively present a high score and a low one. In this case, the performance measurements exclusively represent the initial orientation of the teams’ thinking and not the whole problem treatments. A protocol centered on the initial understanding of problems can only analyze the performance on the initial treatment step and does not need the teams to complete a full problem resolution. On the contrary, the LETUCA protocol aims to reproduce teamworks while coping with complete problem resolutions; hence, the need to gather data relative to complete treatments and to avoid misunderstandings of problems. The unknown exercises of the LETUCA protocol are designed to be easy enough so as to decrease risks of misunderstandings by teams.

Unfortunately, opportunities to create a problem without any guidelines and with a context easy enough to decrease risks of misunderstandings are rare. So, five in twelve exercises do not meet the unknown qualification⁴.

2. One function per teammate

The initial goal of the LETUCA protocol is to test the hypotheses of L’Haridon (2019) linked to space flights; so, this research (L’Haridon, 2019) observes the teamwork in a space flight context. It implies that the participants in the LETUCA protocol must act according to distributed functions or roles like in real operations; e.g. a real commercial flight crew is composed of a captain and a copilot. More broadly, several advantages of role plays used for teamwork training were highlighted by Beaubien and Baker (2004). The interests are minimal resource investment needed especially on large scales, well received role plays by trainees (Beaubien & Baker, 2004), and then poor participant’s reactions might be avoided.

⁴ The distribution is described in the Part II.

Each teammate receives a function at the beginning of an experience of the LETUCA protocol. All these functions are most of the time a captain, a copilot and two astronauts⁵. The distribution of these functions among participants enables:

- The organization of a maximized turnover in order to take into account the constraints of the participants if a longitudinal research is conducted. Indeed, it is possible to balance the number of times each teammate holds each position. Moreover, the teammates develop less habits when holding a specific function and need a continuous adaptation all along their participation to the LETUCA protocol. This adaptation to the functions is relevant with an unknown situation requiring to cope with a failure neither expected nor experienced (L Haridon et al., 2017).
- To limit the teammates' mental projection that could be performed to optimize a specific function. Indeed, since the teammates receive their function few seconds before the beginning of an experience, the participants only have these few seconds to adapt themselves. This distribution of the functions without any notice takes part in the surprise effect.

3. Limited duration of the exercises

Like in real operations, time can be a part of a problem solution. For instance, if pilots experience an aboard fire during a flight, they must land the aircraft as soon as possible; the time is a key factor to solve the problem. Prichard, Bizo, and Stratford (2011) highlight the time management as a team skill. Thus, the LETUCA protocol supplies unknown problems with time constraints (L'Haridon, 2019). Moreover, despite the teammates participate voluntarily to the LETUCA protocol, their respective schedules are dense and so, must not be excessively impacted due to a too long duration of the exercises. At the opposite, in the context of team trainings, Prichard, Stratford, and Hardy (2004) insist on the need of long enough training: "the length of training is likely to be important because new skill proficiency will clearly be related to the opportunities a person has to practise new skills." Thus, a trade-off between a too long time and a too short time to trigger teamwork was established according to the literature dealing with teamwork experiences:

- Baker, Gustafson, Beaubien, Salas, and Barach (2005) made surgical teams work on anesthesia crisis resources management with forty-five-minute scenarios,
- Cooke, Gorman, Duran, and Taylor (2007) and Gorman, Cooke, and Amazeen (2010) studied the work of teams for forty-five minutes while performing a reconnaissance mission with a drone simulator (pictures acquisition),
- Gurtner, Tschan, Semmer, and Nägele (2007) studied the "reflexivity intervention on the team process and on performance in hierarchically structured (...) on a simulated team-based military air-surveillance task" during sessions of fifteen minutes,
- Prichard, Stratford, and Bizo (2006) asked teams to establish a twenty-eight-question list dealing with schizophrenia for fifty minutes; afterwards these questions enable a performance measurement.

Thus, the selected maximum duration for the exercises of the LETUCA protocol is thirty minutes.

⁵ The functions are described in the Part II.

4. Experiences organized in a laboratory

The LETUCA protocol is designed to enable the comparison of teams' performance during experiences. So, teams must work in environments as identical as possible between each other. The environmental characteristics that should be kept identical by the researcher are the experience time, equipment, data, workspace configuration, introduced constraints, and the presence and location of the researcher (L'Haridon, 2019). The laboratory and its environment can fulfill these conditions. Nonetheless, laboratory environments are not real contexts and provide a reduced specter of choices (Debanne, 2013). Indeed, if working conditions vary, results will probably be different. For instance, Baiwir and Delhez (2004) highlight that "precise experiences have shown that the only presence of observers modifies behaviors of participants, and so the group performance" (our translation). The presence of the researcher is mandatory so as to execute the experiences according to the experimental constraints; however, no other persons should be welcomed during experiences. More broadly, the respect of identical conditions should enable to limit the introduction of bias during the LETUCA protocol (L'Haridon, 2019).

Accordingly, the LETUCA protocol is not designed to apply an ecological approach that "translates the attention to the environmental awareness in order to understand the behaviors a person develops to adapt him•herself" (our translation, Valot, 1998).

5. Low-fidelity exercises

The LETUCA protocol was not designed to fully reproduced space flight problems with realistic technical facts (L'Haridon, 2019). "After all, effective training is clearly not synonymous with full mission simulation" (Beaubien & Baker, 2004). Certainly, Beaubien and Baker (2004) discuss about trainings in this quote in comparison with the LETUCA protocol focused on task executions. Nonetheless, the LETUCA protocol makes teams work in a context similar to team training (gathering of the teams, execution of a nonreal task, and performance demand for instance). Moreover, participants do not have the skills and knowledge to treat an actual space flight scenario; hence, the elaboration of simplified problems. The Lunar Survival exercise (Hall & Watson, 1970) is famous and represents this dynamic. The scenario of Lunar Survival can be understood by the largest number of participants, enables a collective thinking and a performance measurement. Weaver and al. (2010) argue that low-fidelity simulations used for team training programs in health care "can be high in cognitive fidelity; (...) they stimulate trainees to engage in the same cognitive processes necessary when transferring and generalizing new skills into their daily work environment". As remarked by Beaubien and Baker (2004), "psychological fidelity is the most important for teamwork skills training" compared to equipment fidelity and environment fidelity. Cannon-Bowers and Bowers (2010) formulate the quote of Weaver and al. (2010) differently but sustain it: a simulation can deal with the structure of the task of a problem and the involved cognitive processes without any physical aspects. This low-fidelity is highlighted "to maximize the initial learning of teamwork skills" (Beaubien & Baker, 2004); thus, this initial learning is also relevant for space flight crews at the beginning of their training. Sundar and al. (2007) support these words of Beaubien and Baker (2004) and suggest possible types of exercises "such as case studies and role plays" (Sundar et al., 2007). Taking into account the potentially low experience of space flights among participants of the LETUCA protocol, if the participants took part in a human space flight training, they will begin it at the initial learning steps, in consistence with Beaubien and Baker (2004).

Beyond the relationship with the experience of space flights participants might have, “low-fidelity simulation tasks are recommended over high-fidelity simulations to support objectivity and reliability because it mitigates confounding effects stemming from task familiarity” (Landon, Rokholt, Slack, and Pecena, 2017). Then, low-fidelity simulations diminish the familiarity linked to known situations. Thus, a participant should encounter a higher difficulty to extract a useful familiar experience for an exercise, hence a stimulation to find new solutions specific to an unknown situation.

Low-fidelity simulations can also “isolate competencies of interest” (Landon, et al., 2017). As presented by L Haridon et al. (2017), an unknown situation was neither expected nor experienced. Thus, when encountering such a situation, teammates should find a solution to a new problem and then they should adapt themselves. Then, low-fidelity simulations could isolate the adaptation competency.

Finally, low-fidelity simulations are relevant to study teamwork while coping with unknown situations.

6. Flowchart of the creation of the LETUCA protocol

The following flowchart (cf. figure 1) presents the method to create the exercises of the LETUCA protocol in order to apply the above necessary specificities (L’Haridon, 2019).

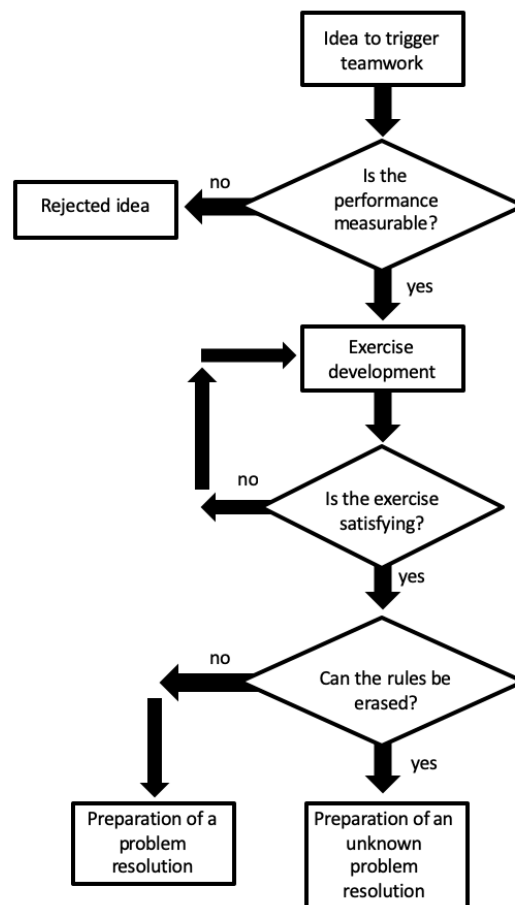


Figure 1. exercise creation flowchart

Conclusion

The LETUCA protocol supplies twelve problems mainly dealing with space flight and unknown situations so as to spark teamwork (L'Haridon, 2019). These problems are simple enough to be solved by non-specialists and are organized with affordable equipment. Some problems are fully designed for the LETUCA protocol, some others are adapted from the literature, and one is implemented from the literature without any modification. These adaptations or the complete creations enable to design exercises diversified enough in order to preserve as much as possible the surprise effect and the unknown character of the exercises. Then, potential transfers of solutions from one problem to another are diminished.

The table 1 synthesizes the qualification of unknown and the origin of each problem.

Exercise	1. Lunar survival	2. Mercury 21	3. Missionaries	4. Bag and the Euro	5. Untangle	6. Fire procedure
Unknown problem qualified?	no	yes	no	yes	yes	yes
Origin of the problem	Hall and Watson (1970)	Adapted from Énigme-facile	Adapted from Énigme-facile	Adapted from Davidson, Deuser, and Sternberg (1994) and Énigme-facile	Adapted from KECHAP FREE GAMES LIMITED	Designed for the protocol LETUCA
Exercise	7. Electrical system	8. Mars report	9. Asteroid avoidance	10. Mars Drone pilot skills	11. Docking port relocation	12. Monument Valley
Unknown problem qualified?	yes	no	yes	no	no	yes
Origin of the problem	Adapted from Leavitt and Mueller (1951)	Designed for the protocol LETUCA	Designed for the protocol LETUCA	Designed for the protocol LETUCA	Adapted from Baroncini (2012)	Adapted from Ustwo (2014)

Table 1. synthesis of the exercises of the LETUCA protocol

Chapter 2: Operational performance measurement

The LETUCA protocol provides exercises to make teams work, the outcomes of which supply an operational performance. This operational performance measures the achievement degree of an assigned task (L'Haridon, 2019). According to the diversity of exercises, operational performances can be based on one or several steps of a single exercise and measured on various dimensions. These dimensions can be a time (as suggested by Noe, Dachner, Saxton, and Keeton, 2011), a number of points or a combination of these two types of data. Then, depending on their composition, these operational performances could be incomparable. Thus, an initial treatment of the result(s) per exercise can be needed to extract one operational performance result of the participating teams. Except for the exercise of Hall and Watson (1970), directly integrated in the LETUCA protocol, no performance measurement methods relevant for the present exercises were found in the literature to initially treat the results. So, performance measurement methods for each problem were designed in the LETUCA protocol. Linked to a specific problem, this is the first step of the measurement of the operational performance.

Despite the various dimensions of the operational performance and the existence of one operational performance result per exercise, the protocol must enable the comparison of the teams' results all along the LETUCA protocol⁶. Thus, a second step of the measurement of the operational performance is needed in order to cancel the dimensions of the operational performances, so the results of the teams during each exercise can be compared to another one.

⁶ If the full LETUCA protocol is employed for a future research.

1. First step of the measurement of the operational performance

An operational performance measurement is built for each exercise of the LETUCA protocol (L'Haridon, 2019). Indeed, the operational performance are based on three units, i.e. a time, a sum of points or composition of times and points. The nature of the measurements being different, it is not possible to create a unique formula to calculate all operational performances. Specific technics are needed to quantify the operational performance of some exercises, e.g. the open performance and the proportionate point method. Then, a first step of the measurement is needed to extract the operational performance of each exercise. Thanks to this step, the operational performance results can be calculated systematically and compared to one another for a single experience.

1.1. Operational performance measurement described in the guidelines

The protocol LETUCA is designed to correspond to real unknown failure cases, then, the teams must be aware of the operational performance measurement. Indeed, an actual and expert crew experiencing an unknown failure should be familiar with the way he could be performant or more precisely, get a high operational performance. The elements of the context and the environment orientate the potential outcomes of the situation. According to the degree of risks on human lives and equipment, a satisfying result could be focused on the initial mission and/or on the mere survival of the crew. For example, following the explosion aboard the Apollo 13 vehicle, the crew and all the ground staff focused on an operational performance depending on the survival of the crew and only then on the completion of the initial mission. If this explosion belonged to the LETUCA protocol, the operational performance would be measured on the effective survival of the crew. Since the teams of the protocol LETUCA are not space experts, they are trained and do not know neither the context nor the environment before the exercise. Thus, the teammates need informing of the operational performance to reach a closer level of operational awareness. So, the organizer describes the operational performance measurement without giving any specific details (L'Haridon, 2019). For example, for UNTANGLE exercise of the LETUCA protocol, the participants must complete the problem with a minimum time.

1.2. Open versus closed performance

In specific exercises, it is not possible to anticipate all the possible answers. According to the established guidelines⁷, the specter of possible responses is too wide to be exhaustively anticipated. Thus, an anticipated⁸ list of possible answers can exist, but it remains non-exhaustive. Indeed, supplementary answers can be found by the participants while they respect the guidelines of the related exercise. Then, these new answers have to be included in the operational performance measurement. So, the final operational performance result of a team exclusively depends on the total validated responses and not only on the anticipated list. Finally, two cases exist:

- If a team only thinks about the answers included in the anticipated list, no performance updates will be highlighted,
- If a team chooses an answer not included in the anticipated list, the researcher will study this answer so as to evaluate its concordance or not to the guidelines. If the answer

⁷ The guidelines must be precise enough, so no doubt is possible among potential answers.

⁸ In other words, a list established by the researcher before the beginning of the exercise.

matches the guidelines, the team will score one point; if it does not, this answer will be rejected.

For example, teams can find as many functions of an object as they can⁹. The researcher can anticipate a list with possible answers; however, it is time-consuming, useless for the operational performance measurement, and probably impossible. Without expecting the answers, the researcher only checks if the answers match with the constraints established in the guidelines. So, the results come from the functions found by the teams.

The performance of these exercises is called open performance (L'Haridon, 2019). The researcher determines guidelines and rules to evaluate the answers and could anticipate some of the potential responses. If new answers are selected by participants, these answers will be analyzed by the researcher regarding the established guidelines. Finally, these new answers can be added or not to the previous anticipated list.

1.3. The proportionate point method

1.3.1. Employment rules

The method of the proportionate point (L'Haridon, 2019) is used to compare the operational performances of teams while they are treating a problem:

- with at least two steps and
- at least one step of which might not be finished by at least one of the participating teams.

This technique is based on the mathematical ratio between two operational performance results for each step. Moreover, this method enables teams to progress according to their own pace, to finish different numbers of steps¹⁰ and finally to perform a calculation of the teams' operational performances. To measure each step operational performance, the proportionate point method necessitates a first constraint:

- (1) The lower the value of a result is, the higher the associated operational performance is.

For instance, a team must solve a problem with the minimum time. Two other constraints are needed:

- (2) The teams have to execute all the steps of the problem in the same order.
- (3) The teams move from one step to the next one only when the previous one is completed.

If these rules are not respected, teams could treat different steps and obtain results coming from various subproblems; thus, these operational performances based on different problems are not comparable. For instance, with an exercise composed of ten subproblems and with instructions without any standard order of completion; one team could work on the first five subproblems while another team could work on the last five ones. In this instance, the results are based on different sub-problems and are not comparable one another. So, it is necessary to force the teams to follow a standard order so as to compare the results.

⁹ e.g. the exercise Bag and the Euro of the LETUCA protocol

¹⁰ One team could finish more steps than another one.

1.3.2. Employment method

The raw performances are the results directly measured during the execution of each step of an exercise; no mathematical treatments are performed to determinate the raw data. A raw performance can be a time, a number of points. The raw performances of all the steps of a problem are real numbers and are the input data of the proportionate point method.

Set N , the number of steps included in the complete problem providing an operational performance measurement thanks to the proportionate point method, where $N \in \mathbb{N}^*$. For the step called n , where $n \in \llbracket 1, N \rrbracket$, for a total of $m + 1$ teams, where $m \in \mathbb{N}^*$, the best raw performance for the step n is considered to be the reference for this step and is called Ω_n . The raw performance of the other teams are called: $\Omega_{n,1}$ for the team number 1, $\Omega_{n,2}$, for the team number 2, $\Omega_{n,3}$, for the team number 3 ... $\Omega_{n,m}$ for the team number m , so that $\Omega_n \geq \Omega_{n,1} \geq \Omega_{n,2} \geq \Omega_{n,3} \dots \Omega_{n,m}$. Then, the numbering of the teams varies according to the measured raw performances of the considered step. The result of a specific team calculated via the proportionate point method is the division of the best raw performance by the raw performance of this specific team of the same step n :

The team (called M) with the best performance for the step n : $P_{n,M} = \frac{\Omega_n}{\Omega_n}$

So, for the best team M : $P_{n,M} = 1$

For the team number 1, the proportionate result is: $P_{n,1} = \frac{\Omega_n}{\Omega_{n,1}}$

With $P_{n,1} \leq 1$, for the team number 1.

For the team number 2, the proportionate result is: $P_{n,2} = \frac{\Omega_n}{\Omega_{n,2}}$

With $P_{n,2} \leq P_{n,1}$, for the team number 2.

For the team number 3, the proportionate result is: $P_{n,3} = \frac{\Omega_n}{\Omega_{n,3}}$

With $P_{n,3} \leq P_{n,2}$, for the team number 3.

Etc.

For the team number m , the proportionate result is: $P_{n,m} = \frac{\Omega_n}{\Omega_{n,m}}$

With $P_{n,m} \leq P_{n,m-1}$, for the team number m .

If a team called m does not solve the step called n , then the associated raw performance $\Omega_{n,m}$ is not measured. Nonetheless, this failure of the team m has to be considered to value the operational performance of the other teams that succeeded this step n . So, a fictive $\Omega_{n,m}$ must

be integrated at the lowest raw performances, then, with the highest values (whatever the dimension of the measure)¹¹. To do so, the result of the step n is defined by:

$$P_{n,m} = \frac{\Omega_n}{\Omega_{n,m}}$$

Then, a failure of the team m to the step n implies that $\Omega_{n,m}$ tends to the highest values:

$$\lim_{\Omega_{n,m} \rightarrow +\infty} P_{n,m} = \lim_{\Omega_{n,m} \rightarrow +\infty} \frac{\Omega_n}{\Omega_{n,m}}$$

And so:

$$\lim_{\Omega_{n,m} \rightarrow +\infty} P_{n,m} = 0$$

Thus, when the team m does not solve the step n:

- $\Omega_{n,m}$ tends to infinity, meaning a low operational performance and
- The operational performance is forced to: $P_{n,m} = 0$

Finally, for the team called i, where $i \in \mathbb{N}^*$, for a complete problem, the operational performance is called P_i and the result of the step n is called $P_{n,i}$. Two cases exist:

- (1) If one or more n exist(s) such as $\Omega_{n,i} = +\infty$ (step not completed), so:

For each n with $\Omega_{n,i} \neq +\infty$, in other words, for the succeeded step(s):

$$P_{n,i} = \frac{\Omega_n}{\Omega_{n,i}}$$

For each n with $\Omega_{n,i} = +\infty$, in other words, for the step(s) unsolved:

$$P_{n,i} = 0$$

- (2) If for all the n, we have $\Omega_{n,i} \neq +\infty$, in other words, all the steps are succeeded, so:

$$P_{n,i} = \frac{\Omega_n}{\Omega_{n,i}}$$

Finally, for the two cases:

$$P_i = \sum_{n=0}^N P_{n,i}$$

To sum up, the proportionate point method consists in establishing a division between the best raw performance by the raw performance of a specific team for a single step of a common problem and then, to sum these divisions for all the steps performed by this specific team. This method demands the three following conditions:

- The lower the value of a result is, the higher the associated operational performance is,
- The teams have to execute all the steps of the problem in the same order,

¹¹ hence the above constraint (1).

- The teams move from one step to the next one only when the previous one is completed.

1.4. Method of the integrals

1.4.1. Employment rules of the method of the integrals

The method of the integrals is used in the LETUCA protocol to calculate an operational performance based on two measures of different natures of an exercise composed with several steps (L'Haridon, 2019). Three rules characterize the method of the integrals.

- (1) The teams can execute the steps of the exercise in the order they want.
- (2) The steps do not have the same weight for the operational performance calculation. So, the resolution of a step can give a higher quantity of points than another step depending on their influence on the complete treatment. For example, during a human space flight, a major oxygen failure is more vital than a breakdown of an entertainment system; thus, the complete treatment of the major oxygen failure is underlined with an increased weight.
- (3) Furthermore, in specific cases, the time to solve a failure also determine the operational performance. Indeed, a failure might have to be treated before other failures depending on their influence on the complete treatment. For instance, during an operational human space flight, a major and vital oxygen failure should be treated before a breakdown of an entertainment system. Then, the operational performance measurement must take into account the times of the resolution of the different steps so as to discriminate the prioritizations established by the participants.

1.4.2. Employment of the method of the integrals

The two elements employed to calculate the operational performance via the method of the integrals are the weights, i.e. this quantity of points, and the time needed to complete the treatment of each step. Thanks to these two parameters, a curve per team is built with along the abscissa axis the time and along the ordinate axis the evolution of the number of points. As soon as a team completes the resolution of a failure, the associated curve rises of the number of points granted for this failure (ordinate axis) at the time of the resolution (abscissa axis). Thus:

- The faster a team solves the failures of decreasing importance, the higher and the faster is the value of the curve, and
- The slower a team solves the failures of increasing importance, the lower and the slower is the value of the curve.

Beyond the visual analyze of the teams' operational performances, the integral of each curve is calculated¹². Then, the value obtained corresponds to the measured operational performance. So, a high result is expected if a team treats the steps of the complete problem in the order of decreasing importance and as fast as possible. Thus, the differences among teams are observable.

Finally, the method of the integrals:

- Enables to calculate an operational performance regardless of the processing order of the steps of a problem,

¹² In practice, the integrals are calculated on the base of the sum of the areas of the rectangles and triangles placed between the abscissa axis and the corresponding curve.

- Necessitates to establish a weighting for each step,
- Necessitates to take into account the resolution time of each step,
- Enables to compare operational performances with two dimensions via a single indicator.

1.4.3. The method of the integrals applied to one exercise

The exercise Mercury 21 (L'Haridon, 2019) meets the specificities of the method of the integrals, hence its use. For instance, the figure 2 highlights the three curves¹³ obtained by L'Haridon (2019) during the execution of three Mercury 21 experiences.

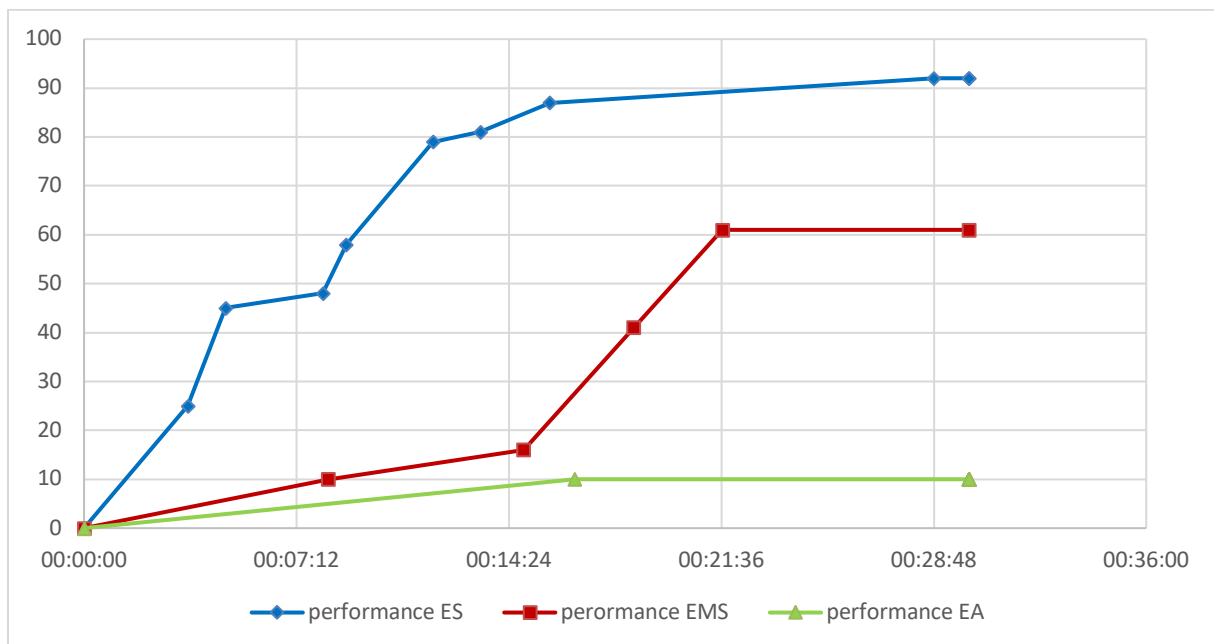


Figure 2. results of L'Haridon (2019) thanks to the Mercury 21 exercise

2. Second step of the measurement of the operational performance

The nature of the operational performances of the exercises of the LETUCA protocol (i.e., time, points or a combination of the two units) and the range of the obtained values do not permit their direct comparison between each exercise. For example, an exercise measuring the teams' capacity to solve a problem as fast as possible is not comparable to another exercise measuring a number of scored points. Nonetheless, the results of the teams are comparable one another for a single exercise. So, the results are compared per exercise and not between each exercise (first step of the measurement of the operational performance). This relativity of the results per exercise is the basis of the tracking of the discrepancies among teams throughout the protocol LETUCA. Indeed, the result of each team is divided by the one of a team used as a reference¹⁴ for the complete protocol, both results belonging to the same exercise. Thanks to this division,

¹³ In the figure 2, one curve presents the results of the team called ES, one for the team called EMS, and one for the team called EA.

¹⁴ The selection of a specific team compared to another cannot modify the relativity of the final operational performances. Nonetheless, it might be advised to use the less performant team as the reference in order to obtain positive values (located above the abscissa axis) of the final operational performance.

there is no more unit (a time divided by time has no unit for instance) and all the performance results are dimensionally homogeneous. Then, all the teams obtain final results relative to a single team used as a reference (L'Haridon, 2019), hence the name of this method: the "General relativity". The General relativity is the second step of the measurement of the operational performance. In fine, the construction of a curve of operational performances per team is built to highlight the evolutions relatively to the other teams.

The General relativity is calculated for each team thanks to the following formula. We set the figures:

- E_i : the experience i , where $i \in \llbracket 1, N \rrbracket$, with N the total number of experiences, $N \in \mathbb{N}^*$
- f_i : the function giving the result of the teams for the experience i
- $P_{i,j}$: the result of the team j for the experience i , where $j \in \llbracket 1, M \rrbracket$, with M the total number of teams participating to the LETUCA protocol, $M \in \mathbb{N}^*$
- The team selected as a reference is called: $j = \text{Ref}$.

The function of the General relativity f_i is defined on \mathfrak{R} by:

$$f_i(P_{i,j}) = \frac{P_{i,j}}{P_{i,\text{Ref}}} - 1$$

Then, the team selected as a reference (Ref) is constantly on the abscissa axis. For a given exercise, if a team has a better operational performance than the reference team, the associated result is placed above the abscissa axis, in other words, above the reference team. For a given exercise, if a team has a worse operational performance than the reference team, the associated result is placed below the abscissa axis.

To sum up, the General relativity necessitates to measure operational performances for a single experience and then, to calculate the relative results of teams compared to a reference one. Throughout the LETUCA protocol, the General relativity formula executes this calculation and then enables the analyze of the evolutions of the teams' operational performance despite the variety of the exercises.

Conclusion

The LETUCA protocol is designed to make teams work on unknown problems so as to generate and compare the related operational performance measurements. In order to meet as far as possible the specificities of an operational context, in fine a human space flight, different characteristics are introduced in the protocol. Indeed, all the participants have functions to follow so they are organized as a team (L'Haridon, 2019) and they have a limited time to solve the exercises. Moreover, the participants could not be specialized in human space flight exploration. Then, to compensate this possible lack of space flight knowledge among participants, low-fidelity exercises are designed so as not to require any previous space flight training.

In order to compare all the operational performances among participating teams, the resolutions of the different problems demand identical experimental conditions. Then, the laboratory environment is selected to perform the LETUCA protocol.

Despite the various dimensions of the results, this comparison of all the operational performances is also achieved thanks to a two-step treatment of the performance data. The first step deals the performance data of each exercise taken into account individually. This step depends on the specificities of a single exercise and enables to calculate a single operational performance per team for a complete exercise. The second step divides all the results of the teams by the result of a reference team so as to obtain a relativity of the operational performances. Finally, all the operational performances of the teams can be analyzed in relation to one another along the LETUCA protocol.

PART II: EXPERIENCES DESCRIPTION

Introduction

Based on a limited time, the assignment of functions to the teammates, the calculation of an operational performance, and the feasibility for non-specialized participants in human space flights, twelve problems are designed and compose the LETUCA protocol (L'Haridon, 2019). One exercise is directly extracted of the literature, seven are adapted of the literature, and four are completely designed for the LETUCA protocol. Despite the various origins of the operational performance, in fine a time, a number of points, and a combination of these two dimensions, an operational performance measurement is available for each exercise.

In order to reproduce the LETUCA protocol, the present Part II presents all the details needed to organize the exercises or to modify them so as to meet new researches specificities. A few exercises are linked with annexes added to supply slides accessible to the participants or elements about the construction of the exercises.

Chapter 1: Lunar survival

Lunar survival is the single exercise directly extracted from the literature without adaptation to the particularities of the LETUCA protocol. Indeed, the required characteristics are included in the Lunar survival exercise of the literature. In an “unpublished dissertation” of Hall in 1963, this author presented the exercise “Lunar survival”, then published by Hall and Watson (1970).

1. Context

A crew has survived a crash of its space vehicle on the Moon surface. So, the astronauts must live through the consequences of the accident by ranging a three-hundred-kilometer distance to the main Moon base. To succeed, the crew has fifteen available objects in order to execute this trip. The required task is to rank these objects in order of decreasing importance according to the context. Two main goals may help this classification establishment, to survive on the Moon and to reach the main base.

2. Interest & specificities

Dealing with space exploration, the Lunar survival exercise enables to begin the LETUCA protocol with a space flight context. A major difficulty of this exercise is to begin the treatment of the problem by defining the two goals of the crew, i.e. to survive on the Moon and to reach the main base. Then, this metacognitive step (L’Haridon, 2019) permits to mentally represent the situation of the crew and the challenges the teammates must cope with. Thus, thanks to this reasoning, the teams can obtain practical elements so as to anticipate the hazards of such a situation. Finally, thanks to this mental representation, the teams can set priorities among objects, hence the establishment of the requested list of decreasing importance.

The specificities of Lunar survival are the need to precise the instruction of the problem into the two goals of the crew in order to mentally represent the execution of the mission.

3. Organization of the teammates

The experience is organized according to the figure 3.

The needed equipment is:

- Two Video Cameras,
- A Tripod for one camera,
- Unlimited Scrap Paper,
- Four pens.

The available time to work on this exercise was thirty minutes.

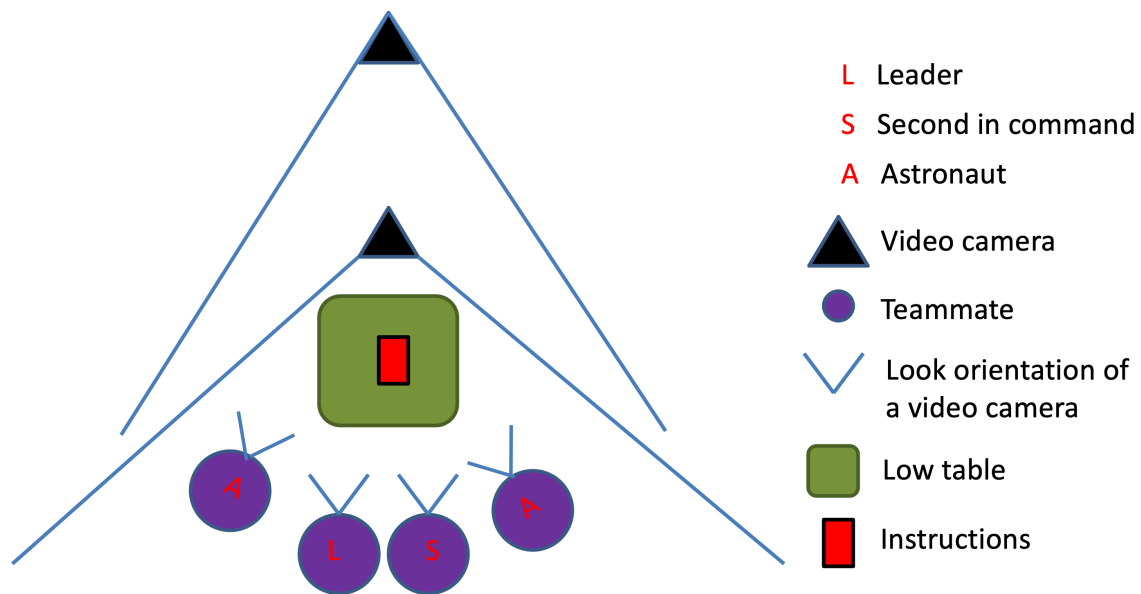


Figure 3. organization of the exercise Lunar survival

4. Elements presented to the participants

4.1. Text read to the teams

The first part of the read text is common with the other exercises of the LETUCA protocol: “I will not speak during the experience except to guarantee the rigor of the protocol. I will not comment your work to permit your own reflection. Please, turn off your cell phones in order not to be disturbed.

All the teams have identical guidelines; what I am reading currently. Please, stay seated while you are filmed so as not to leave the camera range.

The captain of the team is X, the second in command is Y, and you are astronauts (the organizer shows the two last teammates). The decision belongs to the captain. The captain of your team announces a “top” and simultaneously, launches the chronometer and takes the guidelines.”

The second part of the read text is specific to the present exercise:

“After thirty minutes of work, the exercise stops and you shall not touch the answer sheet anymore. Your result will be compared to the official one. You can use the scrap paper.”

4.2. Written instructions

“Scenario:

You are members of a spaceship scheduled to rendezvous with your mother ship on the lighted surface of the moon. Due to mechanical failures, you were forced to land your ship on a spot 320Km from the initial rendezvous point. It is vital for your crew to join the mother ship. During the landing, most of the equipment aboard was damaged except 15 items, listed below.

Your task is to rank the items in order of necessity. Place the number 1 near the most important item, the number 2 near the second most important and so on, through number 15 for the least important.

List of the items to rank:

- Box of matches
- Food concentrate
- 15m of nylon rope
- Parachute silk
- Portable heating unit
- Two .45 caliber pistols
- One case of dehydrated milk
- Two 50Kg tanks of oxygen
- Stellar map
- Self-inflating life raft
- Magnetic compass
- 20 liters of water
- Signal flares
- First aid kit, containing injection needles
- Solar-powered FM receiver-transmitter”

5. Operational performance measurement

The lists established by teams are compared to the one of Hall and Watson (1970). This reference was composed by a single expert of the “Crew Equipment Research Section of the NASA Manned Spacecraft Center in Houston, Texas” (Hall & Watson, 1970). This comparison of the teams’ results to a reference performance established by an expert corresponds to the works of Barnett and Koslowski (2002). Barnett and Koslowski (2002) retained the combination of two “super-experts” results that were experienced in the studied activity.

For Lunar survival, if the position of an item set by a team is different of the position selected by the reference expert (Hall & Watson, 1970), then the absolute value of the difference of the two ranks is memorized (the rank of the team and the one of the expert). All the absolute values of all the items are added, this final sum represents the final performance. The goal is to minimize this final sum, so a low value translates a high correspondence to the reference classification. For instance, if the bottles of oxygen are ranked fifth by a team and the reference result indicates the first position, then the final sum is incremented of the difference of the absolute value, i.e. four points.

The answer established by Hall and Watson (1970) is:

1. Two 50Kg tanks of oxygen
2. 20 liters of water
3. Stellar map
4. Food concentrate
5. Solar-powered FM receiver-transmitter
6. 15m of nylon rope

7. First aid kit, containing injection needles
8. Parachute silk
9. Self-inflating life raft
10. Signal flares
11. Two .45 caliber pistols
12. One case of dehydrated milk
13. Portable heating unit
14. Magnetic compass
15. Box of matches

Chapter 2: Mercury 21

1. Context

The space crew of the mission Mercury 21¹⁵ is approaching the Moon. The crew experiences an explosion aboard its vehicle like Apollo 13. The crews must react to multiple problems in order to preserve its life, the vehicle and the mission.

The cognitive problems are extracted from the internet website: Enigme-facile (our translation: Easy-enigma). As soon as an enigma is extracted from this website, the associated guidelines are adapted to comply with a space context. One of the enigmas has no relation with the context so as to force the teams to adapt themselves during the whole treatment.

2. Interest & specificities

Only the context is given to the teams, so, this experience is classified as unknown situation. According to the aboard explosion and this space flight toward the Moon, the mental representation of the context has a remarkable importance. Indeed, since different systems are impacted because of the explosion, the teams must evaluate the priority of these problems so as to survive. I.e., the teams must treat the most urgent and serious failure, then the second one and so on until the last problem. In other words, the problems must be treated via a logical thinking. This diversity of the failures also implies mental flexibility, creativity, and perseverance to complete the whole exercise.

Moreover, the teammates can be physically divided in two duos. One lies in the forward position and the second one in the aft one. Then, the teams can organize themselves in order to react more efficiently. Thus, two groups can be set to solve simultaneously more problems.

The specificities of Mercury 21 are an unknown exercise coupled with the prioritization of logical problems.

3. Organization of the teammates

The experience is organized according to the figure 4.

The needed equipment is:

- Two video cameras (one to record the four teammates and one for the treatment interface of the problems),
- A tripod for one camera,
- A computer for the treatment interface of the problems (cf. annex 1),
- The technical manual extraction printed on sheets of paper (cf. annex 2),
- A TV screen,
- A connection cable to display the interface of the problems on the TV screen,

¹⁵ Astronaut of the Mercury program of the NASA and first American to orbit the Earth, John Glenn (1921-2016) died a few days before the organization of this exercise within the framework of the LETUCA protocol executed by L'Haridon (2019), hence the name Mercury 21.

- Unlimited scrap papers with four pens.

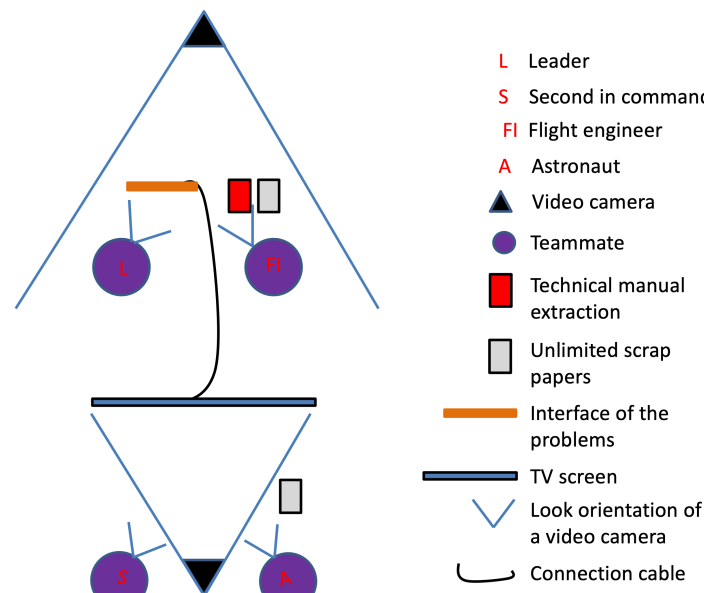


Figure 4. organization of the exercise Mercury 21

4. Elements presented to the participants

4.1. Text read to the teams

The first part of the read text is common with the other exercises of the LETUCA protocol (cf. the common elements presented in the Part II, chapter 1, paragraph 4.1).

The second part of the read text, specific to the present exercise, is:

“I request you to hide your watches. You do not have the time for this experience. You do not even know the duration of the problem.

An initial screen with all the failures will be presented; you currently see a demonstration screen with a single fictive failure. In order to display the failure and its associated treatment, just click on the corresponding button in the bottom part. In this example, only one failure is presented. This is the “water distribution failure” with the corresponding button: “WATER”. After having worked on a treatment, you need to go back to the initial screen with all the failures. You go back to this initial screen thanks to the green button in the bottom right corner of the screen. You can perform these actions with this screen if you want.

A brief extraction of the technical manual of the Mercury 21 spaceship is available on the sheets of paper in front of the flight engineer (the organizer shows the participant acting as a flight engineer). These sheets are mobile, just do what you want of it.

Your performance is measured on the way you react to the situation. You have thirty minutes. When you have a response, it is validated as soon as you present it to the camera, no need to write the responses.

The context:

You are the crew of the mission called Mercury 21. This mission consists in landing on the Moon surface to perform scientific experiments. After a three-day journey, you are approaching the Moon. An explosion happens aboard. You experience vibrations and noise; visual and noise warnings are triggered.

You can proceed to the next slide of the PPT.

Top”

4.2. Basic simulation interface

In order to make the teams work on the failure treatment interface, a simulation tool was designed with the software Microsoft Power Point. This simulation tool enables the participants to discover each problem in the way they want according to the context. The annex 1 presents the designed slides. The actual simulation tool available on a computer has links among the slides to enable the treatment of the problems in the order chosen by each team.

The annex 2 is the technical manual extraction of the vehicle of the mission.

5. Operational performance measurement

The operational performance calculation necessitates two indicators so as to take into account the space context of the exercise Mercury 21. Indeed, the teams must:

- Solve many failures,
- Take into account various priorities, so a specific order of the treatment is required and
- Work as fast as possible because of the specificities of the problems.

For instance, the major oxygen failure is much riskier than the video game one. Then, a unique result must translate this twin performance (order and speed of the treatment). To permit this unique result, on the one hand each failure is assigned a weight according to its level of risk and on the other hand, each treatment time of each problem is recorded during the experience. For example, the major oxygen failure has an important weight compared to the video game one. Thus, like the works of Hall and Watson (1970) and Barnett and Koslowski (2002, with only one expert for the present work), an expert¹⁶ determined the following classification is:

- 25/100 major oxygen failure O2
- 21/100 navigation system failure NAV
- 20/100 parachute deployment failure PARA
- 10/100 Moon landing system failure L/D
- 7/100 main engine failure ENG1
- 6/100 auxiliary electrical system failure ELEC2
- 5/100 heating system failure HTG
- 3/100 automatic pressure regulator failure AUT PR
- 2/100 3rd radio failure RAD3

¹⁶ The expert is L'Haridon (2019) on the basis of an operational reasoning.

- 1/100 entertainment system failure ENT

Thanks to these weights and the treatment times, one curve describes the evolution of each teams' work. Each curve is incremented of the weight of a problem (ordinate axis) at the time (abscissa axis) the related team solves this problem. Thus, the treatment speeds of the teams are taken into account and the height of each curve increases along the whole treatment according to the total number of problems solved (i.e. weights won).

Finally, to calculate the operational performance thanks to the quickness and the order of treatment, the method of the integrals is used (L'Haridon, 2019). The more rapid the treatments are and the less risky the resolution order is, the higher the operational performance is.

As described in the technical manual, if the oxygen problem is unsolved after 20 minutes, then the crew will be lost because of a lack of oxygen. This is the highest priority of all the failures.

Answers:

- O2: fill the 5-liter bottle and transfer the liquid in the 3-liter bottle. There are 2 liters still in the 5-liter bottle, transfer these 2 liters in the 3-liter bottle; this one misses 1 liter to be full. Fill the 5-liter bottle and complete the 3-liter bottle with 1 liter of the 5-liter bottle. Finally, you have 4 liters left in the 5-liter bottle.
Perform a similar reasoning, to complete the second problem of the O2 failure,
- NAV: A can determine his hat's color thanks to the answers of the others via a logical reasoning using deduction,
- PARA: from left to right, red, blue, green, red, green, blue,
- L/D: three implies six,
- ENG1: the solution is three links as presented in the figure 5,

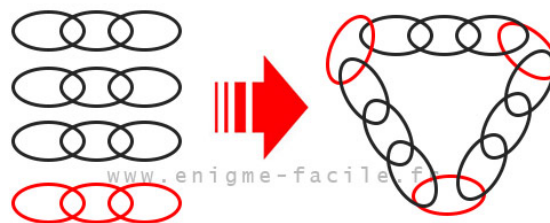


Figure 5. solution of the problem ENG1 (Énigme-facile)

- ELEC2: it possible to isolate the electrical wires thanks to the organization presented in the figure 6,



Figure 6. solution of the problem ELEC2 (Énigme-facile)

- HTG: a line is composed of six resistances; place one of these electrical resistances at the intersection of the two lines. Then, the participants must superimpose two resistances,
- AUT PR: Thursday,
- RAD3: the solution is $2581 = 2$, the teammates must count the number of closed loops in each figure. For example, 0 means 1, 2 means 0, 5 means 0, 8 means 2, and 1 means 0,
- ENT: taking into account that the first file is considered new at the instant of the beginning of the multiplication of the files:

$$1 \times 1 + 9 \times 18 + 28 \times 18^2 + 36 \times 18^3 + 16 \times 18^4 + 1 \times 18^5 = 3788371$$

Chapter 3: Missionaries and cannibals

1. Context

No context is imposed to the teams. The teammates have four letters located on the low tables. Each letter contains one problem of logic. Each letter has a number on it, from one to four. The participants must begin with the letter number one, then two, three and finally four.

The individual problems are well known on the internet. However, there logical sequencing is specifically designed for this protocol.

2. Interest & specificities

A logical sequencing is set to treat the problems composing the exercise Missionaries and cannibals. The teams begin the exercise with a hard problem (letter number one). Its goal is to set a sequence of actions respecting constraints. Then, the teams must focus on another problem (letter number two) without any links with the previous one. Afterwards, the teams must cope with a problem comparable to the first one (letter number three). Indeed, similarities exist but a constraint is taken off. So, this third problem is simpler than the first one. The participants can discover a quick solution if they adapt themselves to this new information arrangement. It enables the direct implementation of the solution of the first problem into the third one, in fine, this solution is the fastest one. The fourth problem is identical to the first one but with an additional constraint (letter number four).

Because of these multiple problems, the teams must exercise adaptation and perseverance during this exercise.

The specificities of Missionaries and cannibals are a mental flexibility necessary to treat several problems dealing with the construction of a sequence of actions respecting variable constraints.

3. Organization of the teammates

The experience is organized according to the figure 7.

The needed equipment is:

- Two video cameras,
- A Tripod for one camera,
- Four closed letters with the associated problems,
- Unlimited scrap paper with four pens.

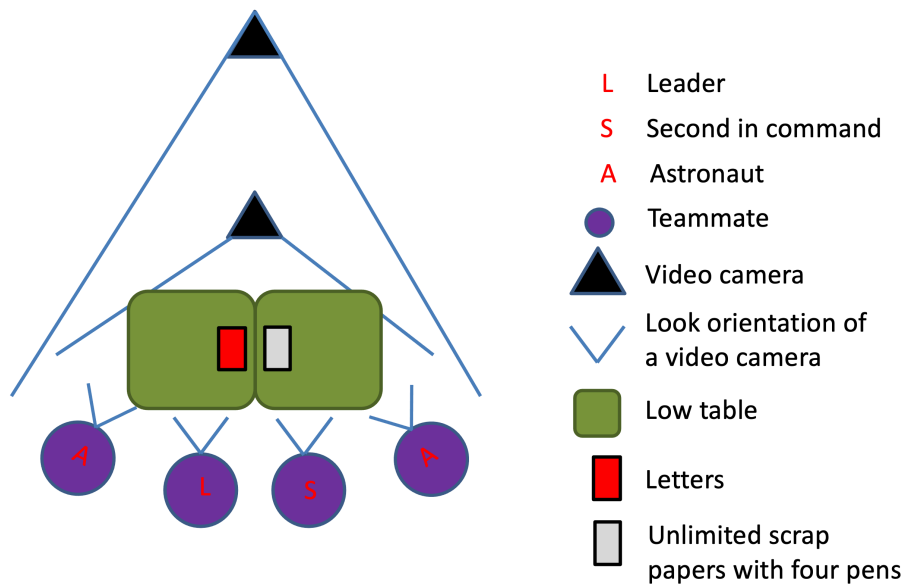


Figure 7. organization of the exercise Missionaries and cannibals

4. Elements presented to the participants

4.1. Text read to the teams

The first part of the read text is common with the other exercises of the LETUCA protocol (cf. the common elements presented in the Part II, chapter 1, paragraph 4.1).

The second part of the read text, specific to the present exercise, is:

“Your performance is measured on the time needed to find a solution to each problem. You have four letters, numbered from one to four. Please begin with the number one, then number two and so on.

You can open the following letter only when the preceding problem is completely solved. You can use the scrap paper from previous problems.

You have 30 minutes, if you finish earlier you can leave earlier.”

4.2. Guidelines presented to the participants

The annex 3, Missionaries and cannibals, presents the guidelines of the four problems presented to the participants.

5. Operational performance measurement

The time needed by the teams to solve each problem is used to measure the operational performance.

The problem number two is not taken into account for the operational performance measurement. Indeed, the purpose of this problem is just to make the teams think and focus

about a problem out of scope. Moreover, the time for this second problem is limited to five minutes maximum. So, the teams do not spend all the rest of the remaining time on treating a problem not counted in the operational performance scale.

The timer for a specific problem is launched as soon as a letter is opened. The answers of the four problems are presented below (Tables 2, 3, and 4 respectively for the problems 1, 3, and 4).

First problem: Problem of the river crossing

Transfer number	Starting shore ¹⁷	Transfer	ending shore
Initial conditions	$M_1F_1 M_2F_2 M_3F_3$		
1	$M_2F_2 M_3F_3$	$M_1F_1 \rightarrow$	
2	$M_2F_2 M_3F_3$	$\leftarrow F_1$	M_1
3	$M_2 M_3F_3$	$F_1 F_2 \rightarrow$	M_1
4	$M_2 M_3F_3$	$\leftarrow F_2$	M_1F_1
5	M_3F_3	$M_2F_2 \rightarrow$	M_1F_1
6	M_3F_3	$\leftarrow F_2$	$M_1F_1 M_2$
7	M_3	$M_2 F_3 \rightarrow$	$M_1F_1 M_2$
8	M_3	$\leftarrow F_3$	$M_1F_1 M_2F_2$
9		$M_3F_3 \rightarrow$	$M_1F_1 M_2F_2$
Final conditions			$M_1F_1 M_2F_2 M_3F_3$

Table 2. solution of the first problem, Missionaries and cannibals

Second problem: The guardians

The question to ask one of the two guards is: “What is the answer of the other guard to the question: where is the door of the freedom?”

Third problem: Missionaries and cannibals

Transfer number	Starting shore ¹⁸	Transfer	ending shore
Initial conditions	$MMM CCC$		
1	$MM CC$	$M C \rightarrow$	
2	$MM CC$	$\leftarrow C$	M
3	$MM C$	$CC \rightarrow$	M
4	$MM C$	$\leftarrow C$	$M C$
5	$M C$	$M C \rightarrow$	$M C$
6	$M C$	$\leftarrow C$	$MM C$
7	M	$CC \rightarrow$	$MM C$
8	M	$\leftarrow C$	$MM CC$
9		$M C \rightarrow$	$MM CC$
Final conditions			$MMM CCC$

Table 3. solution of the third problem, Missionaries and cannibals

¹⁷ M: read male, F: read female. The number below M or F corresponds to the number of the couple, in fine, M_1 is the husband of F_1 .

¹⁸ M: read missionaries, C: read cannibal.

Fourth problem: Second problem of the river crossing

Transfer number	Starting shore	Transfer	ending shore
Initial conditions	$M_1 F_1 M_2 F_2 M F_3$		
1	$M_2 F_2 M_3 F_3$	$M_1 F_1 \rightarrow$	
2	$M_2 F_2 M_3 F_3$	$\leftarrow M_1$	F_1
3	$M_1 M_2 H_3$	$F_2 F_3 \rightarrow$	F_1
4	$M_1 M_2 M_3$	$\leftarrow F_1$	$F_2 F_3$
5	$M_1 F_1$	$M_2 M_3 \rightarrow$	$F_2 F_3$
6	$M_1 F_1$	$\leftarrow M_2 F_2$	$M_3 F_3$
7	$F_1 F_2$	$M_1 M_2 \rightarrow$	$M_3 F_3$
8	$F_1 F_2$	$\leftarrow F_3$	$M_1 M_2 M_3$
9	F_2	$F_1 F_3 \rightarrow$	$M_1 M_2 M_3$
10	F_2	$\leftarrow M_2$	$M_1 F_1 M_3 F_3$
11		$M_2 F_2 \rightarrow$	$M_1 F_1 M_3 F_3$
Final conditions			$M_1 F_1 M_2 F_2 M_3 F_3$

Table 4. solution of the fourth problem, Missionaries and cannibals

Chapter 4: Bag and Euro

1. Context

The teams must think about two independent problems. The first one consists of a brainstorming exercise introduced by Davidson, Deuser, and Sternberg (1994), the bag riddle. This brainstorming is complexified by the way of presenting the answers. Indeed, the teammates must memorize the answers before presenting them all, hence a memorization effort. The second problem deals with a mathematical problem. In this second exercise, the teams must perform a problem detection and then understand the origin of the problem. It is the only scenario of the LETUCA protocol to trigger the metacognitive phase related to the problem detection (L'Haridon, 2019). The Euro riddle comes from the internet website: Enigme-facile.

2. Interest & specificities

The first exercise, the bag riddle, can imply metacognition through the creativity needed to maximize the operational performance. Indeed, mental representation, control or even planning could be tools to increase the number of answers. The teams must also succeed to memorize the list of must also which increasingly lengthens along the treatment. The way the teams improve the teammates' memorization also belongs to metacognitive activities.

The requested brainstorming implies a practical creativity so to imagine the maximum number of answers. This practical creativity can also be optimized depending on the valorization of the teammates' experience and backgrounds.

The second exercise, the Euro, presents two interests. As there are no guidelines, it is an unknown problem. Moreover, it permits the problem detection metacognitive phase. As soon as the problem inserted in a text is detected, it must be solved via a logical reasoning which can be simple depending on the teams.

The specificity of the Bag is the need of a practical creativity coupled with a defined way or not of listing the answers among the teammates. The specificities of the Euro are an unknown problem implying a problem detection. This problem can be solved depending on a logical reasoning.

3. Organization of the teammates

The needed equipment is:

- Two video cameras,
- A Tripod for one camera,
- Two letters with the associated problems,
- Unlimited scrap papers with four pens (for the second the Euro exercise).

During an operational mission performed by a professional team, the teammates know the available equipment. So, there are few debates or no debates among this team about which equipment is present or not. Then, the teamwork is more focused about what to do with that known equipment. In the bag riddle, this knowledge of a professional team implies that the researcher must impose the picture of a bag to the participants in order to force the teams to

begin their reasoning from a common start point (in fine, a common and known equipment). Finally, a bag picture is presented to the teams (cf. annex 4).

The experience is organized according to the figure 8.

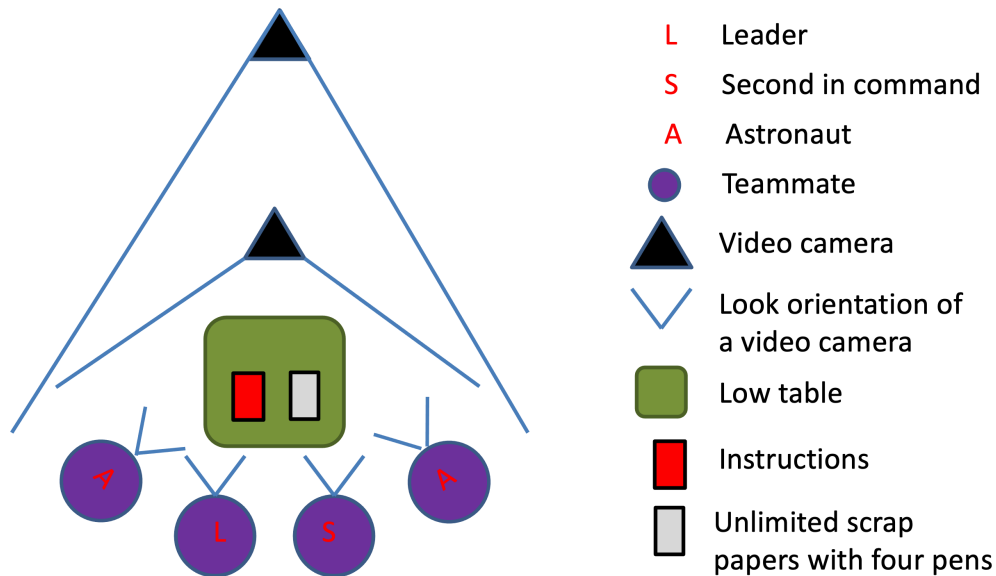


Figure 8. organization of the exercise Bag and dollar

4. Elements presented to the participants

4.1. Text read to the teams

The first part of the read text is common with the other exercises of the LETUCA protocol (cf. the common elements presented in the Part II, chapter 1, paragraph 4.1).

The second part of the read text, specific to the present exercise, is:
 “You cannot write on the guidelines.

You have a problem in the letter number one. Your performance is counted according to the number of announced answers. In order to have your responses accepted, they must be presented in front of the video camera between the 13th and the 15th minutes. The organizer announces the 15th minute. You have no scrap paper for this problem.

At the 15th minute, you switch to the second problem. You can use the scrap paper on the low table during this exercise. You will treat it as fast as you can.

You have 30 minutes maximum to solve both problems. If you finish earlier, you can leave earlier.”

4.2. Guidelines presented to the participants

The annex 4, the bag and the dollar, presents the guidelines.

5. Operational performance measurement

The first exercise requests the teams to invent the maximum functions a bag can have. The teammates announce the answers between the 13th and the 15th minutes. Then, the operational performance is measured according to the number of given functions (from zero to the infinity) for these two minutes. The operational performance of the bag riddle is also evaluated via an open performance (L'Haridon, 2019). The organizer has just to transcribe the answers extracted from the movie. Then, he/she:

- Gathers redundant or similar functions, in this case, only one answer is taken into account,
- Erases irrelevant functions,
- Counts each function of the plastic bag,

The second exercise presents a problem that teams must detect and solve. The result is measured according to the time needed to find the origin of the error. The captain's decision marks the stop of the timer.

Finally, the two scores are added to get the operational performance of this experience.

Answer of the two exercises:

The performance of the bag riddle is open. Indeed, the number of functions of a bag is too large to be exhaustively anticipated. So, the solutions depend on what the teammates list.

The second problem deals with an error inserted in the text. A payment of rooms in a hotel is described and ended by a summary of the movements of the change. In this summary, a sum is presented in the place of a subtraction. After analyzing the description, the teammates can discover that 25€ payed for the rooms plus 3€ given back to the clients plus 2€ for the assistant make a total of 30€ as discussed in the initial count.

Chapter 5: Untangle

1. Context

The exercise is divided in two steps. Firstly, the teams must understand the goal of a problem and solve it as fast as possible. The problem to solve is presented on the figure 9; different points have to be untangled, hence the name of the exercise, Untangle. A few software are freely available on the internet, the one selected for the LETUCA protocol is Stay Away From The Line of Kechap Free Games Limited. Secondly, the teams must think about pieces of advice subsequently used to help fictitious players to win this problem faster. The second part is hidden in an envelope which is opened as soon as the first problem is completed.

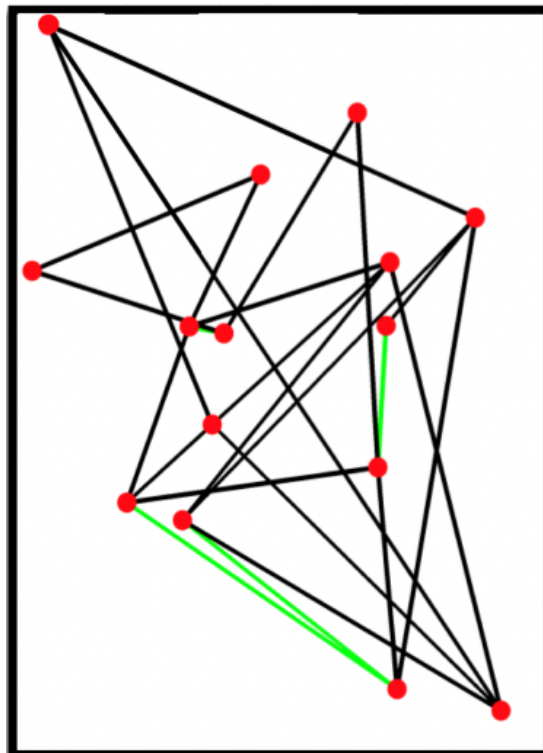


Figure 9. randomly distributed points of the Untangle software

A standard game begins with randomly distributed points (cf. figure 9). If the distribution of the game is kept, the teams do not have the same initial conditions. Indeed, the placement of the points varies each time a game is initiated. In order to diminish the influence of this probability factor, the random placement of the points is fixed by the researcher. Consequently, an identical difficulty level is imposed on the participants.

The organizer concentrates the points by via the following method:

- Difficulty level of the software n^6 ,
- At the top of the screen, place here the 4 branch points (8 points concerned),
- At the bottom right of the screen, place the 3 branch points (3 points concerned),
- At the bottom left of the screen, place the 2 branch points (5 points concerned),
- Separate the 2 branch points one another and classify them in the order of decreasing connections with the linked points. For example, a point linked with two points with 4 branches is classified first compared to a point linked with two points with only 2

branches. This action should be performed first to have a view of all the connections. Keep all these points away of the center for the moment,

- Superimpose at the center of the screen all the points in the following order:
 - The 8 points with 4 branches, begin with the point linked with the most connected points,
 - The 3 points with 3 branches, begin with the point linked with two points with 4 branches.
 - The 5 points with 2 branches, begin with the 2 points linked with the most connected points (first previously classified) and carry on superimposing with the following points.

After this distribution, the employed software integrated in the LETUCA protocol presents a screen similar to the figure 10. Thus, the figure 10 is the starting step of this experience of the LETUCA protocol with all the points concentrated into one point at the center. When the teams start the exercise and begin to move that center point, they discover other points and finally spread all the points on the tablet to get a distribution comparable to the figure 9, for instance.

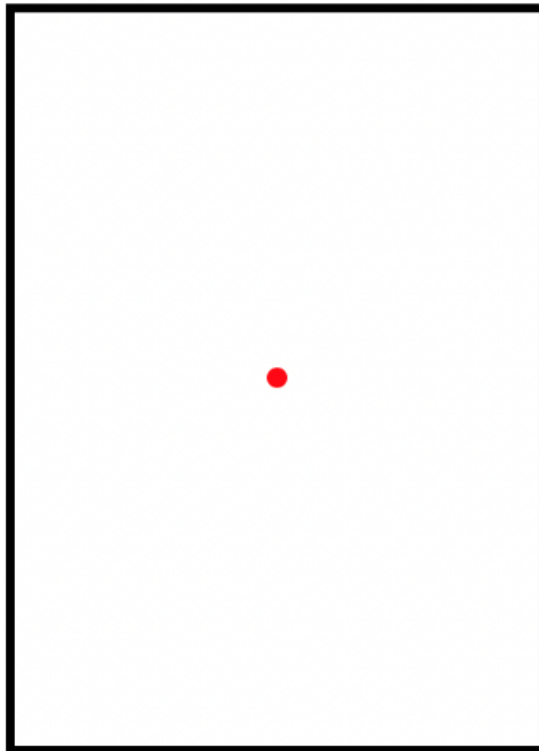


Figure 10. start situation of the Untangle exercise

A timer and an arrow are visible on the screen but are not part of the exercise. The participants are aware that this timer and this arrow are out of the experience.

2. Interest & specificities

The Untangle exercise is an unknown problem. Indeed, the teams are placed in front of a screen (cf. figure 10) without knowing either the elements of a context or the problem to solve. So, the teammates must understand the task and then perform it.

The second phase forces the teams to take a step back about Untangle and to think beyond their own understanding and anticipation of the problem. They must invent pieces of advice usable by other individuals to untangle the points (cf. figure 9). The pieces of advice must be usable in the interest of this exercise and specific to it. Thus, the teams not only need to master the exercise and its rules, but to perform practical and creative reasonings, mental representations, and anticipation endeavors as well.

The specificities of Untangle are an unknown problem without any context, followed by a necessary step back demanding anticipation.

3. Organization of the teammates

The needed equipment is:

- Two video cameras (one to record the teammates and one for the TV screen),
- A tripod for one camera,
- A tablet with the Untangle software,
- A TV screen,
- A connection cable between the TV screen and the tablet,
- A Letter with the guidelines for the second part of the exercise,
- Unlimited scrap paper with four pens.

The experience is organized according to the figure 11.

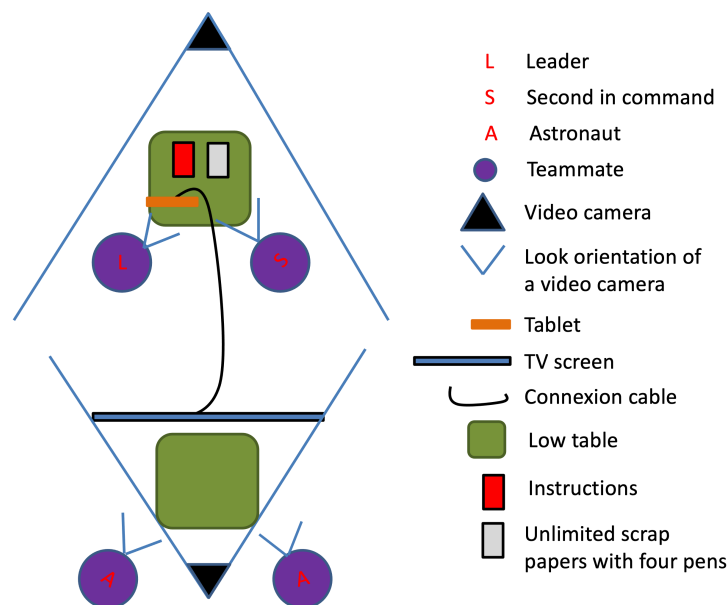


Figure 11. organization of the exercise Untangle

4. Elements presented to the participants

4.1. Text read to the teams

The first part of the read text is common with the other exercises of the LETUCA protocol (cf. the common elements presented in the Part II, chapter 1, paragraph 4.1).

The second part of the read text, specific to the present exercise, is:

“Do you have a chronometer at your disposal? You can prepare it¹⁹. A tablet is in front of you under the papers here²⁰: do not touch it for the moment.

The problem is divided into two phases. The first one consists in winning an exercise on the tablet as fast as you can. Your performance is measured on the time needed. Then, you must complete the problem with a minimum time. As soon as the exercise is succeeded, do not touch the tablet anymore. You begin the second phase, the guidelines of which are in this letter²¹.

The scrap paper is unlimited. You have 30 minutes to treat both phases. When I say “top”, you can access the tablet and begin the resolution. I set up the TV screen now²².

Top.”

4.2. Guidelines presented to the participants

A sheet of paper is inserted into the letter and contains the guidelines of the second phase of the problem:

“The problem is divided into two phases:

1. The first one consists in winning the problem as fast as you can. This phase is over now.
2. The second phase consists in establishing a list composed with pieces of advice to win this problem.

The pieces of advice must be:

- useful for this exercise. They can be simple and obvious just like complex,
- specific to this exercise. For example, if you write: “be focused”, it is common and applicable to all exercises, so it is not validated.

For this second phase, your performance is measured on the number of pieces of advice established and respecting the two above criteria. Only the responses written on the answer sheet are taken into account.

You can use the software as you want: number of games, difficulty level, etc.

You have 30 minutes to perform both phases.”

5. Operational performance measurement

There is a two-step operational performance measurement:

- Firstly, the time needed to solve the first phase,

¹⁹ If no time is available, the organizer gives one to the team.

²⁰ the organizer shows it.

²¹ the organizer shows the letter.

²² The organizer configures the TVscreen.

- Secondly, the number of pieces of advice determined by a team and respecting the two constraints: to be useful for the exercise and specific to it.

The second part is an open performance measurement (L'Haridon, 2019). Indeed, there is no exhaustive list of answers. If an answer respects the two constraints, it is taken into account; if not, it is rejected.

Chapter 6: Fire procedure

1. Context

Four astronauts are performing an exploration in a rover on Mars. Away from the main station, they encounter a fire inside the cabin of the rover. While a member is taking the onboard fire checklist, the binding of the book cracks and all the pages fall onto the floor and get mixed. Unfortunately, there is no paging. Then, the crew's task is to classify the pages in order to treat the fire. The teams have just the context exposed, then, this exercise is unknown qualified.

The onboard fire checklist was adapted from the Airbus A340 one via a three-step work:

- Firstly, all the actions of the “SMOKE/FUMES/AVNCS SMOKE” (Airbus, 2017) checklist were analyzed to understand their relevance in the context of a human exploration with a rover on Mars. So, some actions were transferred to the checklist of the rover immediately, some were modified, and some others were rejected because they were not relevant for a human exploration on Mars.
- Secondly, all the retained actions were sequenced to build a logic checklist. The vocabulary of the actions was simplified so as to easily understand the involved systems. Especially, each action contains at least one words enabling the reader to link the studied action to a specific system. For example, the electrical system is mentioned for each electrical action.
- Thirdly, the layout of the actions was designed neutrally.

The annex 5 contains all the actions of the exercise Fire procedure (L'Haridon, 2019).

2. Interest & specificities

Thanks to the adaptation of the checklist of the Airbus A340 to a Mars environment, the teams can think about operational and technical issues. Indeed, an airliner and a rover on Mars are two similar systems according to various elements. Both systems:

- Transport human lives,
- Operate in hostile environments,
- Are surrounded by unbreathable air, although the nature of the hostility is different: the low atmospheric pressure at cruise altitudes of standard airliners and the chemical composition of the atmosphere and low pressure on the surface of Mars,
- Encounter a high-pressure difference between the cabin and the atmosphere,
- Imply a vital risk for crews if a fire takes place aboard,
- Do not permit a simple exit of the crew if the evacuation of the vehicle is necessary (as a driver can leave his/her car if a fire happens),
- Are equipped with many internal systems which may be potential sources of fire (air conditioning, pressurization, electrical networks and devices, comfort equipment, etc.).

Then, the teams must understand the context and translate it into operational constraints and actions to execute with a logical order. For example, at the beginning of the fighting of a fire in a confined rover, teammates need to prioritize the actions to breath oxygen with a mask immediately or to manipulate a system between each other.

The method to calculate the operational performance of the Fire procedure exercise is identical to the Lunar survival exercise: a reference is used to calculate potential differences between the answers of teams and this reference. Compared to the Lunar survival exercise, the additional and specific interest of the Fire procedure lies in the logical and operational links among the actions of the checklist. Indeed, in the Lunar survival exercise, no causality reasonings are needed among the items.

The specificities of Fire procedure are a space environment demanding a mental representation in order to set a procedure of actions. These actions deal with an operational reasoning involving safety, practical logic, prioritization.

3. Organization of the teammates

The needed equipment is:

- Two video cameras,
- A tripod,
- The reduced technical manual of the rover (cf. annex 5),
- Mixed up checklist.

The experience is organized according to the figure 12.

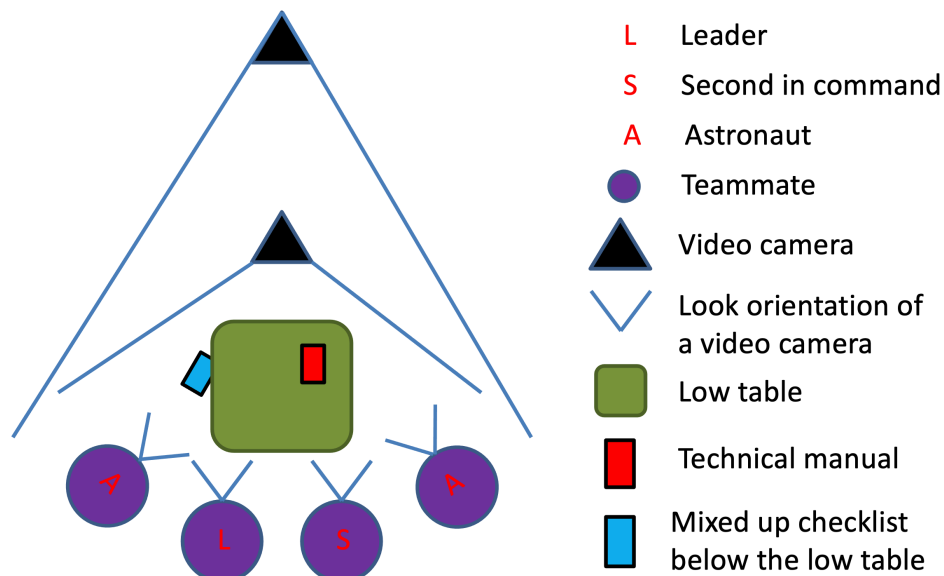


Figure 12. organization of the exercise Fire procedure

4. Elements presented to the participants

4.1. Text read to the teams

The first part of the read text is common with the other exercises of the LETUCA protocol (cf. the common elements presented in the Part II, chapter 1, paragraph 4.1).

The second part of the read text, specific to the present exercise, is:

“You have been on Mars for 10 months with a total crew composed of 8 teammates. The crew is divided into teams of four astronauts each. Four astronauts, the rocket and all the equipment are located in the main base. You are the other team with four astronauts.

You are performing the 12th exploration of the mission. You are moving thanks to a rover on the Mars surface. Your present location is 40Km away of the main base. Your space suits were damaged two days ago and no one is usable anymore. Pieces of information are available in the technical manual here²³.

A fire began in your rover. One of you rushed to seize the checklist. Under the stress, the binding of the fire treatment checklist was removed and all the pages with the actions to perform fell onto the floor. All the pages mixed up. The pages are under the table²⁴. You need this checklist to treat the encountered fire.

Your performance is only measured on the quality your work. You have 30 minutes.

You can take the pages as soon as the exercise starts”

4.2. Guidelines presented to the participants

The actual layout of the actions is available in the annex 5. The below actions are presented in the following order to each team.

- If the smoke stops, maintain the extinction of the internal equipment, comfort equipment: turn on
- If the air conditioning of the scientific wagon is suspected:
 - Generator number 2: check turned on
 - Scientific wagon, bulkhead number 2: close
 - Main air conditioning system: turn off
- If the smoke continues despite the electrical system modification:
 - Cabin fans: turn off
- If the equipment at the origin of the fire is directly identified: turn off its electrical alimentation and isolate it
- If no equipment is found on fire: try another method
- Main air conditioning system: turn on
- If no methods work: consider the activation of the emergency minimal electrical configuration, fastest way with risk taking to the main base: consider and use if needed
- Secondary air conditioning system: turn off
- Generator number 2: turn off
- Scientific wagon, emergency opening of the airlock: execute
- If the smoke continues despite the modification of the air conditioning system:
 - Internal equipment on fire: search and extinguish
 - Generator number 1: turn off

²³ The organizer shows the location of the reduced technical manual (for instance loaded in a tablet or on printed papers).

²⁴ The organizer shows the gathered pages.

- Secondary air conditioning system: check turned on
- Comfort equipment: turn off
- If the smoke continues despite the modification of the air conditioning system:
- If the smoke continues, generator number 2: turn on
- If the smoke continues, secondary air conditioning system: turn on, scientific wagon, airlock: close, scientific wagon, sluice number2: open, try another method
- Emergency lighting of the cabin: turn on
- Scientific wagon: evacuate
- Immediate return to the main base: initiate
- Communication among all the crew members: establish
- If the fire origin cannot be identified and continues or an electrical fire is suspected:
- If an internal equipment is suspected:
- Generator number 1: turn on
- At any time of the procedure, if the situation becomes unmanageable, fastest way with risk taking to the main base, use of extravehicular suits and extraction of the cabin air: consider and execute if needed
- Oxygen masks: use with 100% selector if needed

A reduced technical manual is provided to the teams in order to increase the knowledge of teams about the rover and the context (cf. annex 6).

5. Operational performance measurement

A reference checklist composed of the actions necessary to treat a fire aboard a rover on Mars is designed on the checklist SMOKE/FUMES/AVNCS SMOKE of Airbus (2017). Thus, the determination of an optimal answer reference is based on the works of “super-experts”²⁵ of Airbus (2017), adapted from the method of Barnett and Koslowski (2002) used to measure a performance.

The present operational performance is based on the calculation of Lunar survival. As described above for Lunar survival, if the position of an item set by a team is different of the position selected by the reference checklist, then the absolute value of the difference of the two ranks is memorized (the rank of the team and the one of the super-experts of Airbus). All the absolute values of all the items are added, this final sum represents the final performance. The goal is to minimize this final sum, so a low value translates a high correspondence to the reference classification.

Moreover, actions of the checklist belong to a specific category (i.e. electricity, air conditioning, internal equipment) and there related absolute values are calculated relative to their own categories. Indeed, the prioritization of the systems of the rover between one another is beyond the knowledge and skills of the participants. The consideration to begin the fire extinguishment by taking an action on the air conditioning, then the internal equipment and finally the electrical system is considered too difficult. Thus, the operational performance measurement does not take this classification of the systems between one another into account event if it is presented in the original checklist of Airbus (2017). Then, the actions of the air conditioning, the internal

²⁵ According to the term that was used by Barnett and Koslowski (2002).

equipment or the electrical systems are monitored inside their own category and the absolute values are calculated relative to each category.

However, another category exists: the pre-treatment actions. It includes general actions not linked to a specific system but necessary to fight a fire, for instance: establish the crew communication. Contrary to the actions of the electricity, the air conditioning, and the internal equipment, the items of the pre-treatment and the last action are then counted according to the complete checklist. Indeed, they are not integrated to the functioning of a system and deal with the entire fire checklist. Then, the pre-treatment actions must be extracted by the teams from the systems handling and placed before all the actions of the systems. For example: “Communication between all crew members: establish” is not linked to a system of the rover but with the construction of the situation awareness of the crew. Then, three fictive checklists integrated into the complete one exist:

- Pre-treatment actions,
- Air conditioning actions,
- Internal equipment,
- Electrical systems, and
- The final action.

To gather all the thirty-one actions together without taking into account the classification of the three systems between one another (i.e. electricity, air conditioning, internal equipment), three lists are composed as references:

- Pre-treatment actions²⁶ → air conditioning²⁷ → the final action²⁸,
- Pre-treatment actions → internal equipment²⁹ → the final action,
- Pre-treatment actions → electrical systems³⁰ → the final action.

In these three different checklists, the measurement method of Lunar survival (Hall & Watson, 1970) is applied to the actions of the electricity, the air conditioning, and the internal equipment. The operational performance measurement linked to the actions of the pre-treatment and the final action are measured according to the complete checklist.

Finally, all the absolute values are summed; this ultimate number is a team’s operational performance. The more a team approaches the reference checklist, the less errors this team has, the lower the score is and finally the higher the operational performance is.

The reference checklist used to calculate the operational performance is:

Pre-treatment actions:

- Immediate return toward main base: initiate
- Oxygen masks: use with 100% selector if needed
- Cabin fans: turn off
- Comfort equipment: turn off
- Emergency lighting of the cabin: turn on

²⁶ Actions number 1 to 8.

²⁷ Actions number 9 to 19.

²⁸ Action number 31, this item is the last of all the actions to perform.

²⁹ Actions number 9 to 12.

³⁰ Actions number 9 to 15.

- Communication among all the crew members: establish
- If the equipment at the origin of the fire directly identified: turn off its electrical alimentation and isolate it
- At any time of the procedure, if the situation becomes unmanageable, fastest way with risk taking to the main base, use of extravehicular suits and extraction of the cabin air: consider and execute if needed

Air conditioning:

- If the air conditioning of the scientific wagon is suspected:
 - Scientific wagon: evacuate
 - Scientific wagon, bulkhead number 2: close
 - Scientific wagon, emergency opening of the airlock: execute
- If the smoke continues despite the modification of the air conditioning system:
 - Secondary air conditioning system: check turned on
 - Main air conditioning system: turn off
- If the smoke continues despite the modification of the air conditioning system:
 - Main air conditioning system: turn on
 - Secondary air conditioning system: turn off
- If the smoke continues, secondary air conditioning system: turn on, scientific wagon, airlock: close, scientific wagon, sluice number2: open, try another method

Internal equipment:

- If an internal equipment is suspected:
 - Internal equipment on fire: search and extinguish
- If the smoke stops, maintain the extinction of the internal equipment, comfort equipment: turn on
- If no equipment is found on fire: try another method

Electrical systems:

- If the fire origin cannot be identified and continues or an electrical fire is suspected:
 - Generator number 2: check turned on
 - Generator number 1: turn off
- If the smoke continues despite the electrical system modification:
 - Generator number 1: turn on
 - Generator number 2: turn off
- If the smoke continues, generator number 2: turn on

Final action if the preceding ones are unsuccessful:

- If no methods work: consider the activation of the emergency minimal electrical configuration, fastest way with risk taking to the main base: consider and use if needed

Chapter 7: Electrical system reproduction

1. Context

This exercise adapts a method of Leavitt and Mueller (1951) to trigger teamwork: one teammate describes an abstract pattern orally and other teammates must reproduce this unseen pattern as accurately as possible. For the LETUCA protocol, the teams are divided into two duos. One duo precisely reproduces a schema detained by the other duo only with verbal dialogs. Indeed, the duos are placed so they cannot see each other; the teammates are separated by an obstacle. The first duo has many blank sheets with a pencil, a pencil-sharpener and a rubber. The second duo has one schema composed of lines and symbols, in fine, the electrical system of the Airbus A340 (Airbus, 2017).

Taking into account that the teams have no guidelines (except communicational constraints) and no context, this exercise is unknown qualified. To increase the probability of the teams to understand the task to perform, a big black frame was printed on the answer sheets. Moreover, this frame has the exact dimensions of the electrical system schema detained by the other duo.

2. Interests & specificities

The teammates begin the exercise with one document per duo with no instructions, then, this exercise is unknown. As specified, the teams are divided into two duos which cannot see each other. Moreover, the two duos detain specific data and one of the two has access to numerous pieces of operational information. So, verbal communications are necessary to exchange the information and can be adapted via a dialog discipline, the use of simple words, and the omission of superfluous words to describe the schema. These three characteristics are evaluated thanks to the measurement of the operational performance.

The specificities of Electrical system reproduction are an unknown exercise with a team divided into two duos with two different groups of information, thus the specific interest of verbal communications.

3. Organization of the teammates

The needed equipment is:

- Two video cameras,
- A tripod,
- For the first duo: unlimited scrap paper with four pens (with the black frame on each sheet, cf. annex 7), a pencil, a pencil-sharpener and a rubber. This equipment is hidden before the beginning of the exercise under a cardboard,
- For the second duo: the schema of the electrical systems of the Airbus A340 (Airbus, 2017). This schema is hidden in a letter so the teammates cannot see it before the beginning of the exercise.

It is possible to increase the difficulty. Indeed, the size of the black frame on the answer sheet can be modified while maintaining the dimensions the actual schema. Then, the sizes of the black frame and the schema are no more identical and the teams are no more able to communicate positions via distances but with proportions.

The experience is organized according to the figure 13.

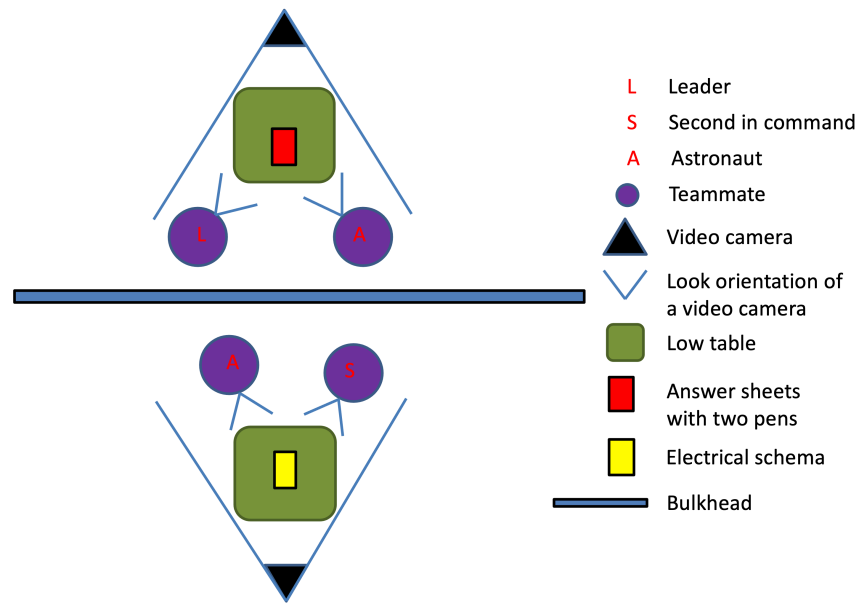


Figure 13. organization of the exercise Electrical system reproduction

4. Elements presented to the participants

4.1. Text read to the teams

The first part of the read text is common with the other exercises of the LETUCA protocol (cf. the common elements presented in the Part II, chapter 1, paragraph 4.1).

The second part of the read text, specific to the present exercise, is:

“In order to give a temporal reference of the beginning on the camera, you³¹ clap your hands at the end of my countdown: I will say “10, 9, 8 to 1, top”. With the “top”, the exercise is launched and you clap your hands. The goal is to mark the start time on the camera in a simple way. Do you understand?”

You do what you want of the elements on the low tables in front of you. I keep just one answer sheet at the end of the experience.

You can talk to one another, but:

- You must not turn back to see the other duo,
- You keep the direction of your chair exclusively,
- You must not exchange any document.

The performance is measured according to the precision and the quality.

You have 30 minutes.”

³¹ The organizer shows the leader.

4.2. Guidelines presented to the participants

The electrical system of the Airbus A340 (Airbus, 2017) presented to the teams is presented in the figure 14.

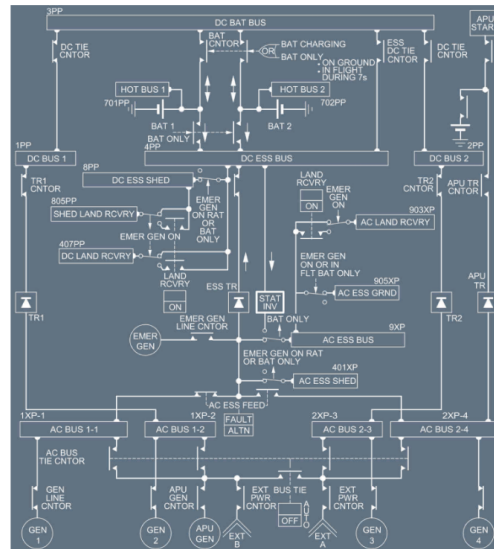


Figure 14. electrical system of the Airbus A340 (Airbus, 2017)

This schema (figure 14) is presented in standard size in the annex 8. The teammates have numerous answer sheets with a printed frame to reproduce the schema (cf. annex 7).

5. Operational performance measurement

Points are scored as soon as one of the following elements are validated (L'Haridon, 2019):

- A symbol copied without any error (good orientation, sign, number of lines) gives one point.
- A symbol well connected with another symbol via the good side of a connection is scored one point. Then, an element connected to three others can give three points if the connections are well established.
- The well written name of an element gives one point. If there is a mistake in a name, no point is scored. If N names are given around an element, N points can be won. A name can be scored if the concerned element is copied, even if it is not well drawn.

Then, each element is scored one time in its own category.

Chapter 8: Mars failure report

1. Context

A crew and its space vehicle are beginning the return trip from Mars to the Earth. During the extraction of the orbit of Mars, an unknown failure happens. The fatigue failure of one of the generators of the space vehicle (L'Haridon, 2019); the annex 9³² explains the chronology of the encountered technical problem. According to a fictive operational procedure, the crew has to write a synthesis, called crew message, to the ground control center in order to:

- Inform the control center of the experienced failure,
- Request for orders,
- Request for potential clearances.

Each teammate has a specific function during the mission. The organizer distributes these functions at the beginning of the exercise. The functions are one captain, one second in command (and also a flight engineer), one biology researcher, and one doctor. As the participants are not actual astronauts, they do not have neither skills nor knowledge about this type of missions and the distribution of tasks among the crewmates' functions. To unbalance this lack of specialization, the distribution of the functions is strengthened by placing individual and specialized reports in front of the concerned member. Indeed, each report contains specific information relevant to the associated function. For instance, only the researcher knows the existence of aboard samples. There are four functions so four reports are delivered. The reports can be read by other teammates but cannot be seized except by the related function; the document has to stay in front of the corresponding teammate. This constraint produces an artificial specialization and isolation of each participant compared to the other ones. Moreover, each member is responsible of his own specialty. For example, the researcher has to preserve the aboard samples.

2. Interests & specificities

This exercise dealing with the consequences of a failure threatening a crew has two main interests.

Firstly, three main sequenced endeavors should be performed:

- To understand technical information distributed among teammates, in order
- To represent mentally an operational situation, so as
- To build a prioritization of the information.

The prioritization of the information is materialized by a written synthesis with a limited number of words. This exercise is the only one of the LETUCA protocol to measure operational performance depending on a written synthesis. Then, a precise communication among participants should be executed in order to represent the event correctly.

Secondly, the astronauts might be competing with one another due to the guidelines. Indeed, the instructions create a specific relational dynamic by requesting the teammates to highlight their own function compared to the others and especially in the synthesis of the event, e.g. failure impacts and parameters of the systems. As an unknown failure happened, the synthesis has a limited length, and despite a potential competitive spirit, the teammates must perform a

³² This annex and its elements are unknown of the teams.

selection of the information collectively which is detrimental to some of the teammates. Nonetheless, this selection benefits the flight back and the survival of the crew and then, this synthesis is the base of the performance measurement.

The specificities of Mars failure report are the construction of a common mental representation of an unknown failure thanks to information distributed among teammates. This mental representation is then employed to write a limited synthesis, the crew message, used for the performance measurement. Then, a prioritization of the gathered information is to be conducted by teammates.

3. Organization of the teammates

The needed equipment is:

- Two video cameras,
- A tripod,
- Unlimited answer sheets for the redaction of the report with four pens,
- A technical manual with a presentation of the general context (cf. annex 10),
- Four reports specialized to each function of the crew (captain, second in command, biology researcher and doctor, cf. annex 11).

The experience is organized according to the figure 15.

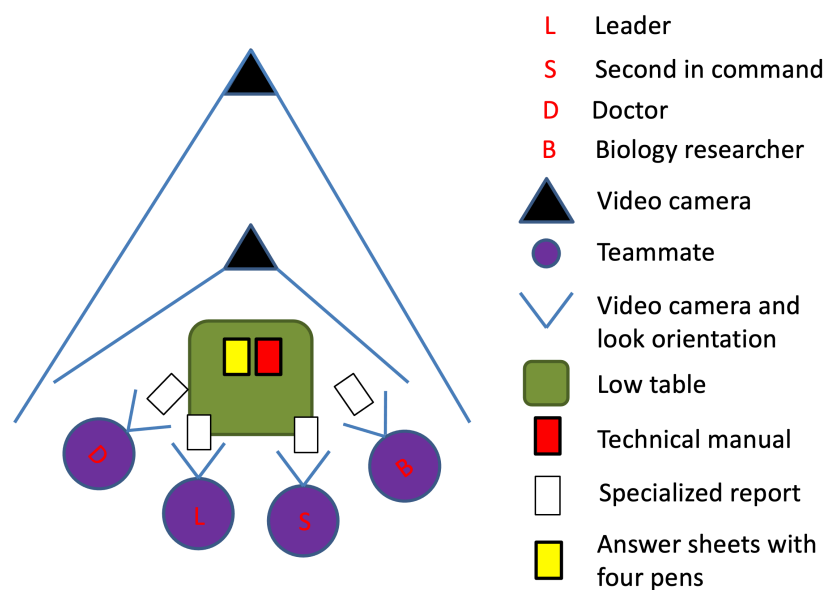


Figure 15. organization of the exercise Mars failure report

4. Elements presented to the participants

4.1. Text read to the teams

The first part of the read text is common with the other exercises of the LETUCA protocol (cf. the common elements presented in the Part II, chapter 1, paragraph 4.1).

The second part of the read text, specific to the present exercise, is:

“Each one of you has a specific function during the mission³³:

- you are the captain,
- you are the second in command and the flight engineer,
- you are the doctor,
- you are the biology researcher.

Then, each one of you has an individual function. You must highlight your function compared to the others. You have a paper sheet specific to you in front of you. Warning, do not exchange the paper sheets with each other. You can read the paper sheets of your teammates, but it must stay in the hands of the good specialist. For example, the captain’s sheet can be read by the doctor, but the doctor must not take the captain’s paper sheet in his/her hands.

Your performance is measured according to the chosen information.

You have 30 minutes maximum. If you finish before, you can leave before.”

4.2. Guidelines presented to the participants

Four specialized reports were given to the teammates, one per function (cf. annex 11).

5. Operational performance measurement

The crew message of each team is analyzed to measure the operational performance. Its measurement takes into account three incompatibilities among the specialized reports:

- Incompatibility to continue the mission and to have the generator n°3 in rotation; indeed, this generator produces destructive vibrations that cause a vital threat to the vehicle,
- Incompatibility to return on the standard trajectory and to start the urgency generator. Indeed, the two actions need too much propellant to be both performed; then, a choice must be established,
- Incompatibility to request the re-initialization of the generator 3 to get back the medical devices and to consider the generator 3 out of service according to the flight engineer’s report.

Six elements are remarkable to evaluate the operational performance of the crew message to obtain:

- The most important element to be transmitted in the report is the request to shut down the generator n°3. This is the only vital element that must be integrated in the crew message. Indeed, the control center must supply a code to stop this generator n°3 to the crew. So, the destructive vibrations endured by the vehicle can be stopped.
- The propellant reserved for contingency trajectory correction is needed to execute two operations. On the one hand, the rescue generator needs 50% of this reserved propellant to be started and then to recover the full operation of the medical equipment. On the other hand, the return on the standard trajectory to the Earth needs 70% of the same

³³ The organizer shows the correct person each time a function is mentioned.

reserved propellant. Thus, a choice must be performed by the teams between both actions.

Taking into account the vital importance of the trajectory and a low risk of employment of the medical equipment during the flight back to the Earth, the teams must use the fuel to perform the trajectory correction.

- The flight engineer has a dense report compared to the other teammates. Indeed, the failure being technical, the flight engineer has access to most of the consequences of the failure.
- A degradation of the vehicle is experienced but begins to be destructive after 12 days of vibrations. This time scale is a trap for the flight engineer because the deadline is not imminent. Nonetheless, it remains essential for the rest of the flight which lasts more than 12 days. Then, it may be misanalysed compared to closer maturities of other problematics. For instance, the degradation of the samples and most of the cited timings are deadlines presented in minutes.
- The rescue generator is located in the medical compartment of the vehicle. The goal is to generate the concentration of the doctor's attention exclusively on the start of this rescue generator to recover the medical equipment.
- According to the second in command's report, the crew message must contain less than 50 words.

Taking into account the limited number of words, in fine 50, which can be included in the crew message (cf. annex 11), the crew cannot transmit all the elements about the failure received from the computer. Then, the crew must select information and the necessary words to explain them among all the elements available. This selection is based on the way space exploration evaluate failure priorities. Within the framework of the development of the Space Lunch System, "the first priority is safety, followed closely by affordability" (Drake & Watts, 2014). More precisely, Barshi and Dempsey (2016) note that « if training deficiencies are present (...), there is an increase in the overall risk to the crew, the vehicle, and the mission." Then, Drake and Watts (2014) present the order of priority and Barshi and Dempsey (2016) give details of the main elements to manage. So, according to the works of Drake and Watts (2014) and Barshi and Dempsey (2016), the crew must prioritize the information to transmit in the crew message with the following order:

- 1: crew survival,
- 2: vehicle preservation,
- 3: mission success.

Finally, the crew message retained as an operational performance reference is (L'Haridon, 2019):

1. Request emergency stop generator n°3 = 5 words
2. Return possible = 2 words
3. System stabilized 48h = 3 words
4. Dev=+1.822054°A/-2.587490L/15020.514D = 1 word
5. Generator n°3 vibrations 5/10 persistent = 5 words
6. 20% samples lost = 3 words
7. Generator n°1, n°2, n°3 stopped = 5 words

8. Then n°1, n°2, n°4 ok = 5 words
9. n°3 unavailable = 2 words
10. 70% reserved propellant necessary for dev= $+1.822054^{\circ}A/-2.587490L/15020.514D$ = 6 words
11. generator n°3 vibrations 9/10 5'' = 5 words
12. 80% medical systems unavailable = 4 words
13. request help = 2 words

Then, the crew message needs 48 words for a maximum of 50.

Chapter 9: Asteroid avoidance

1. Context

A crew is flying back from Mars to the Earth. Suddenly, the main computer prints 3D graphs and data tables. They are two table of coordinates and six graphs with the time included, (O; x, y), (O; y, z), and (O; z, x). Labelled “trajectory of the spaceship” or “trajectory of the asteroid”, these documents present the trajectories of the spaceship and an asteroid (cf. annex 12 for the coordinates and annex 13 for the curves).

The teams do not receive any guidelines, only the context is exposed. So, this exercise is qualified as unknown situation (L Haridon et al., 2017).

2. Interests & specificities

There are three steps to complete this exercise.

Firstly, the situation is unknown and the teams must understand the problem. According to the context, the teams must build a mental representation of the situation and expect an incoming collision. Indeed, one of the data is entitled “trajectory of the asteroid” and the extraction of the technical manual deal with collision avoidance. The first challenge is precisely to localize the exact position of the collision and the related time. To do so, the teams must analyze the coordinates and the time scale of the three-dimension graphs and data tables.

Without being selected in the present version of the LETUCA protocol, three ways are available to increase the difficulty level of the Asteroid avoidance exercise:

- The teams can work on references based on two different times and/or speeds of the objects on the axis (O, x).
- The two trajectories can be designed so they do not cross each other at a single point³⁴, so the impact is not obvious. Nonetheless, two closest points exist where the two objects are at the minimum distance from each other. The locations of these two closest points are established within an error margin established in the tables, so the spaceship experiences a hazard of collision. This error margin simulates calculation imprecisions. Finally, the teams must deem that a collision is probable and the trajectory must be modified.
- While teammates work on the exercise, the organizer diminishes the time initially announced to finish the exercise, for example: “due to new estimations of the trajectory of the asteroid, you have 5 minutes left”.

These difficulties require higher knowledge in mathematics and physics. The LETUCA protocol being designed to test the largest specter of persons, such complexifications might not comply with this objective, depending on the participants. Then, these additional difficulties reduce the number of teammates able to resolve this exercise. Nevertheless, these potential evolutions are suggested to make this exercise evolve if needed for further researches.

Secondly, a trajectory correction must be executed. Indeed, the trajectory of the asteroid is uncontrolled and the only hope the crew has lies in the propulsion system. In the aim of

³⁴ In other words, no point belongs to the two trajectories.

simplifying the determination of the correction, no superfluous details are suggested to the teams and a few parameters are imposed:

- No trajectory deviations allowed, only speed adjustments,
- The engines to use,
- The combustion duration,
- The reversed propulsion to recover standard flight parameters: after a speed increase, the speed is reduced to the standard value. Indeed, after the collision avoidance, the crew's space vehicle must not be too fast either when it integrates the Earth's orbit.

Such a correction might not be an obvious task to perform; so, the teams need to access and understand the related elements to calculate such a correction. Thus, a reduced technical manual containing the description of the propulsion system is available and describes avoidance rules. The propulsion system was designed thanks to data of NASA technical documents (NASA, 2016). The avoidance rules were established thanks to collision avoidance methods discussed in a commercial shipping context by Chauvin, Clostermann and Hoc (2009). In this commercial context, these authors explain (2009) the needs to respect:

- The "economics", the translation into the LETUCA protocol is to avoid useless propellant consumption,
- The "geometrical rules", the translation into the LETUCA protocol is the physical collision avoidance,
- The "collision avoidance regulations", the translation into the LETUCA protocol is the necessity to cross an alien object at more than 2 Km.

Due to these elements, a last trajectory point to perform the correction exists. Beyond that location, the space vehicle is too close of the asteroid to avoid it safely. The teams must assimilate this specific point to perform the correction in time. According to the data (cf. annexes 12 and 13), this last trajectory point has the coordinates: (5, 10, -7).

Thirdly, the previous correction calculated to avoid the spacecraft to penetrate the danger sphere around the asteroid³⁵ can be optimized. The only way to perform this optimization is to reduce the consumed propellant (according to the danger sphere) so as to keep a maximized propellant quantity for potential future corrections. For example, teammates could choose to increase the correction in order to ensure a higher distance between the space vehicle and the asteroid. Nonetheless, an extra distance is not needed and means an extra consumption to fly away the asteroid's danger sphere.

Two curves of three dimensions each were created (x , y and z are real numbers; L'Haridon, 2019; annex 13), the time scale is added in the data given to the teams. The below equations correspond to the trajectories of both objects:

- Trajectory of the spaceship:

$$y = 2. x$$

$$z = -y + 3$$

³⁵ The technical manual indicates a minimum safety margin of 2Km on at least one of the three axes.

$$x = -\frac{z}{2} + \frac{3}{2}$$

- Trajectory of the asteroid:

$$y = \frac{x + 21}{2}$$

$$z = 31 - 3.y$$

$$x = \frac{-2.z - 1}{3}$$

The above equations, in fine, the trajectories of the spaceship and the asteroid, with the collision point are represented in 3 dimensions³⁶ with the GEOGEBRA software in figure 16.

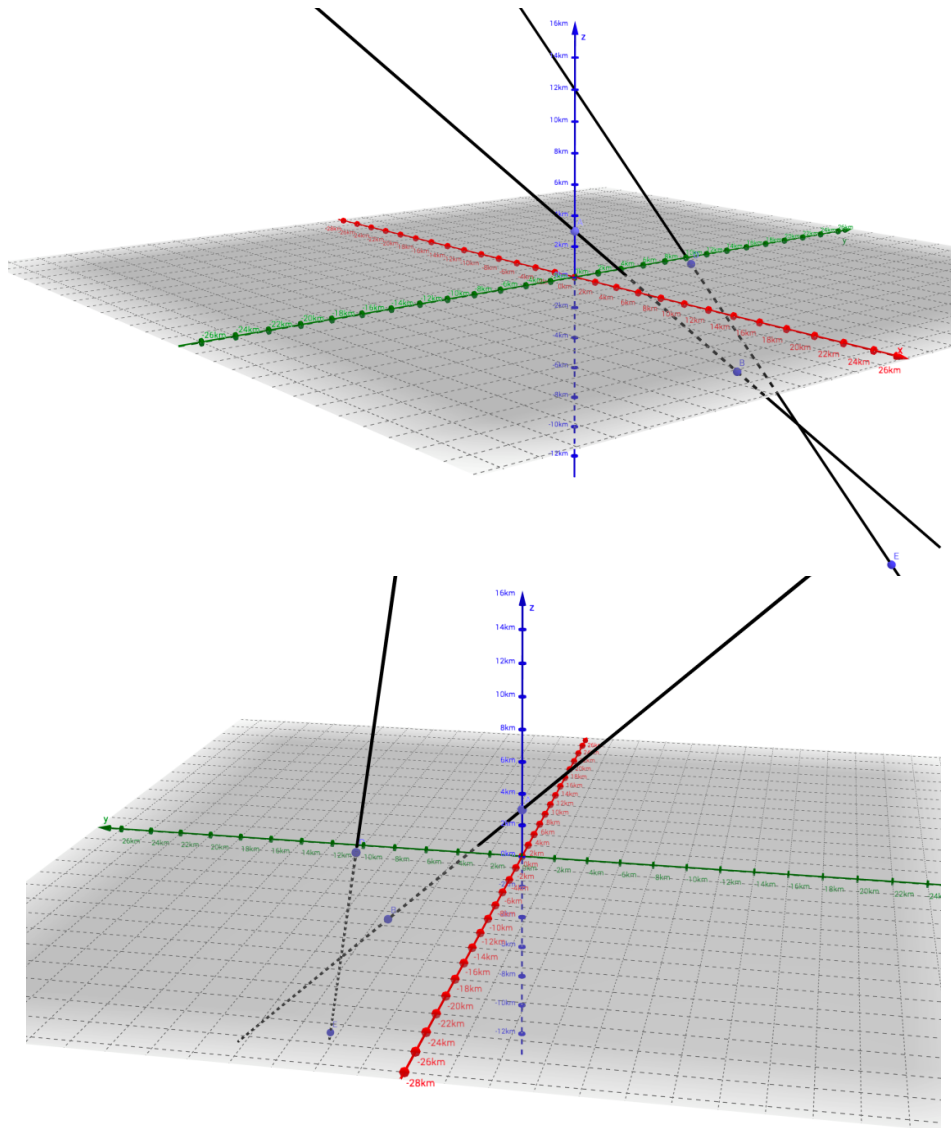


Figure 16 trajectories of the spaceship and the asteroid

³⁶ The time is not taken into account in the curves of the figure 16.

The specificities of Asteroid avoidance are an unknown problem demanding a mental representation of the situation thanks to mathematical and logical reasonings and if possible, requiring participants to take a step back to optimize the performed action.

3. Organization of the teammates

The needed equipment is:

- Two video cameras,
- A tripod,
- Unlimited answer sheets with four pens,
- Two tables with the exact data of the two trajectories (with the time scale included, cf. annex 12),
- Six graphs with the two trajectories in four dimensions (with the time scale included, cf. annex 13),
- The technical manual dealing with the propulsion system and the correction methods.

The experience is organized according to the figure 17.

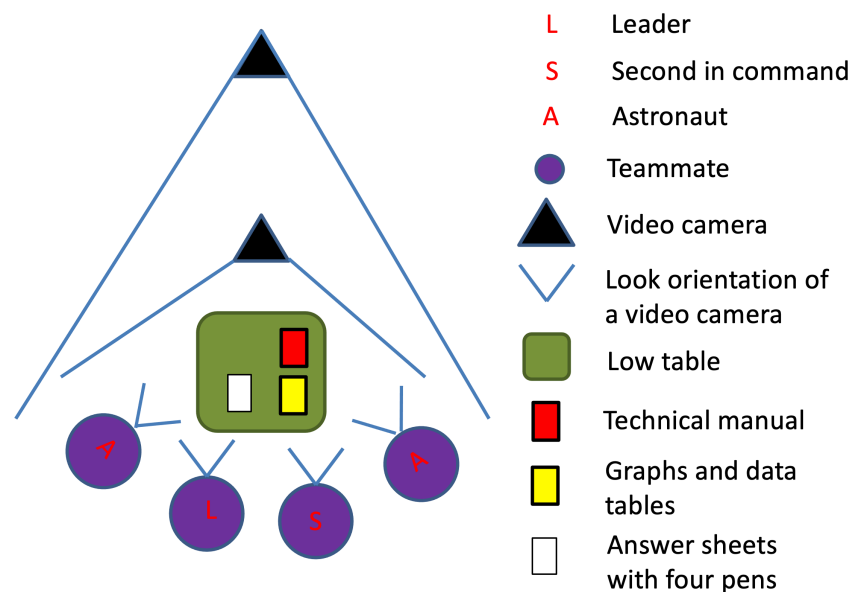


Figure 17. organization of the exercise Asteroid avoidance

4. Elements presented to the participants

4.1. Text read to the teams

The first part of the read text is common with the other exercises of the LETUCA protocol (cf. the common elements presented in the Part II, chapter 1, paragraph 4.1).

The second part of the read text, specific to the present exercise, is:

“Do you have a timer at your disposal? You can prepare it³⁷. You do what you want of the documents in front of you.

You have finished your 6-month mission on Mars. You took off from Mars and begin your flight toward the Earth. You start to experience the routine of the return flight.

Suddenly, your onboard computer prints these papers³⁸, the first one is white³⁹.

You have 30 minutes; your performance is measured on your rapidity to treat what is happening while taking into account the context.

I say “top” to launch the timer.”

4.2. Guidelines presented to the participants

The organizer prepares the documents needed to perform the exercise before its beginning. They are divided in three annexes:

- Annex 12: data of the trajectories,
- Annex 13: curves of the trajectories,
- Annex 14: technical manual dealing with the propulsion system and the correction method.

5. Operational performance measurement

This exercise is divided into three steps. The operational performances of the steps one and two are measured thanks to the time needed to obtain the related solution. The third step is evaluated according to the optimization of the result. In order to time the treatments precisely, the words of the leader of each team are the references for each timing. Indeed, a team’s decision comes from the leader⁴⁰. The information used as references for each step of the operational performance measurement are:

- First step: the time to understand that a collision is about to happen at the point named 03h00 with the coordinates (7, 14, -11). The interest to concentrate the operational performance measurement on the recognition of the collision point is to precisely mark the leader’s situation awareness.
- Second step: it is the time to calculate a valid trajectory correction. To be validated, the correction has to enable the collision avoidance and to be executed early enough to guarantee a distance of more than 2 Km between the vehicle and the asteroid when no correction is performed.
- Third step, the optimization is measured by comparing the propellant consumption of the correction chosen by a team to the minimum consumption. The less fuel a team consumes for the selected correction, the more trajectory corrections this team is still

³⁷ If no timers are available among the teammates, the organizer supplies one.

³⁸ The organizer shows the paper sheets with the data.

³⁹ The first page is white in order to hide the data before the beginning of the exercise.

⁴⁰ According to the definition of astronauts’ teams of L’Haridon (2019), a hierarchy exists and then a leader.

able to execute and then, the better the operational performance is. Thus, the result of the third step is the division of the least consuming correction (in fine 10% of the propellant reserved for trajectory corrections) by the correction of teams. So, this division provides a quantity without dimension.

A 0,3-ponderation coefficient is imposed to this third result in order to limit the influence of the optimization on the total operational performance of the exercise. This third step is only an optimization; contrary to the two previous steps, the third one does not deal with a survival challenge directly.

Taking into account this three-step problem, one or several teams might not solve one or several steps. Then, the concerned teams do not fulfill the whole exercise while other teams end it. Moreover, this exercise respects the following characteristics:

- Several steps exist,
- The best operational performances of teams are the lowest values (in fine, time and fuel consumption),
- A specific treatment order is imposed to the teams.

Thus, the method of the proportionate point is used (L'Haridon, 2019).

The answers of the three steps are:

- First step, the collision takes place at the point: 3h00 (7, 14, -11).
- Second step, the correction must be executed at the latest at the point: (5, 10, -7). The correction must propel the spaceship at least 2Km away, which means a 20-second burst of the engines RS-25.
- Third step, in order to optimize the propellant consumption, the engines RS-25 must be ignited for 20 seconds. Thus, a sufficient 2 Km advance is acquired.

Chapter 10: Mars Drone pilot skills and knowledge

1. Context

A manned mission takes place on Mars. The four teammates taking part to the exercise belong to a larger fictive crew of eight astronauts. Half of the total crew are four fictive astronauts who are performing an exploration of Mars aboard a rover. The other half are the participants. They are located in the main base and are waiting for the return of the rover.

The rover breaks down and is blocked (cf. figure 18). The failure is unknown and the crew in the rover has no solutions to solve the problem by his own. After a while, the ground control on Earth develops a check-list able to solve the failure of the rover. The ground control sends the check-list to the actual teammates in the main base.

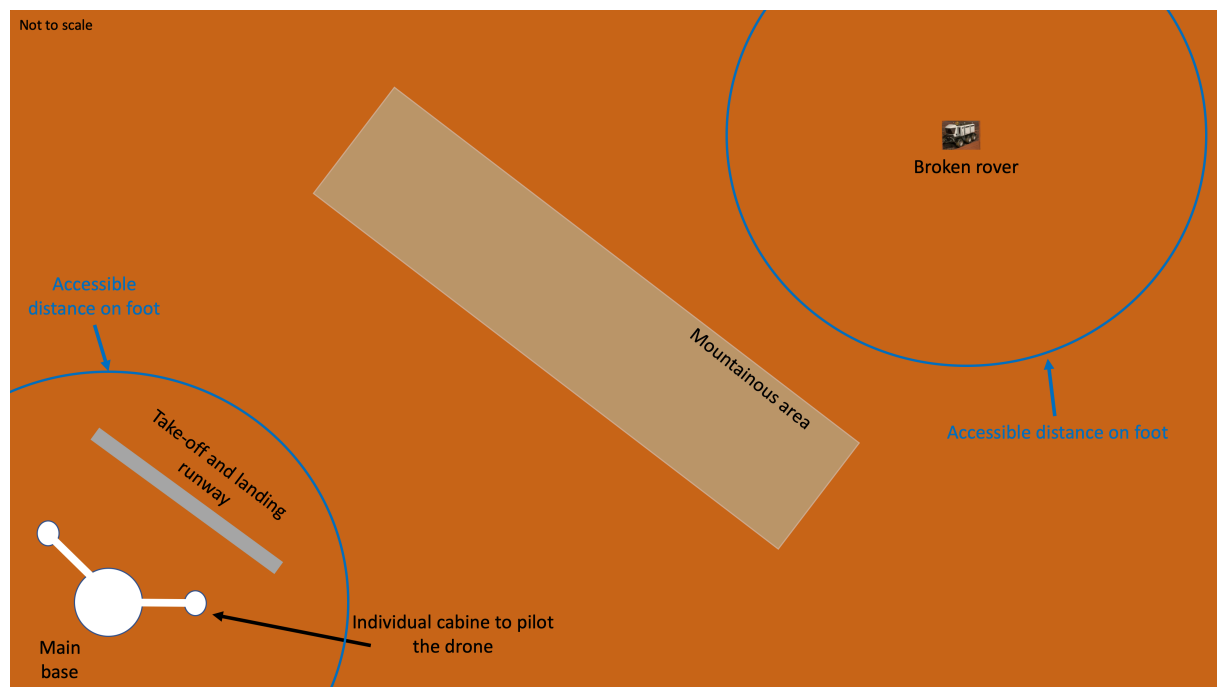


Figure 18. aerial view of the team distribution

The rover crew cannot receive this check-list due to communication difficulties associated with the endured failure. The signal receiver of the rover is damaged, so it cannot receive any message from the ground control on Earth or even the base anymore; the distance is too large. Then, the crew in the main base must perform a radio relay, with a drone, between their location and the rover. Then, the distance is decreased and the signal receiver of the rover can work. Unfortunately, the only drone pilot is blocked in the rover. So, one pilot must be chosen among the actual teammates.

The raised challenge is: how to choose a drone pilot?

2. Interests & specificities

The teams must take into account the contextual and mission particularities of the guidelines in order to establish a selection method (L'Haridon, 2019). This selection method must take into account different criteria:

- To select an improvised operator to pilot a drone without any training,

- To perform a standard flight with racetracks in a restrained volume for one hour (duration of the transmission of the checklist). This delay demands the drone pilot to be concentrated and enduring,
- To execute the flight despite the drone pilot's isolation in the main base (cf. figure 18): he cannot talk with the rest of the teammates located in the main base while the drone is airborne. While executing the mission, the pilot cannot expect any support,
- Objective skills must be selected to choose the pilot.

Taking into account these constraints, the teams must mentally represent the drone mission on Mars and translate this mental representation into **weighted** skills and knowledge detained by only one teammate. Indeed, the pilot is isolated in the cockpit; so, the skills and knowledge cannot be disseminated among the teammates. One teammate must be able to perform all the tasks alone. For example, one teammate cannot handle the radio while another one pilots the drone. Thus, a practical reasoning and creativity must be applied by teammates so as to anticipate the operational tasks to perform, e.g. navigation, use of the radio, application of standard operating procedures, and failure treatments.

The specificities of Mars Drone pilot skills and knowledge are the construction of a mental representation thanks to practical reasoning and creativity and then applied to an operational mission. The teammates use this mental representation to define criteria in order to select a teammate to perform a precise mission.

3. Organization of the teammates

The experience is organized according to the figure 19.

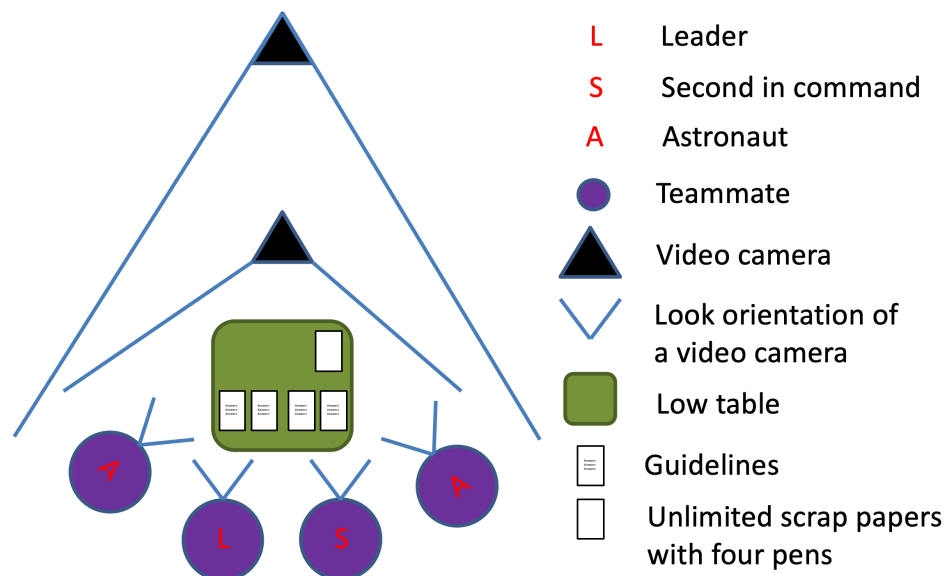


Figure 19. organization of the exercise Drone pilot's skills

The needed equipment is:

- Two video cameras,
- A tripod,

- Unlimited scrap paper with four pens,
- The guidelines announced by the organizer,
- Printed slides describing the context.

4. Elements presented to the participants

4.1. Text read to the teams

The first part of the read text is common with the other exercises of the LETUCA protocol (cf. the common elements presented in the Part II, chapter 1, paragraph 4.1).

The second part of the read text, specific to the present exercise, is:

“I don’t read you any particular text for this exercise. I give you the guidelines written on these paper sheets. You have four identical papers, one per teammate.

You have maximum 30 minutes. If you finish before, you can leave before.

Top”

4.2. Guidelines presented to the participants

Guidelines are printed and presented to each teammate (cf. annex 15). The text is dense and complex; so, to be sufficiently assimilated, it is delivered to each teammate. They can read it as many times as they want.

Printed slides are supplied to the teams to present the context (cf. annex 16). Two particularities are remarkable in these slides.

Firstly, many aircraft technologies exist and have consequences on the requested pilot’s skills, e.g. launch rail departure, helicopter, standard aircraft, propeller, etc. Then, a picture of the drone is presented to fix the type of the needed piloting⁴¹. Like in real operations, a lot of elements are fixed at the start of the mission, in fine, the initial state (used equipment, teammates, etc). The translation of this initial state into this exercise is: all the teams know the type of drone available on Mars. Then, the elements of the definition and identification of the problem is common to all the Teams.

Secondly, technical pieces of information are provided to enable the teams to target the necessary skills for this mission.

5. Operational performance measurement

The psychological studies and research center of the French Air Force (CERP’AIR, 2017) developed a list of skills and knowledge used by drone pilots in military operations. Then, this list is used to select the most appropriate staff to complete missions conducted with drones. Within the framework of the LETUCA protocol, these skills and knowledge included in larger categories were filtered and adapted to the context of an in-flight radio relay establishment on Mars. Like for the Fire procedure exercise, some skills and knowledge were transferred

⁴¹ This technic is also used in the bag exercise where a picture of the bag is imposed to force the teams to begin their reasoning from a common start point.

immediately to the present situation, some were modified, and some others were rejected. Indeed, all the particularities of a military mission with a drone are not relevant for a scientific exploration on Mars. Thus, a reference list was established for the exercise of the LETUCA protocol. The organization of this reference list is described below and all the items are available in the annex 17.

All the skills and knowledge have not the same importance; for example, the optimization of the mission is less important than the security of the persons and or the materials. Thus, similarly to the operational performance measurement of Mercury 21, a weighting discriminates the importance of skills and knowledge one another. The most important skill or knowledge of the complete list has the highest weight, the second one has the second most important weight, etc. The sum of all the weights is 100 points, then, if a team inscribes all the relevant skills and knowledge, this team scores 100 points.

The weighting method is divided in three precision levels (L'Haridon, 2019), the third one depends on the answers chosen by a team, as described by the figure 20.

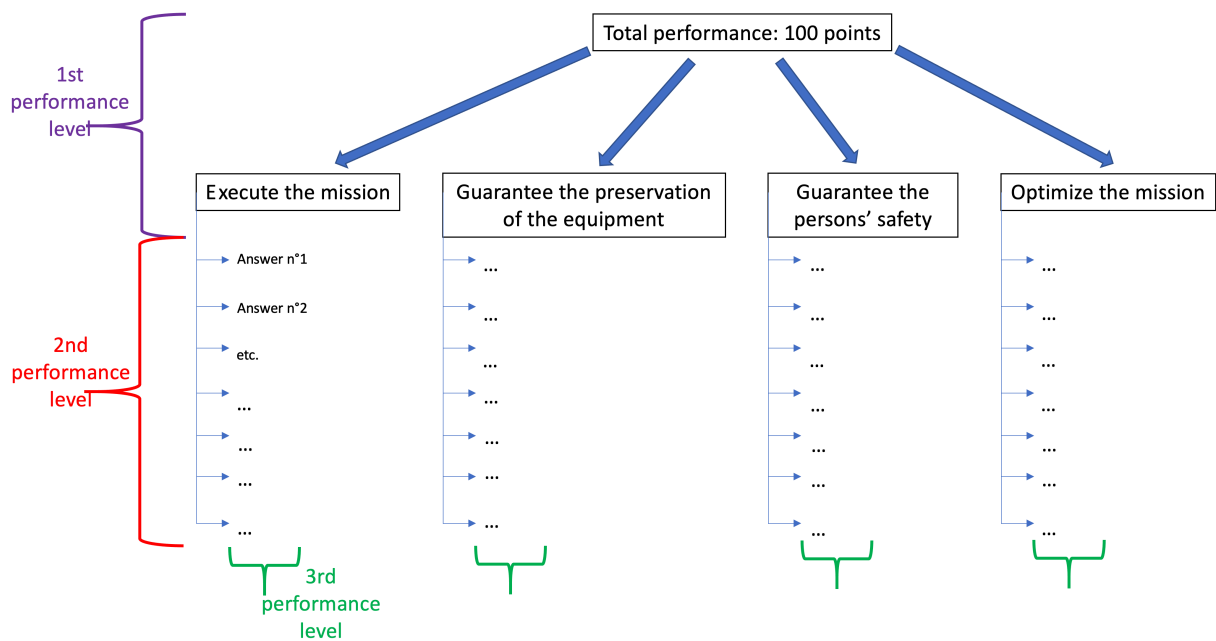


Figure 20. performance levels of the Drone pilot's skills exercise

The first and more general performance level deals with the weighting of four general activities used to pilot a drone on Mars among one another. The four general activities are:

- Execute the mission,
- Guarantee the preservation of the equipment,
- Guarantee the persons' safety,
- Optimize the mission.

These four categories play a different role in the mission success. So, the weighting consists in distributing the 100 points among the four general activities. E.g., since the persons' safety is more important than the mission optimization, their safety must detain a heavier weight in the list.

However, these general activities can be divided into detailed skills and knowledge, hence a second performance level. Then, a second weighting must be executed to discriminate skills and knowledge within each one of the four general activities. For example, in the general activity called “Execute the mission” (cf. figure 20), to take-off the drone is more important than a precise programming of the drone sensors.

The third level deals with the level of precision of an answer: does this answer is too large or too precise compared to the corresponding item of the second performance level? For example, an answer may be too precise, so it is partial. For instance, the item “to takeoff” requires maintaining the runway heading, correcting the wind at lift off, etc. If a team only announces the runway course keeping, the answer will be partial in relation to the larger task of the take-off execution. Nonetheless, a partial answer is not wrong, but incomplete. On the contrary, if an answer is too large, it will be irrelevant or not relevant enough for a drone pilot’s selection. Being the reference of the French Air Force in evaluating skills and knowledge corresponding to a specific job and in participating to operational professionals’ selections, the CERP’AIR (2017) determined a level of precision for the list this center produced. Thus, the level of precision (too precise versus too large) of this exercise of the LETUCA protocol is identical to the level of precision of the list of the CERP’AIR (2017).

If a team gives too much detailed elements included in a single skill or knowledge, then this skill or knowledge is too much specified and misses some elements. So, the answer is partial. Numerous partial answers exist and it is impossible to anticipate all of them. Then, if a team writes down a partial answer, the associated performance will have to be measured individually. For instance, if the partial answer covers a large part of the complete skill or knowledge, most of the points skill or knowledge assigned to this skill or knowledge will be scored. So, if a team gives an exhaustive list of all the items of a complete skill or knowledge⁴², all the associated points will be counted according to the corresponding weighting. On the contrary, if an answer is too large compared to the level of precision of the CERP’AIR (2017), this answer is not taken into account for the performance because it is not relevant for a drone pilot’s selection.

A team’s operational performance is the sum of the points assigned to each skill and knowledge belonging to the second performance level which were gained. The details of the total weighting are presented in the annex 17.

Additional remarks are necessary to measure the operational performance:

- The teammates do not know the list of skills and knowledge established by L’Haridon (2019) to measure the operational performance. So, the vocabulary used by teams to formulate answers may differ from the list. Thus, a language analysis is necessary to understand if the teams’ ideas correspond or not to the reference list (annex 17).
- The time to announce each skill is not taken into account, unlike the Mercury 21 exercise. Indeed, the goal is to establish a selection method ready to use in less than 30 minutes. The measured state is the final one; no intermediate states or progression gradients are requested.
- The Drone pilot’s skills and knowledge exercise is not an open performance because the list of skills and knowledge is fixed before the experience (cf. annex 17).

⁴² Belonging to a second performance level item

Chapter 11: Docking port relocation

1. Context

A computer virus was downloaded in the central computer of the International Space Station (ISS) while a crew is aboard (in fine, the participants of the exercise). To erase this virus, the ground control center performed a complete reset of the station. It worked but two unanticipated consequences happened:

- The computer controlling the docking port where the Soyuz of the crew is located overheated. Consequently, this computer is now out of service. Moreover, due to this malfunction, this docking point will be lost 35 minutes later. Then, if the crew of the Soyuz stays docked to this location, the module will also be lost in 35 minutes. So, to keep the Soyuz operational, the crew has to transfer it from the failed docking port to another one.
- The flight controls and interfaces of the Soyuz were reinitialized to the first version of the related software. Unfortunately, the teams were not trained on this very first version.

The goals of this exercise are to force the teams to learn quickly the displays and to understand the control commands of the flight controls of the Soyuz with the first version. Software were already used for teamwork experiences, for instance Volpe, Cannon-Bowers, Salas, and Spector (1996) employed a “PC-based F-16 aircraft simulation” to investigate cross-training on team functioning. The software used as a Soyuz simulator for this LETUCA exercise is SoyuzSim (Baroncini, 2012) on iPad. The figure 21 presents a standard display of the interface of the Soyuz while the module is approaching an ISS docking port.

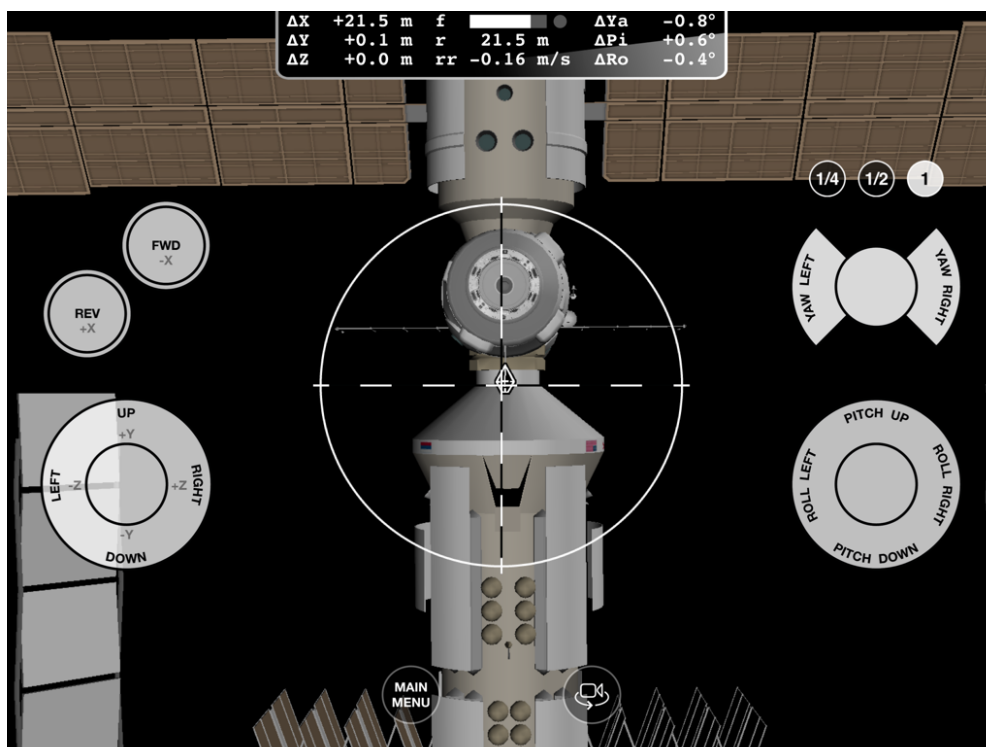


Figure 21. view from the simulator of the Soyuz

2. Interests & specificities

At the beginning of the exercise, the organizer distributes the functions to the teammates, one of which is the pilot role. So, one of the teammates becomes the pilot of the Soyuz. He is the only one authorized to act on the simulator. Then, the three out of four crewmates are not allowed to handle the simulator and might develop some frustration, in particular the captain. It is an interest of this exercise, i.e. to place the teams in a frustrating situation.

In real operations, teammates can be under the pressure from vibrations, time constraints, noise, etc. while they are completing a specific and less impressive task. Similarly, in the Docking port relocation exercise, the teams encounter a threatening situation. Indeed, if no actions are performed, the only vehicle to fly back to Earth will remain stowed at the docking port. Thus, a transfer of the Soyuz must be executed in less than 30 minutes and the teams might be easily focused on the transfer of the Soyuz. Nevertheless, this relocation is not the goal of the exercise; as described in the guidelines, the goals are to learn and understand the elements changed due to the modification of the software version:

- Displays,
- Engine commands,
- Practical knowledge about trajectory commands.

Finally, an aspect of this exercise is to evaluate the capacity of the teams to focus on a specific task despite an attractive environment.

Several interests exist so as to give this exercise an operational environment. Firstly, the total time available to complete the task is reduced while teams are working. Indeed, the treatment time is decreased by three minutes over an initial 22-minute duration. The goal is to disturb the teams and to force their adaptation. Secondly, the teams work on a low-fidelity space flight simulator. Then, the environment is operational and the reasonings of teams need to be logic and practical (flight parameters, flight commands, and information displays).

The specificities of Docking port relocation are a potential frustrating situation, in which teams must remain focused on a specific goal despite an attractive operational environment.

3. Organization of the teammates

The needed equipment is:

- Two video cameras,
- A tripod,
- A tablet with the software SoyuzSim (Baroncini, 2012),
- A TV screen,
- A connection cable between the TV screen and the tablet,
- Unlimited scrap paper with four pens,
- Guidelines of the exercise (cf. annex 18),
- Guidelines of the simulator (cf. annex 19),
- The technical manual of the Soyuz (cf. annex 20).

The experience is organized according to the figure 22.

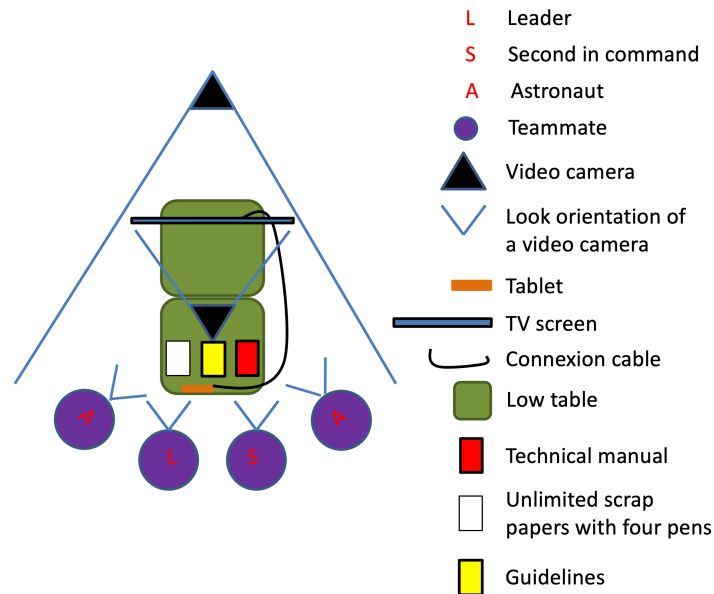


Figure 22. organization of the exercise Docking port relocation

4. Elements presented to the participants

4.1. Text read to the teams

The first part of the read text is common with the other exercises of the LETUCA protocol (cf. the common elements presented in the Part II, chapter 1, paragraph 4.1).

The second part of the read text, specific to the present exercise, is:

“This exercise belongs to a scientific research, I request you to act with professionalism during the task completion. The exercise lasts 22 minutes⁴³.

The four of you are aboard the International Space Station. Your space vehicle, a Soyuz module, used to join the space station and to fly back to Earth, is docked to the “ZVEZDA” docking port⁴⁴. The day goes on and each one of you is focused on his own personal tasks.

Suddenly, a total electricity extinction occurs in the International Space Station. A few seconds later, the electricity comes back and the onboard printer prints these paper sheets⁴⁵.

Please have your seat⁴⁶. I launch the timer in 10 seconds, afterwards you can read the paper sheets.”

As soon as the timer indicates 15 minutes, the organizer says: “you have only 4 minutes left.”

⁴³ 30 minutes is a too long compared to the tasks to perform.

⁴⁴ The organizer shows the docking point on the computer presentation.

⁴⁵ The organizer shows the technical manual and the guidelines.

⁴⁶ The organizer distributes the functions and the seats.

4.2. Guidelines presented to the participants

The software SoyuzSim (Baroncini, 2012) is loaded in a tablet available on the low table (cf. figure 22). The guidelines are read but also printed and at the teammate's disposal (cf. annex 18). Indeed, many information and constraints are required to complete the exercise. Each element must be taken into account; so, the teams have a free access to these elements. A second document is a user manual of the simulation software of a Soyuz module (cf. annex 19).

Based on a schema of the NASA presenting the ISS and on SoyuzSim (Baroncini, 2012), pictures of the environment of the ISS and the docking procedure are presented (cf. annex 20). Indeed, in that situation, the astronauts would already know numerous elements of their environment: the trajectory of the docking port relocation, the dimensions of the space station, the external guidance system, the safety margins, etc. On the contrary, participants of the LETUCA protocol might not know these elements because they are not trained for such missions on the ISS. Then, the prior knowledge of the context and the technical manual (annex 20) has no relationship with the measurement of the operational performance of the exercise Docking port relocation. Thus, the teams receive these elements and the operational performance measurement is focused on the established goals (to learn the displays and to understand the control commands of the Soyuz). Finally, the teams are more available to work on the displays and the control commands.

5. Operational performance measurement

The operational performance measurement is focused on the:

- Knowledge of the commands,
- Knowledge of the information, and
- Manœuvre planning.

Each time an element of the displays or the control commands is defined and inscribed on the answer sheet, one point is scored. Then, the final result of this exercise is the answer sheet. The need to write down the answers gives a professional context and decrease the probability that the teams' attention only focuses on the game software.

The answers included in the knowledge of the commands presented on the screen are:

- Existence of a viewfinder for pilot the Soyuz,
- Lateral motion command, left and right (LEFT and RIGHT),
- Lateral motion command, counterthrust needed,
- Vertical motion command, up and down (UP and DOWN),
- Vertical motion command, counterthrust needed,
- Heading line motion command, forward and reverse (FWD and REV),
- Heading line motion command, counterthrust needed,
- Yaw motion command, left and right (YAW LEFT and RIGHT),
- Yaw motion command, no counterthrust needed,
- Roll motion command, left and right (ROLL LEFT and RIGHT),
- Roll motion command, no counterthrust needed,
- Pitch motion command, up and down (PITCH UP and DOWN),
- Pitch motion command, no counterthrust needed,

- Gain command 1 to use the full power of the engine,
- Gain command 1/2 to use half the full power of the engine,
- Gain command 1/4 to use one-quarter of the full power of the engine,
- Lack of automatic pilot.

The answers included in the knowledge of the information presented on the screen are:

- Distance on the axis Oy between the Soyuz and the target of the docking point: ΔX ,
- Distance on the axis Oy between the Soyuz and the target of the docking point: ΔY ,
- Distance on the axis Oz between the Soyuz and the target of the docking point: ΔZ ,
- Consumed propellant with the corresponding scale: f,
- Black or white point next to the propellant indicator f: consumption in progress if the point is white, otherwise it is black,
- Total distance between the Soyuz and the target of the docking point: r,
- Derivative of the total distance between the Soyuz and the target of the docking point, in fine, the speed relative to the target of the docking point: rr,
- Difference between the direction angle of the Soyuz and the docking target: ΔY_a ,
- Difference between the roll angle of the Soyuz and the docking target: ΔP_i ,
- Difference between the pitch angle of the Soyuz and the docking target: ΔR_o ,
- Presentation of the standard messages during the undocking and docking of the Soyuz,
- The reference of the displayed angles and distances is the target of the docking port.

The answers included in the manoeuver planning are:

- Docking maximum speed,
- Docking minimum speed.

Chapter 12: Monument Valley

1. Context

The scenario is rudimentary. The teams are placed in front of an unusual video game loaded in a tablet and must succeed as fast as possible. The used software is Monument Valley (Ustwo, 2014). The teammates move a character (white character in the figure 23) on platforms according to specific rules.

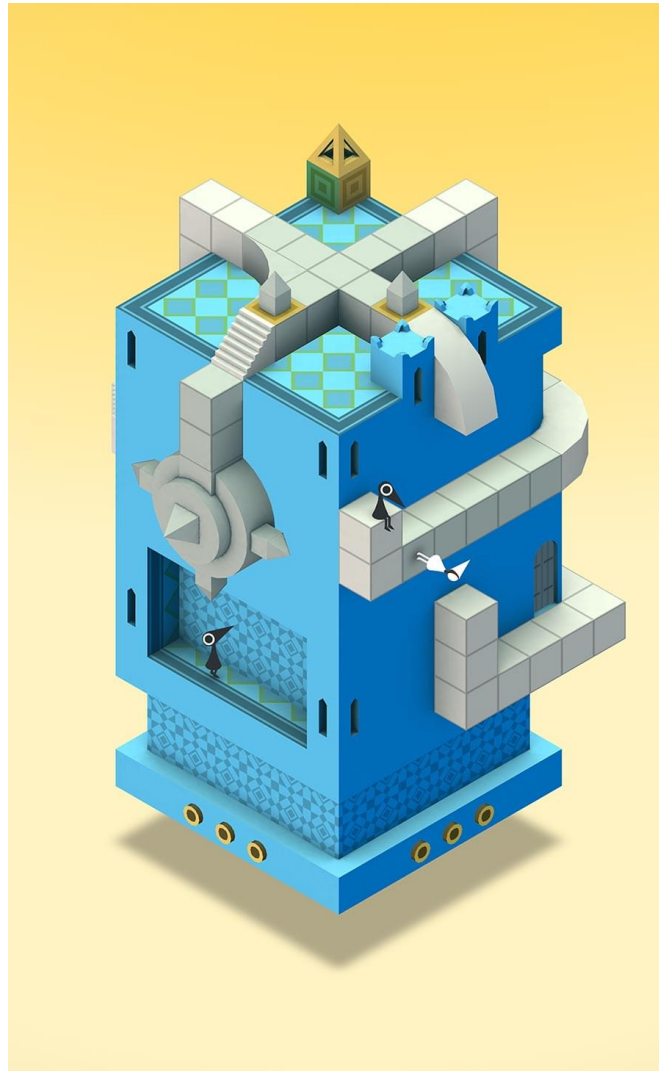


Figure 23. one of the used platforms of Monument Valley (Ustwo, 2014)

The following list enumerates all the specificities of Monuments Valley (Ustwo, 2014):

- Elements of the environment can rotate to enable displacements,
- Elements of the environment can translate to enable displacements,
- Elements of the environment can be twisted to enable displacements,
- Platforms are inspired of the Waterfall of Escher (1961),
- The gravitational field is modified according to the location of the character (inspired by the Relativity of Escher, 1953),
- Characters are obstacles for some moves,
- To imprison elements which are obstacles,
- Elements must be used to access new platforms.

Specifically, “Ida’s dream” chapter gathers the following specificities:

- Elements of the environment can rotate to enable displacements,
- Elements of the environment can translate to enable displacements,
- Elements of the environment can be twisted to enable displacements,
- Inspired by the Waterfall of Escher (1961),
- Gravitational field modification according to the orientation of the walk (inspired by the Relativity of Escher, 1953),
- Use of one character and one object to access new platforms.

In Monuments Valley, the “Ida’s dream” chapter (Ustwo, 2014) is chosen for the LETUCA experience. Following an analysis of the specificities of the whole software, this chapter is considered as an abstract of Monuments Valley (Ustwo, 2014).

2. Interests & specificities

Moreover, no instructions are given to understand how the environment works and to determine the problem to solve, so as to make Monuments Valley (Ustwo, 2014) an unknown problem.

Monuments Valley (Ustwo, 2014) forces the participants to react and to adapt themselves to unusual rules (for instance, a nonstandard gravity field and modifications of the environment). Especially, Monuments Valley is partially built on the works of Escher, the Relativity (1953) and the Waterfall (1961). These works of art present the inside of a building walk without any top and bottom where people on all surfaces and an infinite waterfall respectively. These unusual rules are distributed among six games in Monuments Valley (Ustwo, 2014), each with its own individual goal and rules. Then, the teams need a constant mental flexibility, creativity, and mental representation endeavor.

The specificities of Monument Valley are an unknown exercise built on six individual problems necessitating a systematic cognitive adaptation.

3. Organization of the teammates

The needed equipment is:

- The “Ida’s dream” chapter of Monuments valley (Ustwo, 2014), loaded in a tablet,
- Two video cameras,
- A tripod,
- A TV screen,
- A connection cable between the TV screen and the tablet.

The experience and the game start together.

The experience is organized according to the figure 24.

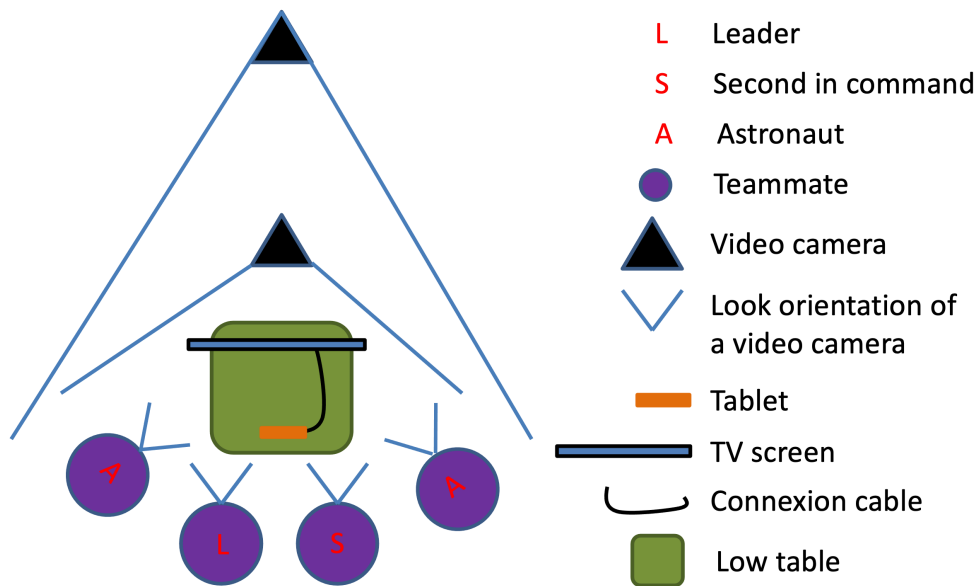


Figure 24. organization of the exercise Monument Valley

4. Elements presented to the participants

4.1. Text read to the teams

The first part of the read text is common with the other exercises of the LETUCA protocol (cf. the common elements presented in the Part II, chapter 1, paragraph 4.1).

The second part of the read text, specific to the present exercise, is:

“Do not touch the two buttons at the top left of the screen:

- the 1st button: a little circle with a point at the center, it is used to go back to the main menu,
- the 2nd button: a grey square with a big point inside, it is used to leave the software.

We understand easily that they do not belong to the experience, so, please, do not touch these two buttons.

Your performance is measured on the time needed to end the complete game and each sub game. The complete game begins on a main platform composed of different doors. An sub game starts when you use a door and ends when you leave that same door. Attention, the faster you finish each sub game and the more sub games you win, the higher is your performance. So, do not loose time when you are on the main platform.

You must proceed to as many doors as possible in a very specific order: from the closest door from the initial position to the furthest door. There is only one path; so, there is no ambiguity about the distance among the different doors. If you make a mistake, I will interrupt you in order to reconfigure the tablet, so, you will lose time and your performance will be diminished. As long as I say nothing, just keep on progressing.

I repeat, you must proceed form the closest door from the initial position to the furthest door.

You have maximum 30 minutes, if you finish earlier, you can leave earlier.

Top”

4.2. Guidelines presented to the participants

The teams work with the “Ida’s dream” chapter of Monuments valley (Ustwo, 2014). An experience is launched on a special angle of observation above the main platform and a specific position of the main character. The goal of these two settings is to give the teams the very specific sequencing of the door to follow during the resolution of all the sub games.

The angle of observation used for the beginning of the game is also determined to orientate the first character’s movements decided by the teams into the good direction. So, the probability that the teammates send the character at the opposite side of the platform and do not respect the progression order is decreased. This angle is managed by rotating the main platform, the section of which is square. So, they are four corners and one of them is all the time located at the center of the screen. Thus, four possible position of the platform exist. The required angle of observation is defined by⁴⁷:

- to the left of the corner: the first door and the main character and
- to the right of the corner: an empty corridor, with neither stairs nor doors.

The position of the character is defined with the following settings. A door is located on the left side of the corner, the character is placed at the left of this door, at one move. The character is also looking at the door. To get this orientation, the lift must be lowered in order to extend the path and enable the character to rotate and go back at the good position with the correct orientation. Finally, the lift is raised so the teammates must discover it later.

5. Operational performance measurement

“Ida’s dream” of Monuments valley (Ustwo, 2014) is divided into five chapters (or sub games) with each time specific particularities. As many chapters as possible must be completed. Each time necessary to complete a chapter is measured.

The teams must perform the sub games in the order of increasing distance from the starting point. For example, the first chapter is just near the character at the beginning of the experience and then, must be completed first. So, all the teams will proceed with the same order. Thus, if a team does not finish all the chapters, the ones fulfilled will be common with the other teams.

Then, the Monument Valley experience respects the following characteristics:

- Several steps belong to a single exercise,
- The best operational performance of teams is the lowest value,
- And a specific problems treatment order is imposed to the teams.

Thus, the method of the proportionate point is used (L’Haridon, 2019).

⁴⁷ Only one configuration is possible according to these settings.

Chapter 13: construction and gathering exercises

Breuker (1994) explains that “problems can be characterized by their (minimal) solutions, i.e. their generic conclusions. A generic conclusion is an abstract description of an object that covers the set of conclusions.” Breuker (1994) adds examples of types of generic conclusions; some are consensual (diagnosis, design, and planning) and some others are suggested by Breuker (1994, e.g. assessment and monitoring). L’Haridon (2019) uses this classification of problems based on the success to establish a solution or a goal to reach (Baiwir & Delhez, 2004). The exercises having different goals, then, it is possible to discriminate the problems of the LETUCA protocol one another.

In five exercises and sub-exercises, the participants have to gather results without any links among one another; these results are used to calculate the operational performance. The concerned exercises are called *gathering exercises* (our translation, L’Haridon, 2019). The concerned LETUCA protocol exercises are:

- The bag (Davidson et al., 1994), the teams have to find potential functions of a bag,
- Untangle, second part, the goal is to list specific pieces of advice enabling to win a game,
- Electrical system reproduction, inspired of the work of Leavitt and Mueller (1951), independent elements must be drawn and written,
- Mars Drone pilot skills and knowledge, skills and knowledge of a drone pilot on Mars must be established,
- Docking port relocation, adapted from the software of Baroncini (2012), the goal is to understand a human/machine interface⁴⁸.

In Nine other exercises and sub-exercises, the participants have to build a single or some multiple interdependent results, used for the operational performance calculation. These exercises are called *construction exercises* (our translation, L’Haridon, 2019). The concerned exercises of the LETUCA protocol are:

- Lunar survival (Hall & Watson, 1970), a list of priorities must be established,
- Mercury 21, the prioritization of several failures must be performed, followed by the resolution of the related sub-problems. This exercise is adapted from the internet website Enigme-facile,
- Missionaries and cannibals, the participants have to set a procedure and then to adapt it. This exercise is adapted from the internet website Enigme-facile,
- Euro, the participants must find the origin of an error in a mathematical reasoning. This exercise is adapted from the internet website Enigme-facile,
- Untangle, first part (adapted from Kechap Free Games Limited), the participants must understand a mobile schema so as to solve it,
- Fire procedure, a checklist of actions must be reordered according to a space exploration context,
- Mars failure report, information must be classified according to their importance in a space exploration context,
- Asteroid avoidance, the participants have to treat a problem from its beginning to its completion,

⁴⁸ The groups of results have no links among one another.

- Monument Valley, several logical problems must be solved, adapted from Ustwo (2014).

Conclusion

Twelve exercises compose the LETUCA protocol, each one has its own specificities including a context, an operational performance measurement, the qualification of gathering or construction, and interests. Seven out of the twelve exercises are classified as unknown problem (L Haridon et al., 2017), i.e.:

- Mercury 21,
- Euro,
- Untangle,
- Fire procedure,
- Electrical system reproduction,
- Asteroid avoidance,
- Monument Valley.

The exercises and their scenarios can be treated without any particular knowledge in space exploration; thus, participants need no previous space training. Moreover, each exercise last less than thirty minutes, are independent one another, and can be reproduced with office equipment. Then, depending on these specificities, future scientific research can reuse, adapt the LETUCA protocol and focus on one or several exercises.

GENERAL CONCLUSION

L'Haridon (2019) designed the LETUCA protocol, composed of twelve exercises mainly dealing with an astronautical context. L'Haridon (2019) used this protocol for the completion of a PhD about the improvement of team operational performances while coping with unknown problems in operational environments. Then, the LETUCA protocol is developed to make teams work on exercises in order to establish operational performances. To achieve this goal, two key elements determine the design of the exercises.

First, an actual team working in an operational environment understands how to be performant according to its own experience. So, the participants must also be able to understand the way to be performant at the beginning of each exercise even if they did not receive any space training before their involvement in the LETUCA protocol. To do so, information about the way to get a high operational performance are written in the guidelines of the exercises.

Second, the analyze of the operational performance of the participating teams requires the comparison of all the results one another despite the different natures they have. Indeed, some exercises are based on a time (Fire procedure and Monument Valley), some others on a number of points (Lunar survival, Missionaries and cannibals, Electrical system reproduction, Mars failure report, Mars drone pilot skills, and Docking port relocation), and some on times and points simultaneously (Mercury 21 and the Bag and Euro, Untangle, and Asteroid avoidance). Then, this comparison of the results demands the design of several mathematical technics for the LETUCA protocol. Some technics are included in specific exercises according to their intrinsic characteristics, in fine the Open versus closed performance, the Method of the proportionate point, and the Method of the integrals (L'Haridon, 2019). These three technics enable to extract one single result highlighting the operational performance of a team for each exercise, even if several sub-games exist. These technics only treat the data of each single exercise and the complete comparison is not possible for the whole LETUCA protocol; so, they compose the first step of the operational performance measurement. So as to compare all the operational performance results one another, the LETUCA protocol uses the "General relativity" method (L'Haridon, 2019). The associated formula employs one of the teams as a reference all along the LETUCA protocol. In doing so, all the other teams' operational performance results are compared to this reference. Then, each team's operational performance becomes a quantity relative to the reference team without any unit and the all operational performances can be compared finally. In fine, the mathematical relativity of the results enables the researcher to completely analyze the operational performance of the teams.

Thus, a two-step measurement exists, one step to sum up the operational performance for a single exercise and a second one to compare all the operational performance results.

In parallel to the operational performance measurement, characteristics detail the LETUCA protocol so as to meet the needs of L'Haridon (2019). Firstly, this protocol is used to make teams work collectively in a simulation of operational environment. Then, in all the exercises, the teammates receive specific functions like operational crews. Secondly, the LETUCA protocol is organized in a laboratory environment. Indeed, the goal of the protocol is to compare the operational performances of teams, then similar conditions must be set. So, the participating teams have a similar environment on which reasonings and decisions specific to each team can be selected. Moreover, the available means and the laboratory conditions imply to situate the LETUCA protocol at a low-fidelity simulation of space flights. Nonetheless, this level is useful at the "initial learning" (Beaubien & Baker, 2004) and it stimulates "trainees to engage in the same cognitive processes necessary when transferring and generalizing new skills into their daily work environment" (Weaver et al., 2010). Thirdly, one risk of the LETUCA protocol is to encounter one or several interruptions of the participation of one or several teammates. Then, L'Haridon (2019) designed the exercises to easily insert them into the daily life of the participants. Taking into account this need, the maximum duration to complete the resolutions

is thirty minutes and the problems are easy enough to be solved without any space exploration training.

More broadly, the present method explains all the characteristics and supplies the necessary elements of the exercises in order to reproduce the LETUCA protocol for future researches. The context, interests, organization of the laboratory, performance measurements, and the elements presented to the teams are available in the present method.

Then, the LETUCA protocol can be used with only specific exercises or with the twelve ones. In this second case, the exercises are sufficiently different from one another because of their initial design. Then, a surprise effect exists so as to avoid any transfer of treatment method from one problem to another. So, if the participating teams do not know a problem at its beginning, they cannot expect the solution of an exercise at the start of its resolution. Moreover, seven out of twelve exercises are unknown qualified. Indeed, a context are given to the teams but without any guidelines; thus, these exercises are similar to the unknown situations encountered in actual operations (L'Haridon, 2019).

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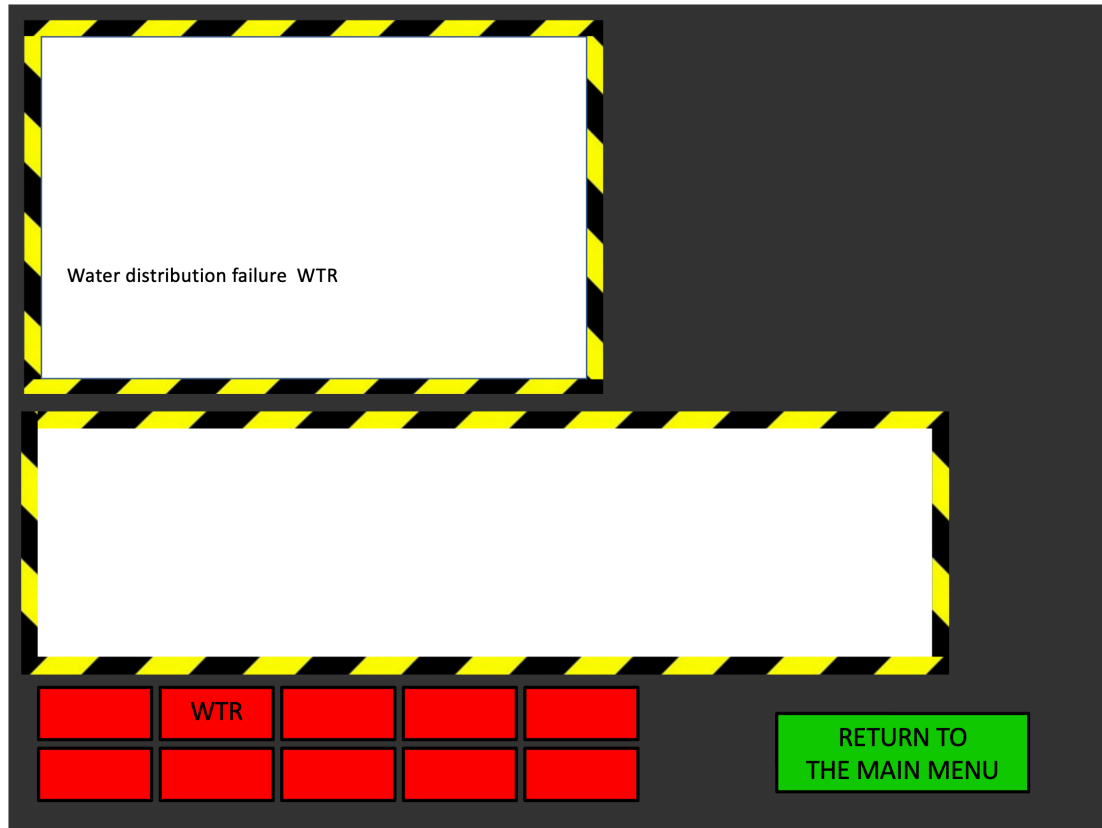
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ANNEX 1: FAILURES INTERFACE



Beginning of the exercise:

React to the event

The next « click » starts the chronometer

Automatic pressure regulator failure AUT PR
 Entertainment system failure ENT
 Heating system failure HTG
 Moon landing system failure L/D
 Navigation system failure NAV
 Major oxygen failure O2
 Secondary electrical system failure ELEC2
 Main engine failure ENG1
 3rd radio failure RAD 3
 Parachute deployment failure PARA

AUT PR

HTG

NAV

ELEC2

RAD 3

ENT

L/D

O2

ENG1

PARA

RETURN TO
THE MAIN MENU

Automatic pressure regulator failure AUT PR
 Entertainment system failure ENT
 Heating system failure HTG
 Moon landing system failure L/D
 Navigation system failure NAV
 Major oxygen failure O2
 Secondary electrical system failure ELEC2
 Main engine failure ENG1
 3rd radio failure RAD 3
 Parachute deployment failure PARA

The calculator n°1 is calibrated to lie on Monday, Tuesday and Wednesday. The calculator n°2 is calibrated to lie on Thursday, Friday and Saturday. The other days, they say the truth.
 The calculator n°1 gives: "yesterday: lies". The calculator n°2 gives: "yesterday: lies".

Indicate which day is programmed in the system.

AUT PR

HTG

NAV

ELEC2

RAD 3

ENT

L/D

O2

ENG1

PARA

RETURN TO
THE MAIN MENU

Automatic pressure regulator failure AUT PR
 Entertainment system failure ENT
 Heating system failure HTG
 Moon landing system failure L/D
 Navigation system failure NAV
 Major oxygen failure O2
 Secondary electrical system failure ELEC2
 Main engine failure ENG1
 3rd radio failure RAD 3
 Parachute deployment failure PARA

You own one file in the entertainment software. This file is multiplying itself, it is only going to saturate the entertainment system.

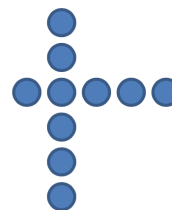
The question is: how many files will you have in 10 hours taking into account that each file can produce 18 files each hour after existing at least 2 hours?
 At the origin, only one entertainment file exists.

AUT PR	HTG	NAV	ELEC2	RAD 3
ENT	L/D	O2	ENG1	PARA

RETURN TO THE MAIN MENU

Automatic pressure regulator failure AUT PR
 Entertainment system failure ENT
 Heating system failure HTG
 Moon landing system failure L/D
 Navigation system failure NAV
 Major oxygen failure O2
 Secondary electrical system failure ELEC2
 Main engine failure ENG1
 3rd radio failure RAD 3
 Parachute deployment failure PARA

The explosion has moved the position of the electrical resistances of the heating system. So, they must be repositioned. Two lines with 6 resistances each must be formed by relocating just one resistance.



Find the solution.

AUT PR	HTG	NAV	ELEC2	RAD 3
ENT	L/D	O2	ENG1	PARA

RETURN TO THE MAIN MENU

Automatic pressure regulator failure AUT PR
Entertainment system failure ENT
Heating system failure HTG
Moon landing system failure L/D
Navigation system failure NAV
Major oxygen failure O2
Secondary electrical system failure ELEC2
Main engine failure ENG1
3rd radio failure RAD 3
Parachute deployment failure PARA

The explosion has erased an element of the flight control system needed for the Moon landing. So, it must be recovered:
9->72, 8->56, 7->42, 6->30, 5->20

How many makes 3?

AUT PR

HTG

NAV

ELEC2

RAD 3

ENT

L/D

O2

ENG1

PARA

RETURN TO
THE MAIN MENU

Automatic pressure regulator failure AUT PR
Entertainment system failure ENT
Heating system failure HTG
Moon landing system failure L/D
Navigation system failure NAV
Major oxygen failure O2
Secondary electrical system failure ELEC2
Main engine failure ENG1
3rd radio failure RAD 3
Parachute deployment failure PARA

Three men are placed one behind the other. Each one wears a hat on his head. The hats were taken randomly among three black hats and two white hats. The men do not know which hat they have on their own head.

The man C sees the two other men, the man B sees only the man A and the man A does not see anyone. Each man can hear the answers of the others.

The man C is asked if he knows his hat's color. He answers "no". Same question to B, he answers "no". But A knows the color of his hat, how does he do?

AUT PR

HTG

NAV

ELEC2

RAD 3

ENT

L/D

O2

ENG1

PARA

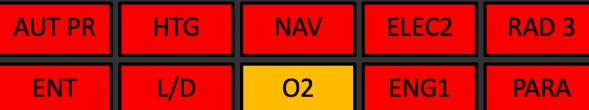
RETURN TO
THE MAIN MENU

Automatic pressure regulator failure AUT PR
Entertainment system failure ENT
Heating system failure HTG
Moon landing system failure L/D
Navigation system failure NAV
Major oxygen failure O2
Secondary electrical system failure ELEC2
Main engine failure ENG1
3rd radio failure RAD 3
Parachute deployment failure PARA

1st O2 failure:

You must inject in just one time exactly 4 liters of liquid oxygen in the circuit to restore the oxygen system. To do so, you have two non-graduated bottles. One can contain 5 liters and the other one 3 liters.

How can you exactly measure 4 liters in the 5-liter bottle?



PB O2 n°2

Automatic pressure regulator failure AUT PR
Entertainment system failure ENT
Heating system failure HTG
Moon landing system failure L/D
Navigation system failure NAV
Major oxygen failure O2
Secondary electrical system failure ELEC2
Main engine failure ENG1
3rd radio failure RAD 3
Parachute deployment failure PARA

2nd O2 failure:

You must inject in just one time exactly 2 liters of liquid oxygen in the circuit to restore the oxygen system. To do this, you have two non-graduated bottles. One can contain 3 liters and the other one 4 liters.

How can you exactly measure 2 liters in the 4-liter bottle?



RETURN TO
THE MAIN MENU

Automatic pressure regulator failure AUT PR
 Entertainment system failure ENT
 Heating system failure HTG
 Moon landing system failure L/D
 Navigation system failure NAV
 Major oxygen failure O2
 Secondary electrical system failure ELEC2
 Main engine failure ENG1
 3rd radio failure RAD 3
 Parachute deployment failure PARA

Seven electrical wires are located in a tube. The explosion has degraded the isolation, so you must separate the wires to avoid any short-circuit. You can only use three insulators (in red in the example). The wires are flexible and no longer electrified.



Find the solution.

AUT PR	HTG	NAV	ELEC2	RAD 3
ENT	L/D	O2	ENG1	PARA

RETURN TO THE MAIN MENU

Automatic pressure regulator failure AUT PR
 Entertainment system failure ENT
 Heating system failure HTG
 Moon landing system failure L/D
 Navigation system failure NAV
 Major oxygen failure O2
 Secondary electrical system failure ELEC2
 Main engine failure ENG1
 3rd radio failure RAD 3
 Parachute deployment failure PARA

You have four chains, each one is composed of three links. You need to put the chains together to get one closed chain with a maximum length. This new chain is necessary to fix the engine thanks to the outside robotic arm.

What is the minimum number of links you must cut and then weld again to get this longest possible chain?

AUT PR	HTG	NAV	ELEC2	RAD 3
ENT	L/D	O2	ENG1	PARA

RETURN TO THE MAIN MENU

Automatic pressure regulator failure AUT PR
Entertainment system failure ENT
Heating system failure HTG
Moon landing system failure L/D
Navigation system failure NAV
Major oxygen failure O2
Secondary electrical system failure ELEC2
Main engine failure ENG1
3rd radio failure RAD 3
Parachute deployment failure PARA

A coding default is detected in the radio n°3 software, solve the following problem:

8809 = 6, 7111 = 0, 2172 = 0, 6666 = 4, 1111 = 0, 3213 = 0, 7662 = 2, 9312 = 1, 0000 = 4,
2222 = 0, 3333 = 0, 5555 = 0, 8193 = 3, 8096 = 5, 7777 = 0, 9999 = 4, 7756 = 1, 6855 = 3,
9881 = 5, 5531 = 0,

How many is 2581 =?

AUT PR	HTG	NAV	ELEC2	RAD 3
ENT	L/D	O2	ENG1	PARA

RETURN TO
THE MAIN MENU

Automatic pressure regulator failure AUT PR
Entertainment system failure ENT
Heating system failure HTG
Moon landing system failure L/D
Navigation system failure NAV
Major oxygen failure O2
Secondary electrical system failure ELEC2
Main engine failure ENG1
3rd radio failure RAD 3
Parachute deployment failure PARA

The six parachute lines have matted, so they must be replaced as needed.

Give the good disposal, taking into account that:
One line is between the two green lines,
Two lines are placed between the two red lines,
Three lines separate the two blue lines,
One blue line is placed to the far right.

AUT PR	HTG	NAV	ELEC2	RAD 3
ENT	L/D	O2	ENG1	PARA

RETURN TO
THE MAIN MENU

**ANNEX 2: TECHNICAL MANUAL EXTRACTION, MERCURY
21 MISSION**

TECHNICAL MANUAL EXTRACTION

MERCURY 21 MISSION

Summary:

1. Pressurization
2. Entertainment system
3. Heating system
4. Moon landing system
5. Navigational system
6. Onboard oxygen
7. Electrical networks
8. Propulsion
9. Radio equipment
10. Earth atmosphere re-entry system

1. Pressurization

Two systems control the onboard pressurization.

The first system manages the pressurization regulation, the recycling and the chemical composition of the air automatically. Two independent calculators perform the automatic control. The failure of one does not degrade the automatic operation.

The second system controls the pressurization regulation, the recycling and the chemical composition of the air manually. Its operation does not degrade the onboard pressurization. When the manual mode is activated, the astronauts must monitor these functions every three days and, if needed, have to control them manually. This mode ensures the full onboard pressurization.

2. Entertainment system

The onboard entertainment system is composed of a TV screen, a computer with more than 2000 movies selected between 1990 and 2020, a sound system and a last generation video game console.

An electrical failure implies a temporary stop of the entertainment system.

3. Heating system

The heating system supplies the temperature requested by the crew. When the heating system is out of service, the delivered temperature varies between 10°C and 15°C. The crew cannot set the temperature anymore, despite the impact on the comfort.

4. Moon landing system

The Moon landing system is the only way to land on the Moon surface. If it is deficient, the crew will not try any landing. Indeed, the crew will take a too high level of risks about the integrity of the vehicle.

5. Navigational system

The navigational system is the only device to control the complete trajectory. There is no manual mode. This system performs the following functions:

- Earth take-off,
- Low-Earth orbit insertion,
- Creation of the Earth catapult effect,
- Transfer to the Moon,
- Integration into the low-Moon orbit,
- Creation of the Moon catapult effect,
- Transfer to the Earth,
- Integration into the low-Earth orbit,
- Earth-atmosphere re-entry.

6. Onboard oxygen

The onboard oxygen system contains the oxygen and controls its supply to the pressurization system. A major failure of the oxygen supply limits the survival of the crew to 20 minutes maximum.

7. Electrical networks

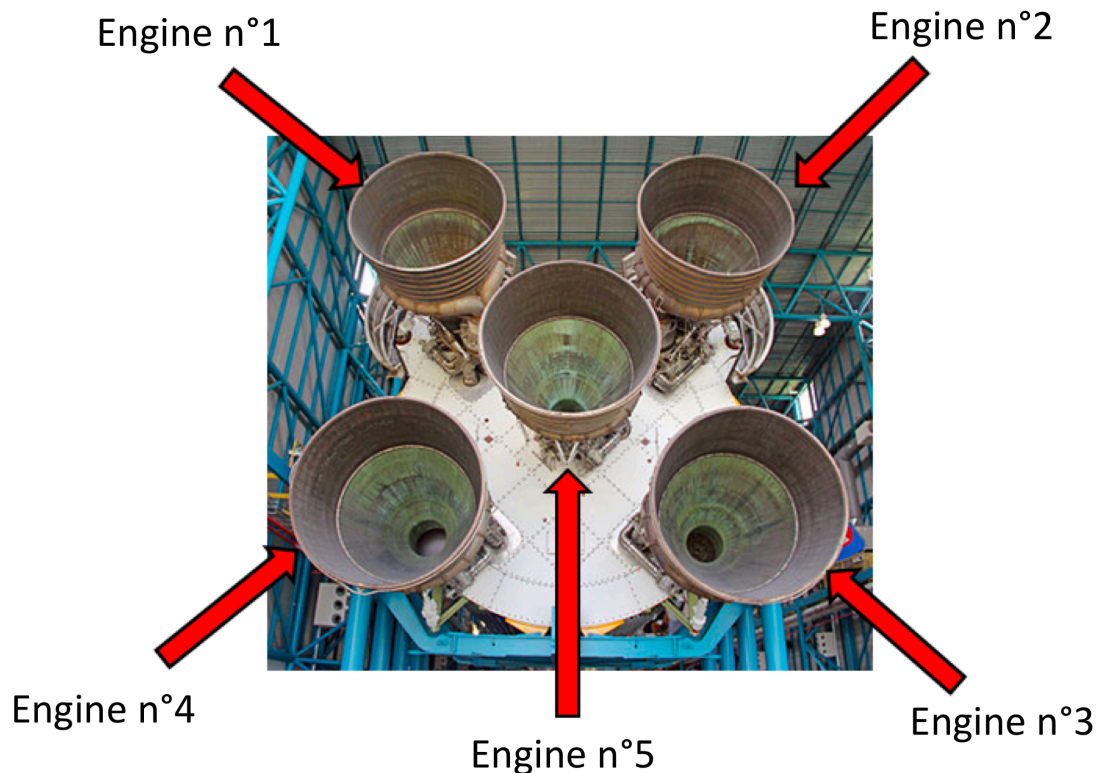
Two onboard electrical networks exist.

The first electrical network exclusively controls the vital elements of the spaceship. Two generators provide electrical current to this first network.

The second electrical network controls the auxiliary devices. Its loss involves no risk for the crew survival. In case of failure of the second electrical network, many connected systems are shut down. So, the associated technical procedures are difficult and long to execute.

8. Propulsion

The propulsion system is composed of 5 engines:



The failure of one of the following engines implies the loss of the navigation of the spaceship: n°1, 2, 3 and 4.

The failure of the engine n°5 does not degrade the navigation. Nonetheless, an increase of the propulsion duration is needed so as to recover the trajectory without any failure. Despite the

loss of the engine n°5, more propellant is consumed to execute this longer burning and this increased consumption diminishes the number of potential trajectory corrections for the rest of the flight. Trajectory corrections are highly probable during a Moon mission.

9. Radio equipment

The communication system between the ground control and the space vehicle includes three independent radios. The failure of one radio has no consequences on the good working of the two others.

10. Earth atmosphere re-entry system

The Earth-atmosphere re-entry system includes three redundant calculators, ten spoilers and a parachute.

The losses of two calculators and/or five spoilers do not degrade the re-entry capacity.

A failure of the parachute involves the crash of the vehicle and the death of the crew during the re-entry into the atmosphere of the Earth.

ANNEX 3: GUIDELINES OF THE MISSIONARIES AND THE CANNIBALS

1. Problem of the river crossing

Three couples, each one includes a wife and a husband, must cross a large river with one bark. The constraints are:

- The bark can contain a maximum of two persons,
- The bark is the only way to cross the river,
- At least one person must stay in the bark to perform a transfer from one shore to the other,
- It is not possible to have a wife without her husband on one shore. Indeed, the husbands are jealous. So, it is not possible to have more women than men on one shore.

Give the details of the in and out transfers on an answer sheet. The goal is not to give the minimum number of transfers (nine). Only a solution is requested.

Be careful, a mistake is easy to make; a mistake means zero point. You can use the pens and the scrap paper.

2. The guardians

A prisoner is detained in a tower with two doors. One of the doors leads to the exit, the other one leads to the dungeons. A guard is located in front of each door. One of them says always the truth, the other one lies every time.

Which unique question the prisoner can ask to only one of the guards in order to identify of the door leading to freedom?

You have **maximum five minutes** to solve this question, if you overshoot the time, you begin the following problem. The organizer announces the fifth minute.

You can use the pens and the scrap paper.

Give the answer to the camera to take it into account. The whole team must understand the solution.

3. Missionaries and cannibals

Caution, for this exercise, you must not write.

Three cannibals and three missionaries face a large river that they must cross with a boat. Everybody must cross the river. The constraints are:

- The boat can contain a maximum of two persons,
- The boat is the only way to cross the river,
- At least one person must stay in the boat to perform a transfer from one shore to the other one,
- It is not possible to have more cannibals than missionaries on the same shore. Otherwise, the cannibals eat the missionaries,
- The cannibals can cooperate confidently.

Caution, you can take profit of the scrap paper already used.

Give the details of the in and out transfers on an answer sheet. The goal is not to give the minimum number of transfers. Only a solution is requested.

4. Second problem of the river crossing

Three couples face a large river that they must cross with a bark. The constraints are:

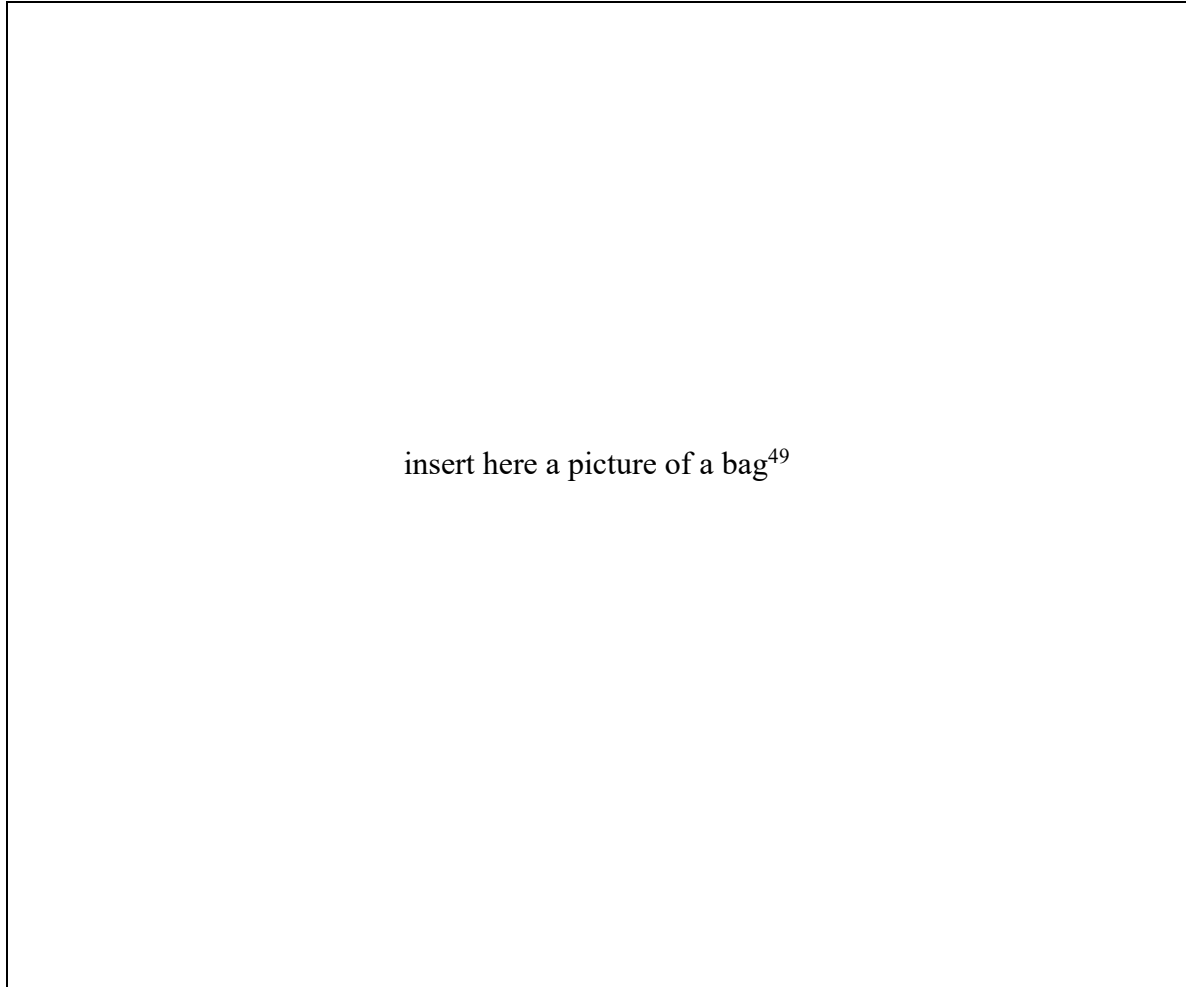
- The bark can contain a maximum of two persons,
- The bark is the only way to cross the river,
- At least one person must stay in the bark to perform a transfer from one shore to the other,
- It is not possible to have a wife without her husband on one shore. Indeed, the husband are jealous. So, it is not possible to have more women than men on one shore.
- Caution, a woman cannot be in the bark, moored at a shore where lies a man and with her husband located on the other shore. This man could try to flirt with this woman.

Be careful, a mistake is easy to make; a mistake means zero point. You can use the pens and the scrap paper. The minimum number of transfers is eleven. If you find less, it means that you are wrong.

Give the details of the in and out transfers on an answer sheet. The goal is not to find the minimum number of transfers. Only a solution is requested.

ANNEX 4: THE BAG AND THE EURO

How many different uses can you attribute to this plastic bag?



you have 13 minutes to think freely. The answers are validated if they are announced between the 13th and the 15th minutes. The answers given before the 13th minute are not taken into account.

⁴⁹ To avoid any copyright problem for the present LETUCA protocol, the researcher will add a picture of a bag inside this square on his own.

Three travelers book a hotel room which costs 30€. The manager says the bill is 30€, so each guest pays 10€.

Later, the manager realizes that the bill must only cost 25€. To rectify the mistake, he gives the bellhop 5€ in coins of 1€ for the travelers. On the way to the room of the travelers, the bellhop realizes that he cannot equally divide the money. As the travelers do not know the total of the revised bill, the bellhop decides to give each traveler 1€ and to keep 2€ as a tip for himself.

Each traveler paid 9€. the bellhop kept 2€. We have $3 \times 9€$ which make 27€. We add the bellhop's 2€, thus 29€.

ANNEX 5: MIXED LIST OF THE ACTIONS OF THE FIRE PROCEDURE

If the smoke stops, maintain the extinction of the internal equipment, comfort equipment: turn on

If the air conditioning of the scientific wagon is suspected:

Generator number 2: check turned on

Scientific wagon, bulkhead number 2: close

Main air conditioning system: turn off

If the smoke continues despite the electrical system modification:

Cabin fans: turn off

If the equipment at the origin of the fire is directly identified: turn off its electrical alimentation and isolate it

If no equipment is found on fire: try another method

Main air conditioning system: turn on

If no methods work: consider the activation of the emergency minimal electrical configuration, fastest way with risk taking to the main base: consider and use if needed

Secondary air conditioning system: turn off

Generator number 2: turn off

Scientific wagon, emergency opening of the airlock:
execute

If the smoke continues despite the modification of the air conditioning system:

Internal equipment on fire: search and extinguish

Generator number 1: turn off

Secondary air conditioning system: check turned on

Comfort equipment: turn off

If the smoke continues despite the modification of the air conditioning system:

If the smoke continues, generator number 2: turn on

If the smoke continues, secondary air conditioning system: turn on, scientific wagon, airlock: close, scientific wagon, sluice number2: open, try another method

Emergency lighting of the cabin: turn on

Scientific wagon: evacuate

Immediate return to the main base: initiate

Communication among all the crew members: establish

If the fire origin cannot be identified and continues or an electrical fire is suspected:

If an internal equipment is suspected:

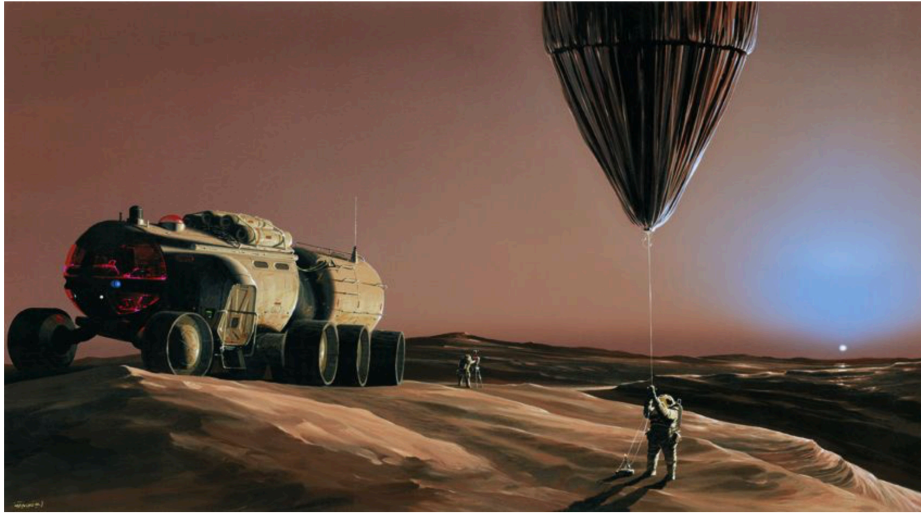
Generator number 1: turn on

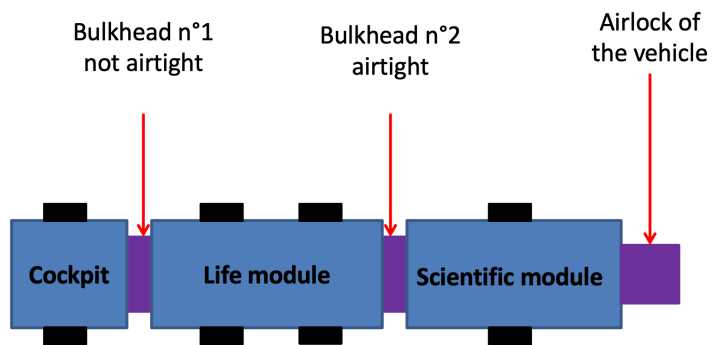
At any time of the procedure, if the situation becomes unmanageable, fastest way with risk taking to the main base, use of extravehicular suits and extraction of the cabin air: consider and execute if needed

Oxygen masks: use with 100% selector if needed

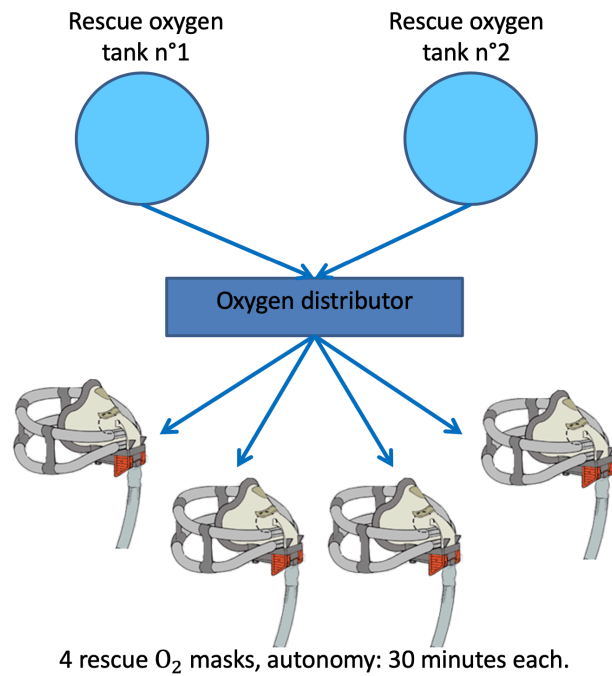
ANNEX 6: REDUCED TECHNICAL MANUAL

Reduced technical manual

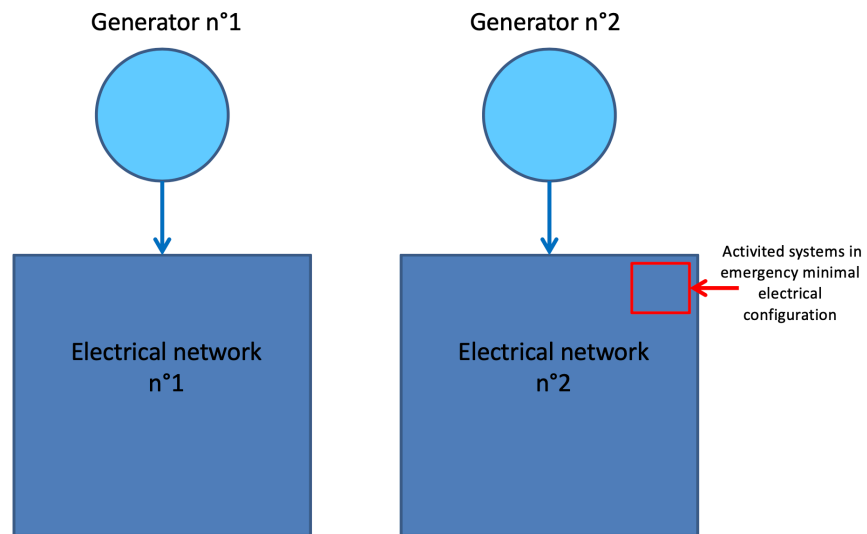




Rescue oxygen networks:



Simplified electrical networks:



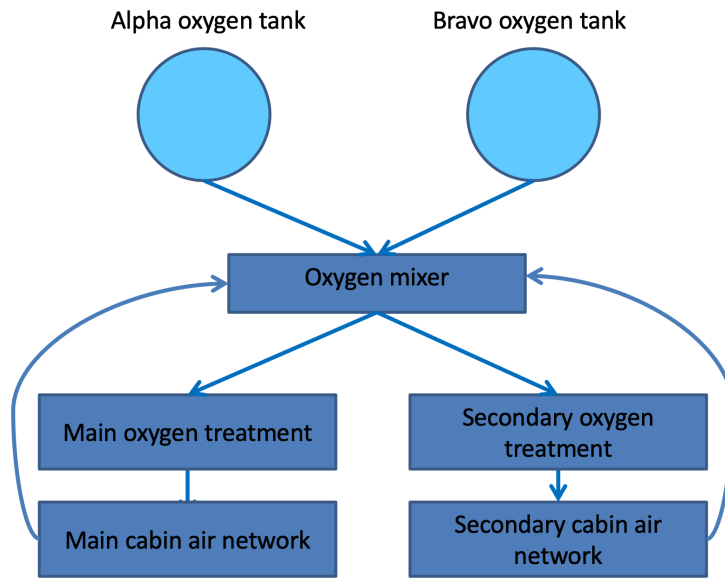
Simplified electrical networks:

All the security **equipment are doubled**, a first equipment group is connected to the network n°1 and a second one to the network n°2. The stop of a network does **not lead to any immediat security degradation**.

Normal functioning: the equipment of the network n°1 works and the equipment of the network n°2 is in stand by mode and ready to work at any time.

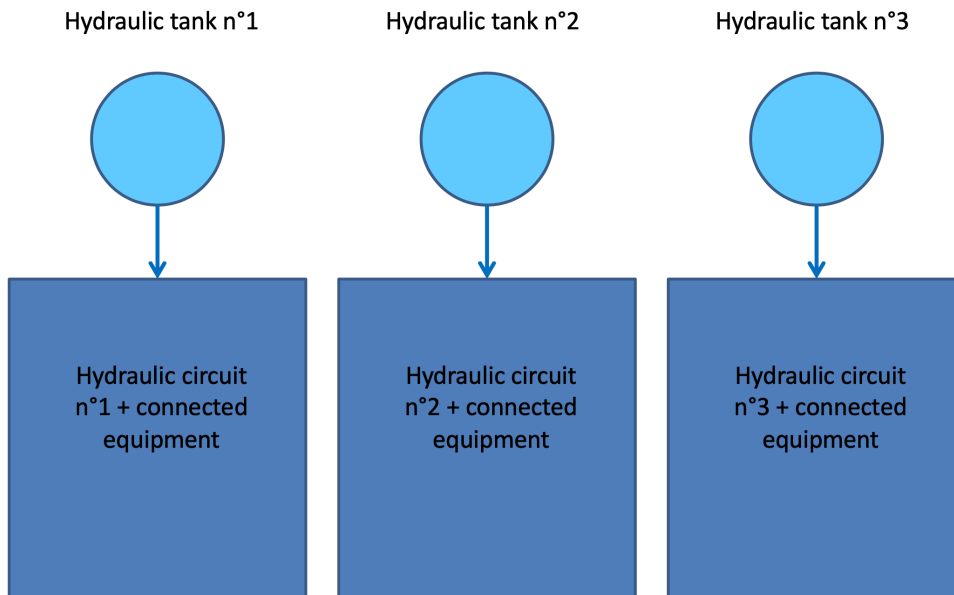
The comfort equipment are composed of entertainment and improved cooking devices.

Simplified air conditioning network:



Normal functioning: main system functioning at **98%** and secondary system functioning at **2%** and ready to supply 100% of the demand at any moment.

Simplified hydraulic networks:



Mission:

- 12th scientific exploration of the mission,
- Use of an exploration rover.

Technical state of the vehicle:

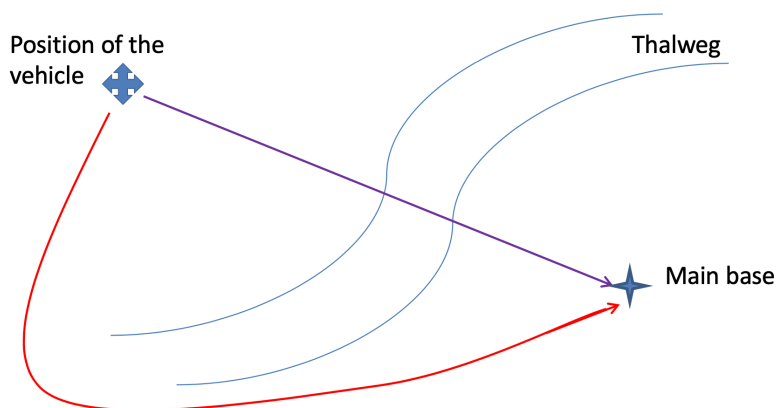
- Oxygen autonomy of the vehicle: 30 hours,
- All the extravehicular suits of the rover were damaged.

Organisation of the crew:

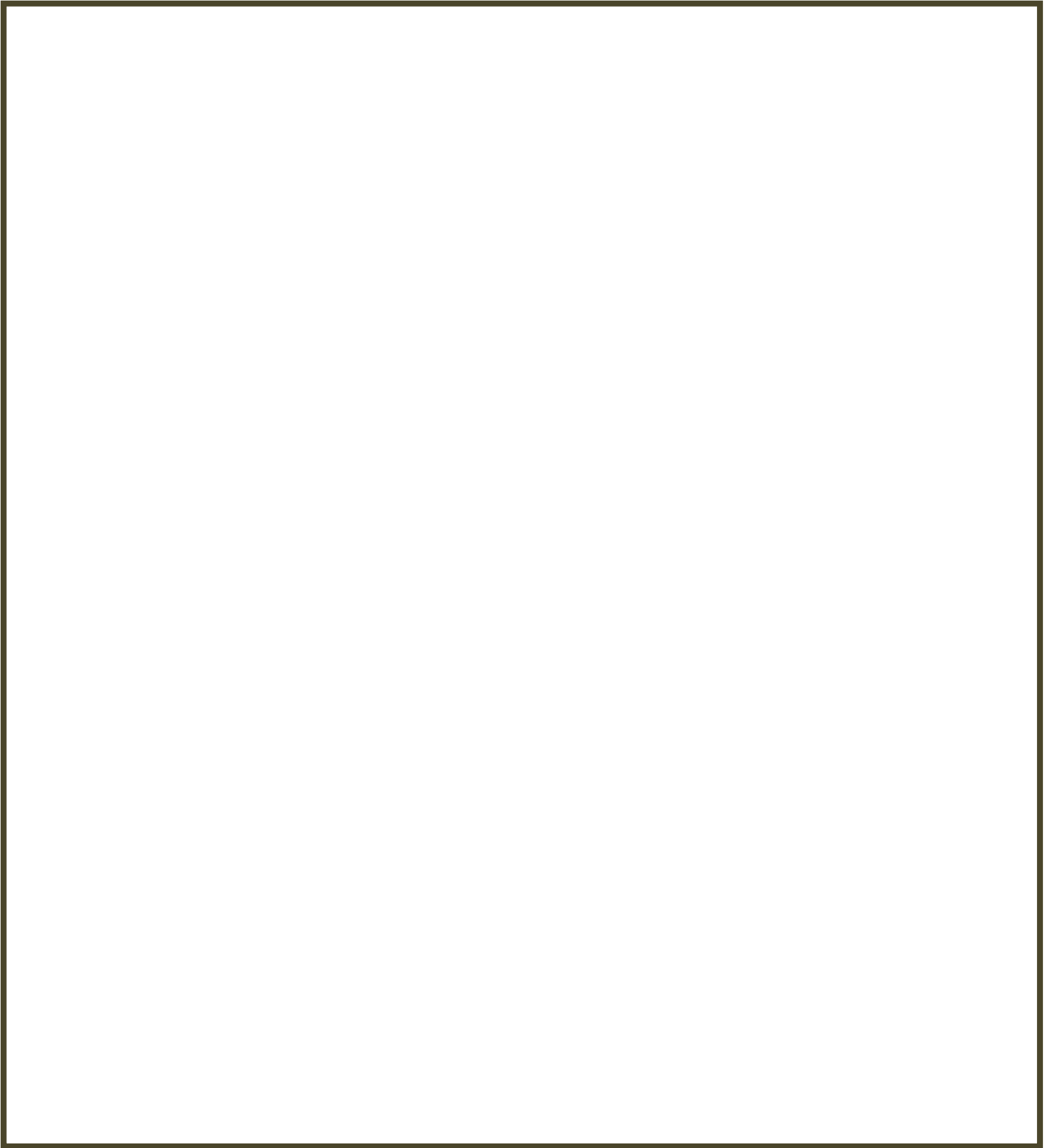
- One captain,
- One second in command (also the pilot of the rover),
- Two astronauts.

Position:

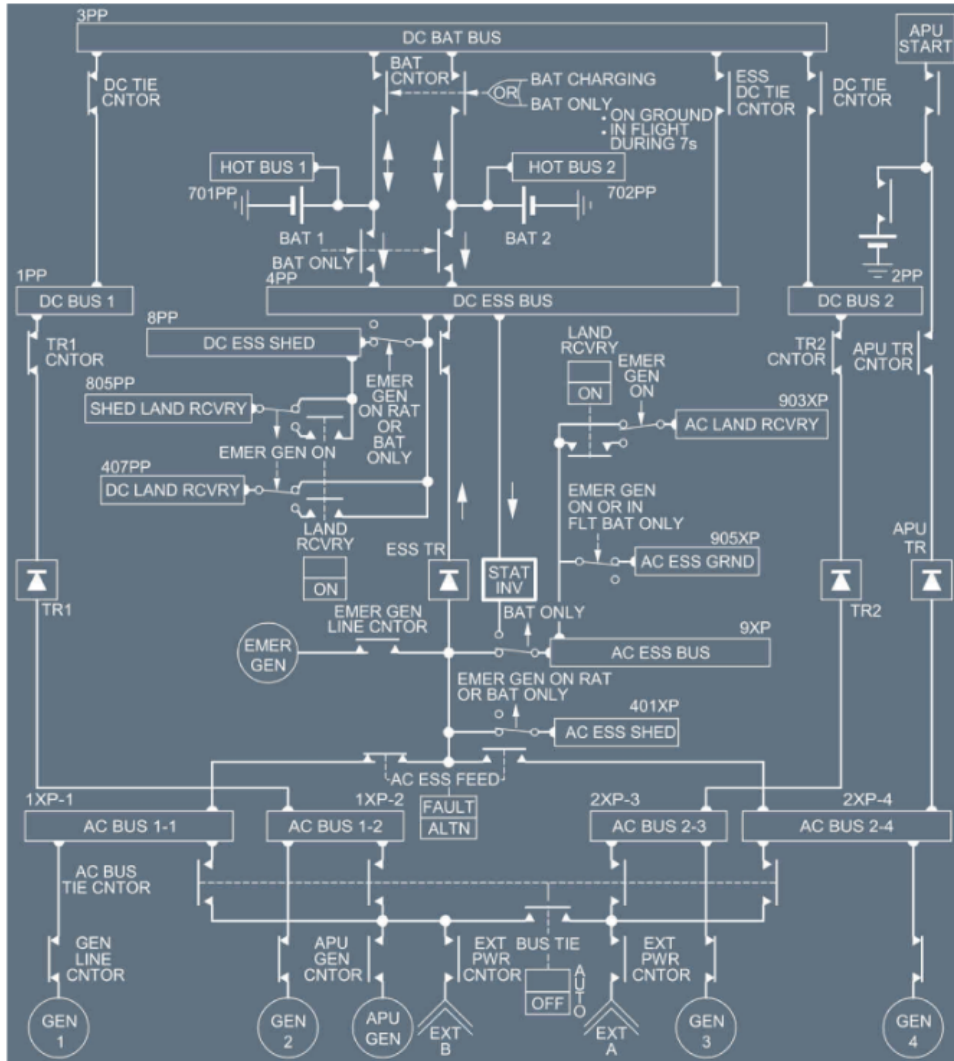
- Distance to the main base: 40Km,
- Return time to the main base 1h25 via a minimum risk trajectory (no landform on the trajectory, red arrow),
- Return time to the main base 0h50 via a risky trajectory (presence of landforms, purple arrow).



ANNEX 7: ANSWER SHEET OF THE REPRODUCTION OF THE ELECTRICAL SYSTEM OF THE AIRBUS A340



ANNEX 8: ELECTRICAL SYSTEM OF THE AIRBUS A340

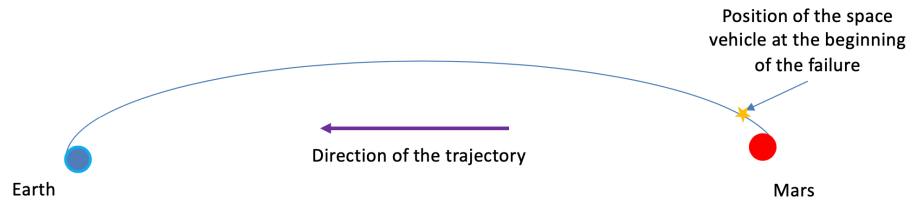


ANNEX 9: CHRONOLOGY OF THE FATIGUE FAILURE OF THE GENERATOR N°3



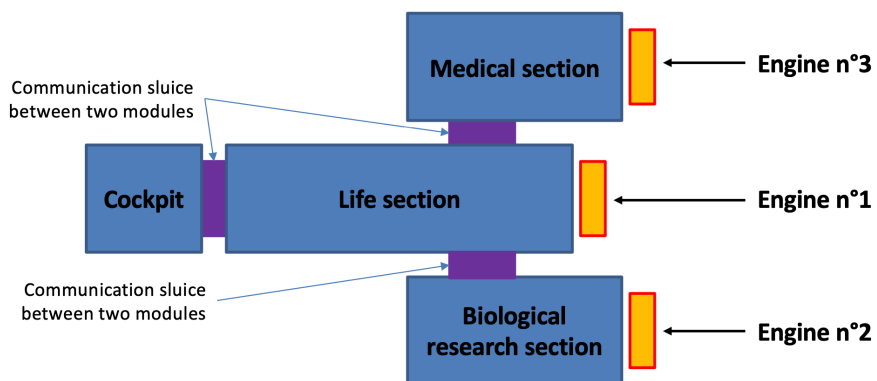
ANNEX 10: TECHNICAL MANUAL

Return trajectory

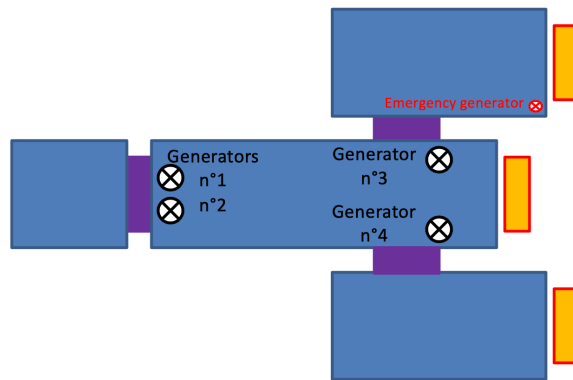


Not to scale

Simplified plan of the space vehicle



Locations of the generators



ANNEX 11: SPECIALIZED REPORTS

Captain

You are the captain of a mission on Mars. It is the departure phase from Mars and you have a 6-month trip before landing on the Earth. The crew is composed of you, a second in command (and flight engineer), and two mission specialists (a biology researcher and a doctor).

At the departure from Mars, an unknown failure happened in your spaceship. You experienced violent vibrations and electrical problems. Your crew treated the failure temporarily. Because of communication delays between the ground control center and you, the crew cannot get any help from the Earth for the moment (two-hour delay before the response of the ground control center).

You (as the captain) have just calculated that the vehicle is stabilized for 20 hours. No supplementary problem is going to happen for the next 20 hours.

According to the crew composition, each astronaut has access to his/her specific information about the failure thanks to the reports of the systems. Be aware that engineers and technicians are parts of the ground control center and that they know the vehicle much better than you.

The operational procedures demand that the crew writes a “crew message” to the ground control center about the encountered failure. Then, the ground control sends you back a message. In parallel, during the standard functioning of the onboard computer, an automatic report with technical data is transmitted to the ground control center. The automatic report contains all the technical data (the status of the systems, measured deviations, performed actions on systems, etc.).

Your task:

To send an understandable “crew message” to the ground control center on an answer sheet.

Report of the systems, captain's field:

- Stabilization of the system for 20 hours minimum,
- Request guidelines to terminate the treatment of the failure.

Second in command and flight engineer

You are second in command and flight engineer of a human space flight coming back from Mars. Being the only engineer of the crew, you are in charge of the **flight safety and the return on Earth**.

The crew is composed of you, a captain, and two mission specialists (a biology researcher and a doctor).

At the departure from Mars, an unknown failure happened in your spaceship. The crew stabilized the failure. So now, you must write a “crew message” about the failure to the ground control center on Earth.

In parallel, during standard functioning of the onboard computer, an automatic report with technical data is transmitted to the ground control center. The automatic report transmits all the technical data (the status of the systems, measured deviations, performed actions on systems, etc.).

According to the crew composition, each astronaut has access to his/her own information about the encountered failure thanks to the report of the systems.

Report of the systems, second in command and flight engineer's field:

- Unsolved failure: transmission of the automatic report with technical data to the ground control center impossible,
- Misalignment of the communication transmitting antenna: decrease of the transmission and reception power to/from the Earth,
- Decrease of the transmitting power to the ground control center: 50 words maximum can be transmitted, free layout (line feed possible without any restriction), only one message possible, no other ways exist to communicate with the ground control center,
- Degradation of the reception power of messages from the ground control center: the system is configured for only one message with 1000 words maximum. After the reception of this message, a restart of the communication system will be performed to receive other messages. 48 hours are necessary to complete this restart,
- Stabilization of the system succeeded for 20 hours, no evolution expected during this delay,
- Major trajectory deviation: $Dev=+1.822054^\circ A/-2.587490L/15020.514D$, the spaceship is deviated from the standard return trajectory,
- 70% of the propellant reserve (reserve used for contingency corrections of the trajectory during the return flight) is necessary to fly back on the standard return trajectory, correction linked to the major deviation $Dev=+1.822054^\circ A/-2.587490L/15020.514D$,
- Interruptions of the generators 1/4, 3/4 et 4/4: temporary switching to the emergency electrical configuration (less than 3 minutes),
- Temporary switching to the emergency electrical configuration (less than 3 minutes): temporary interruption of many third category equipment (equipment not necessary for survival),
- Generator n°1 and n°4: return to a normal electrical functioning,
- Generator n°1, n°2 and n°4 in function and sufficient for the complete electrical supply of the spaceship (except the restart of the system: more electrical power is needed),
- Rotation of the generator n°3 detected and no electrical power delivered despite 5 automatic restarts: abnormal functioning,
- Major vibrations detected in the generator n°3, vibrations of level 9/10 for 3 seconds: possible consequences on other systems,
- Vibrations detected in the generator n°3, persistent vibrations of level 5/10: nearby sections encountering destructive vibrations beyond 14 days of non-stop exposition,
- Vibrations detected in the generator n°3, persistent vibrations of level 5/10 transmitted to the medical section: destructive degradation of the access sluice to the medical section beyond 12 days of non-stop exposition,
- Normal and reversible braking of the generator n°3 definitively out of order,
- Emergency and definitive braking of the generator n°3 operative, activation according to the authorization of the ground control center (via the transmission of a code from the ground control center, reception aboard the vehicle always possible despite the failures, emergency and definitive stop of the generator n°3 impossible without this code),

- The onboard systems still guarantee an autonomous return to the Earth (automatic pilot, propulsion and trajectory correction systems, life, cooling, electrical, hydraulic, collision avoidance and solar winds previsions and detection systems).

Postscript: a character group with “/” and/or “n°” and/or “=” is counted for only one word, for example: “Fgr=2256,02/784,75” is counted for one word.

Postscript: the times count for just one word per unit. “56h” for 56 hours or “85’ ” for 85 minutes count each for one word, for instance. If the two are associated, “56h85’ ” counts for two words.

Astronaut mission specialist, doctor:

You are a mission specialist: a doctor, of a human space flight coming back from Mars. The crew is composed of you, a captain, a second in command (and flight engineer) and another mission specialist (biology researcher).

As a doctor, you manage the medical systems (a dental chair, radiography devices, an analyzing computer of radiographies, an electroencephalogram system, an electrocardiogram, and a reduced orthoptic table). You also perform the medical monitoring of the crew, but no medical problems are detected since the beginning of the mission. You are the only crewmember **responsible for the health of the crew and the correct functioning of the medical systems.**

At the departure from Mars, an unknown failure happened in your spaceship. The crew stabilized the failure. So now, you must write a “crew message” about the failure to the ground control center on Earth.

According to the crew composition, each astronaut has access to his/her own information about the encountered failure thanks to the report of the systems.

Report of the systems, doctor's field:

- Total electrical failure of the medical module of the spaceship (duration < 10 minutes), recovery of some medical systems in progress,
- Resolved failures: screen overheating, abnormal electrical frequency, interruption of the ventilation,
- Unresolved failures: loss of 80% of the medical systems (dental chair, radiography devices, analysing computer of radiographies, electroencephalogram system and reduced orthoptic table).
- Possible recovery of 100% of the medical systems via reinitialization of the generator n°3 (procedure: normal braking of the generator then normal restart) or start of the rescue generator. Either action permits an electrical power increase necessary for the restart of the impacted systems,
- Your calculations indicate that 50% of the propellant reserve (reserve used for contingency corrections of the trajectory during the return flight) are necessary to start the rescue generator. The start of the rescue generator implies the intervention of the ground control center on Earth via the transmission of a starting code; this start is impossible without this code.

Astronaut mission specialist, biology researcher:

You are a mission specialist: a biology researcher, of a human space flight coming back from Mars. You are the only **responsible of the Martian samples and the correct functioning of the onboard research devices**.

The crew is composed of you, a captain, a second in command (and flight engineer) and another mission specialist (a doctor).

At the departure from Mars, an unknown failure happened in your spaceship. The crew stabilized the failure. So now, you must write a “crew message” about the failure to the ground control center on Earth.

According to the crew composition, each astronaut has access to his/her own information about the encountered failure thanks to the report of the systems.

Report of the systems, biology researcher's field:

- Electrical failure detected in the scientific module of the spaceship (duration < 4 minutes); consequence: loss for 13 minutes of the temperature regulation of the organic samples collected on Mars,
- Loss for 13 minutes of the temperature regulation; consequence: 20% of the samples are lost,
- Loss for 13 minutes of the temperature regulation linked to the functioning of 3 out of 4 generators; consequence: a temporary or definitive stop of another generator leads to the loss of 90% of the samples,
- Aboard persistent level 5/10 vibrations detected; consequence: continual loss of the samples with persistent level 5/10 vibrations,
- Aboard persistent level 5/10 vibrations detected; consequence: total loss of the organic samples beyond 24 hours of level 5/10 vibrations,
- Electrical dephasing of the current produced by the generator n°1 in the scientific module (duration < 5 minutes); consequence: scientific systems are short-circuited; no research works are possible during the fly back.

ANNEX 12: TRAJECTORIES DATA

Space vehicle

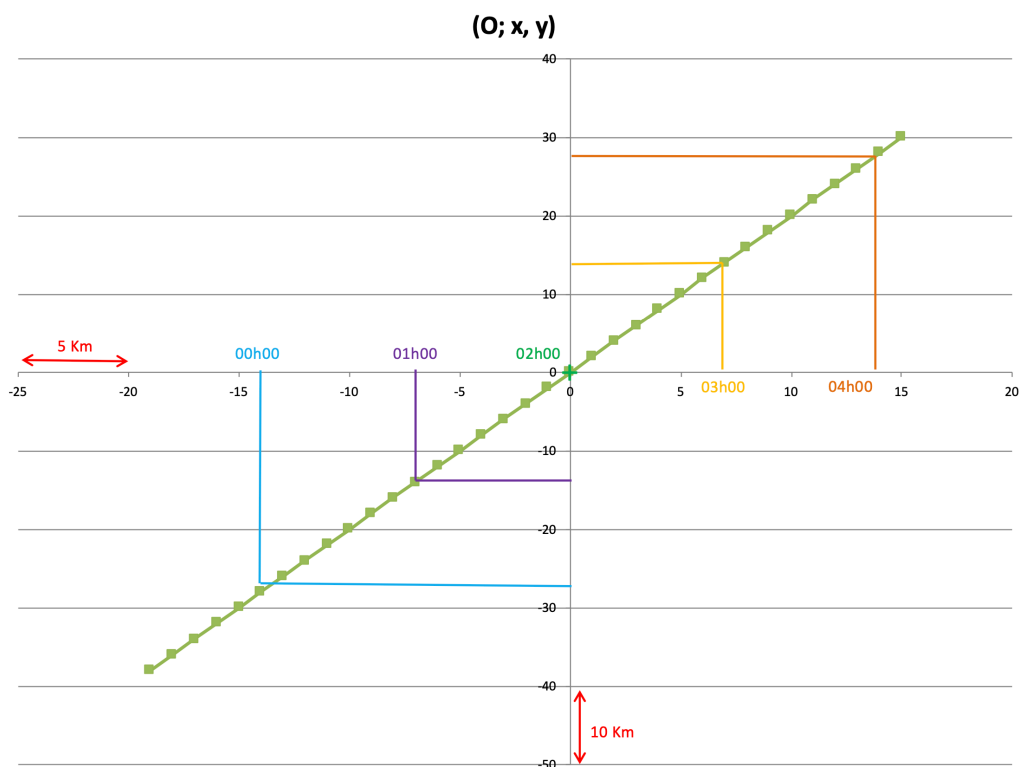
y=2.x		z= -y+3		x= -z/2+3/2		00h00
(O; x, y)		(O; y, z)		(O; z, x)		01h00
x	y	y	z	z	x	02h00
-19	-38	-19	22	-19	11	03h00
-18	-36	-18	21	-18	10,5	04h00
-17	-34	-17	20	-17	10	
-16	-32	-16	19	-16	9,5	
-15	-30	-15	18	-15	9	
-14	-28	-14	17	-14	8,5	
-13	-26	-13	16	-13	8	
-12	-24	-12	15	-12	7,5	
-11	-22	-11	14	-11	7	
-10	-20	-10	13	-10	6,5	
-9	-18	-9	12	-9	6	
-8	-16	-8	11	-8	5,5	
-7	-14	-7	10	-7	5	
-6	-12	-6	9	-6	4,5	
-5	-10	-5	8	-5	4	
-4	-8	-4	7	-4	3,5	
-3	-6	-3	6	-3	3	
-2	-4	-2	5	-2	2,5	
-1	-2	-1	4	-1	2	
0	0	0	3	0	1,5	
1	2	1	2	1	1	
2	4	2	1	2	0,5	
3	6	3	0	3	0	
4	8	4	-1	4	-0,5	
5	10	5	-2	5	-1	
6	12	6	-3	6	-1,5	
7	14	7	-4	7	-2	
8	16	8	-5	8	-2,5	
9	18	9	-6	9	-3	
10	20	10	-7	10	-3,5	
11	22	11	-8	11	-4	
12	24	12	-9	12	-4,5	
13	26	13	-10	13	-5	
14	28	14	-11	14	-5,5	
15	30	15	-12	15	-6	
16	32	16	-13	16	-6,5	
17	34	17	-14	17	-7	
18	36	18	-15	18	-7,5	
19	38	19	-16	19	-8	
20	40	20	-17	20	-8,5	

Asteroid

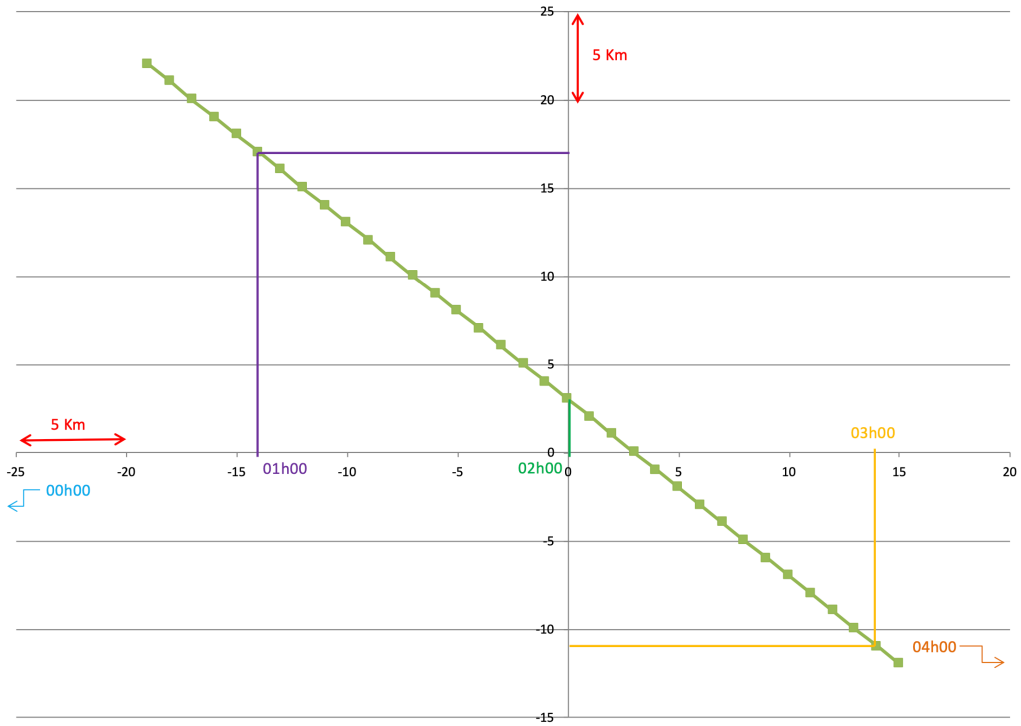
$y=(x+21)/2$		$z=31-3.y$		$x=(-2.z-1)/3$		00h00
(O; x, y)		(O; y, z)		(O; z, x)		01h00
x	y	y	z	z	x	02h00
-21	0	-21	94	-21,5	14	03h00
-20	0,5	-20	91	-21	13,6666667	04h00
-19	1	-19	88	-20	13	
-18	1,5	-18	85	-19	12,3333333	
-17	2	-17	82	-18	11,6666667	
-16	2,5	-16	79	-17	11	
-15	3	-15	76	-16	10,3333333	
-14	3,5	-14	73	-15	9,6666667	
-13	4	-13	70	-14	9	
-12	4,5	-12	67	-13	8,3333333	
-11	5	-11	64	-12	7,6666667	
-10	5,5	-10	61	-11	7	
-9	6	-9	58	-10	6,3333333	
-8	6,5	-8	55	-9	5,6666667	
-7	7	-7	52	-8	5	
-6	7,5	-6	49	-7	4,3333333	
-5	8	-5	46	-6	3,6666667	
-4	8,5	-4	43	-5	3	
-3	9	-3	40	-4	2,3333333	
-2	9,5	-2	37	-3	1,6666667	
-1	10	-1	34	-2	1	
0	10,5	0	31	-1	0,3333333	
1	11	1	28	-0,5	0	
2	11,5	2	25	0	-0,3333333	
3	12	3	22	1	-1	
4	12,5	3,5	20,5	2	-1,6666667	
5	13	4	19	3	-2,3333333	
6	13,5	5	16	4	-3	
7	14	6	13	5	-3,6666667	
8	14,5	7	10	6	-4,3333333	
9	15	8	7	7	-5	
10	15,5	9	4	8	-5,6666667	
11	16	10	1	9	-6,3333333	
12	16,5	10,5	-0,5	10	-7	
13	17	11	-2	11	-7,6666667	
14	17,5	12	-5	12	-8,3333333	
15	18	13	-8	13	-9	
16	18,5	14	-11	14	-9,6666667	
17	19	15	-14	15	-10,3333333	
		16	-17	16	-11	
		17	-20	17	-11,6666667	
		17,5	-21,5	18	-12,3333333	
		18	-23	19	-13	
		19	-26	20	-13,6666667	
		20	-29	20,5	-14	
				21	-14,3333333	
				22	-15	

ANNEX 13: CURVES OF THE TRAJECTORIES

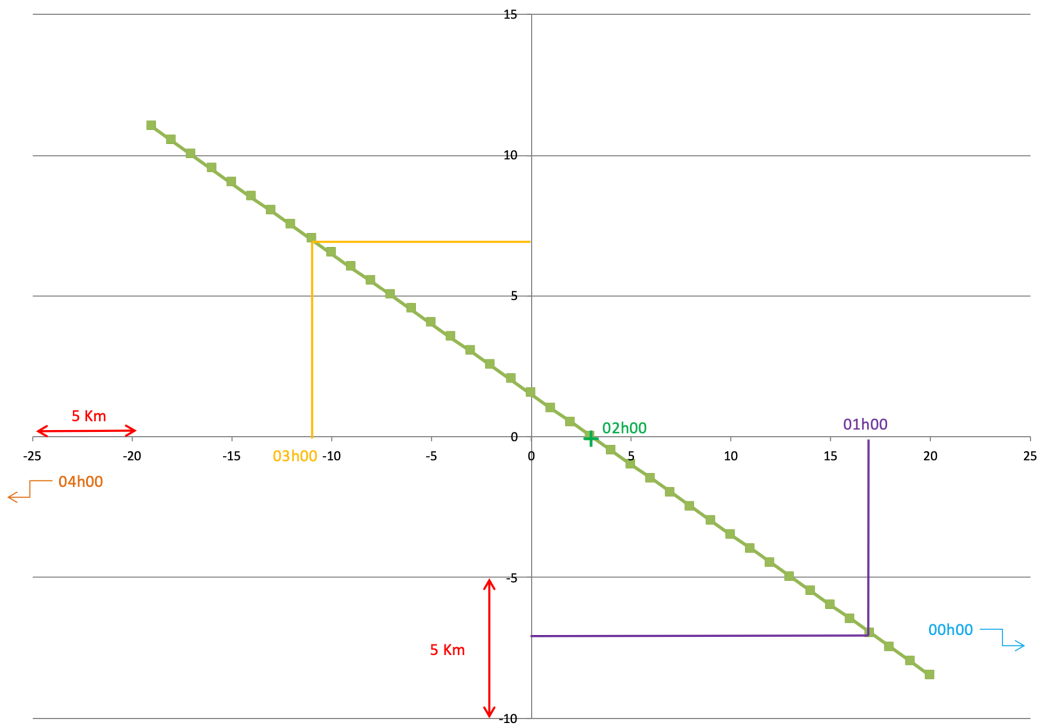
Trajectory of the spaceship,
Automatic return trajectory to the Earth.



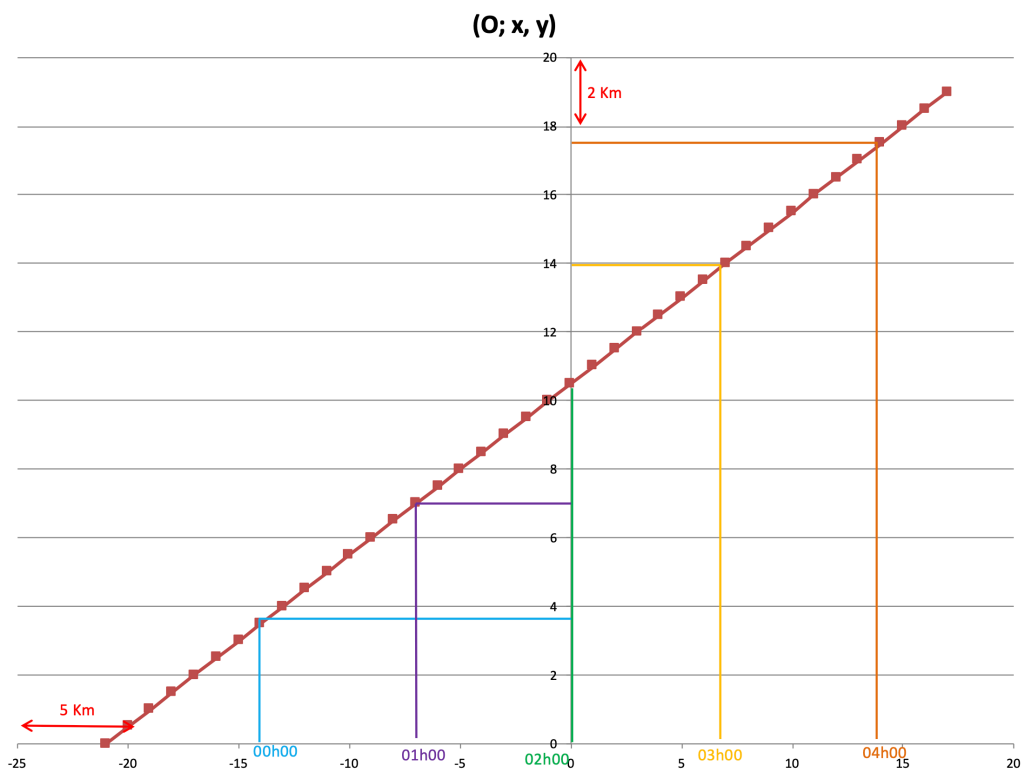
(O; y, z)

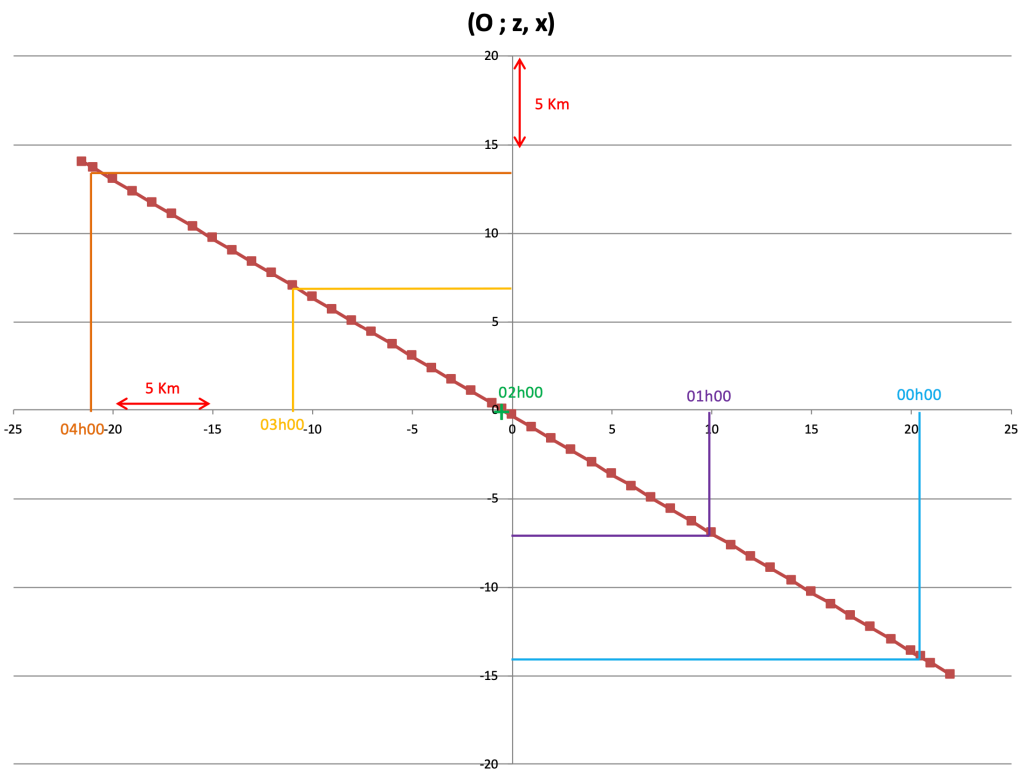
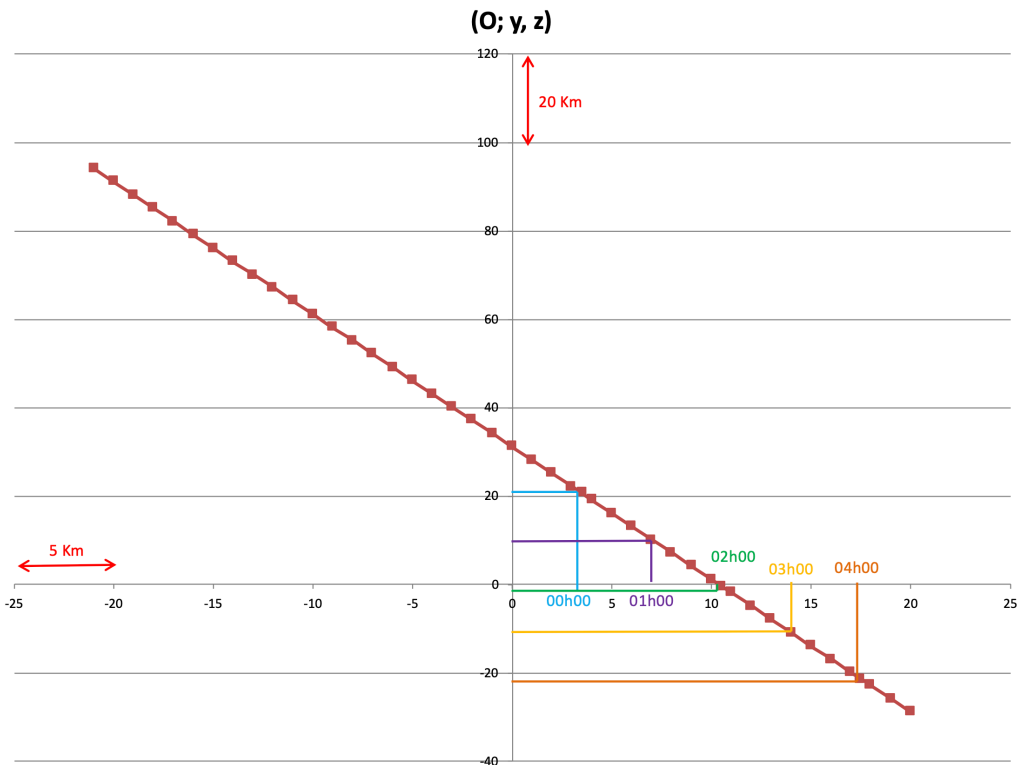


(O; z, x)



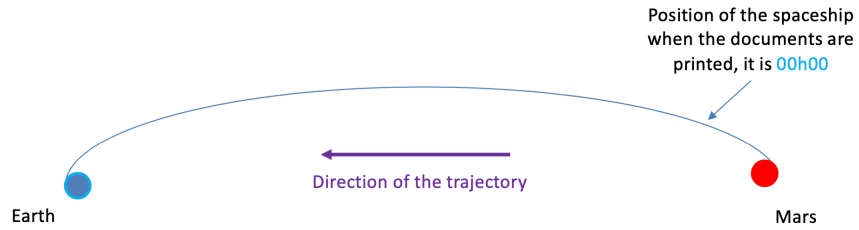
Trajectory of the asteroid



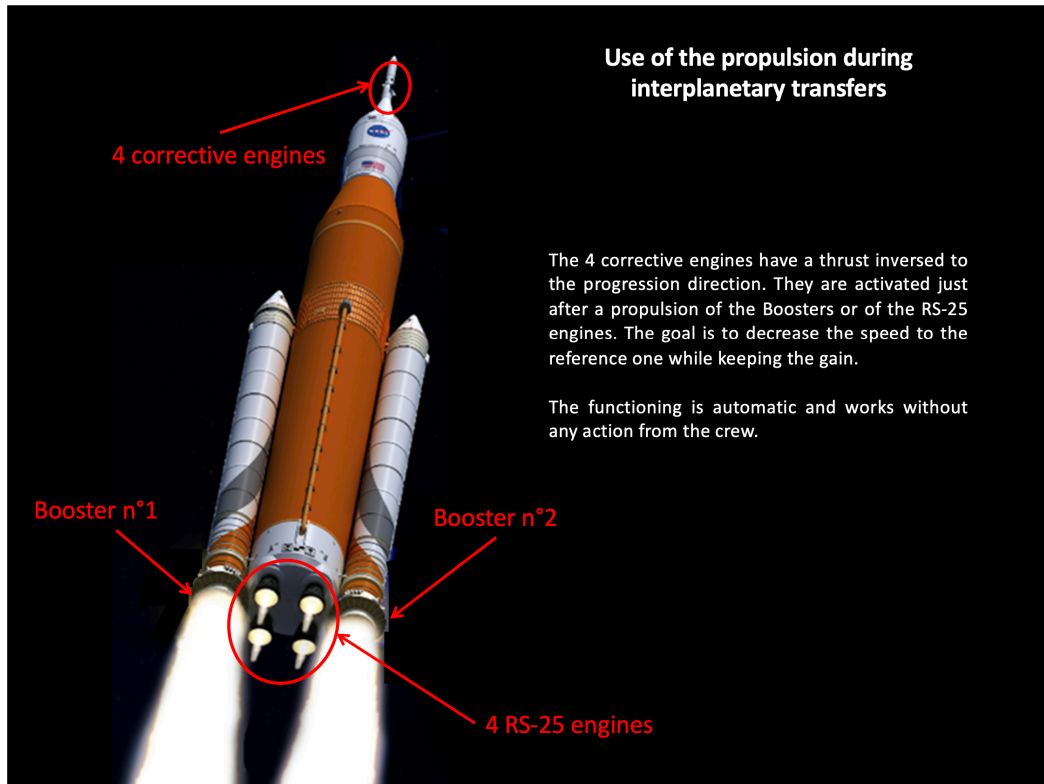


ANNEX 14: TECHNICAL MANUAL EXTRACTION


Return trajectory



Not to scale



Functioning particularities of the propulsion system:

 Abnormal case: manual trajectory corrections


- Manual trajectory corrections necessarily executed in the **direction of the trajectory** via speed variations.

- **Minimal admissible discrepancy** between two crossing objects due to safety reasons: **2 Km whatever the axis** (O; x, y, z) and these 2 Km can only be measured on a single axis: (O; x) or (O; y) or (O; z). **2 Km are enough to certify the safety of the vehicle.**

- If a correction is in progress with the propulsion system, it is possible to cross an object below 2 Km. The safety is not impacted in this case.

- The vehicle and the asteroid have the **same speed on the axis (O, x)**: when the vehicle ranges 1 Km on (O, x), the asteroid also ranges 1 Km on (O, x). However, the speeds are different on (O, y) and (O, z).

Functioning particularities of the propulsion system:

 Abnormal case: manual trajectory corrections

Boosters n°1 & n°2:

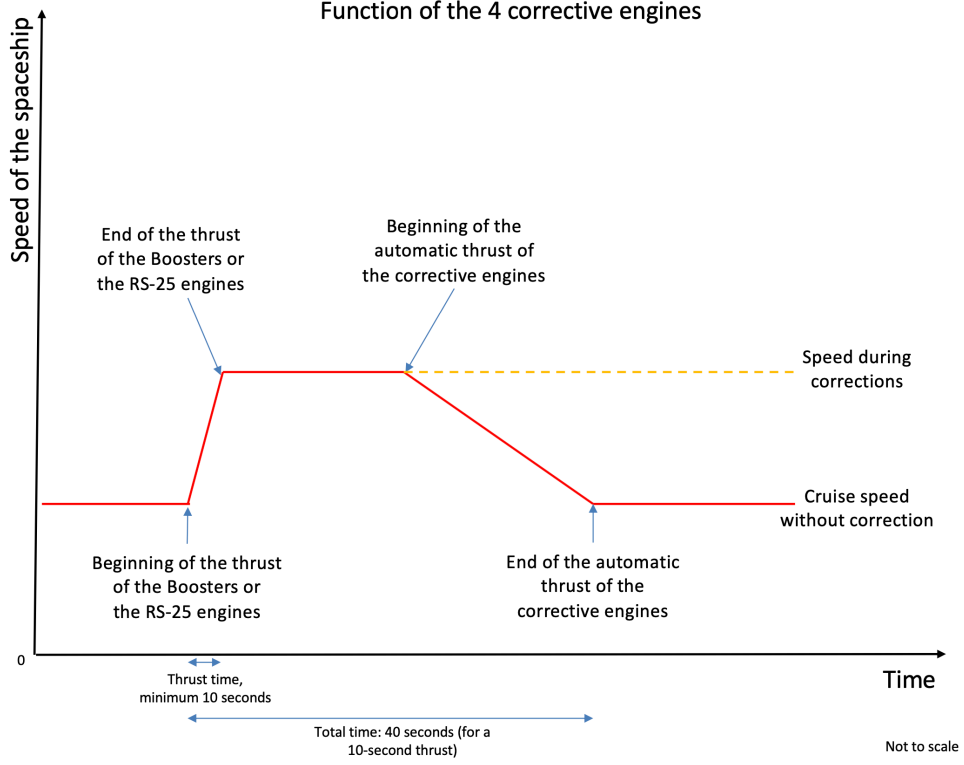
- Functioning only with the two boosters,
- Minimal functioning duration: 10 seconds,
- Delivered thrust by the 2 boosters: distance gain on all axis, **4 Km of which are measured on the axis (O; x)**, with the 2 boosters and with a 10-second thrust,
- The thrust of the boosters for 10 seconds requires 50% of the propellant reserved for trajectory corrections.

4 RS-25 engines:

- Functioning only with the 4 RS-25 engines,
- Minimal functioning duration: 10 seconds,
- Delivered thrust by the 4 RS-25 engines: distance gain on all axis, **1 Km of which is measured on the axis (O; x)** with the 4 RS-25 engines and with a 10-second thrust,
- The thrust of the 4 RS-25 engines for 10 seconds requires 5% of the propellant reserved for trajectory corrections. A thrust of the 4 RS-25 engines for 20 seconds requires 10%, 30 seconds 15%, etc.

The propellant reserved for the trajectory corrections is a propellant reserve usable in case of contingency during the interplanetary transfer.

Function of the 4 corrective engines



ANNEX 15: DRONE PILOT GUIDELINES

You belong to an eight-member team on Mars. Four members are in the main base. You are these four members. Four others are performing an exploration mission with a rover on Mars. Unfortunately, the rover has broken down and is now blocked 80Km away from the main base.

The encountered failure was unknown and the crew in the rover had no checklist to cope with the event. So, the ground control center on Earth created a new checklist to treat the failure. You, in the main base, received this new checklist.

Due to electrical problems caused by the unknown failure, the crew in the rover was not able to receive this checklist. Indeed, the communication receptor of the rover was too weak to intercept any signals from the Earth or even from the main base.

Now, the main base (you) must perform a mission to:

- Send a research drone midway between the rover and the main base to perform a radio relay (see the tablet),
- Transmit the checklist with the radio so as to permit the treatment of the failure of the rover.

The work aboard the rover needs a one-hour communication between the main base and the rover, via the research drone.

A pilot is required to pilot the drone. This person:

- Is the only one to be able to communicate with the rover because of the isolation of the pilot cabin in the main base (see the tablet),
- Cannot speak with the rest of the main base during a flight of the drone,
- Cannot speak with the rest of the ground control center during a flight of the drone.

Unfortunately, the only drone pilot is in the rover.

Your goal is to enumerate the skills and knowledge that a drone pilot must have to succeed this specific mission. All these skills and knowledge must permit you to select a pilot among you.

Your performance is calculated on:

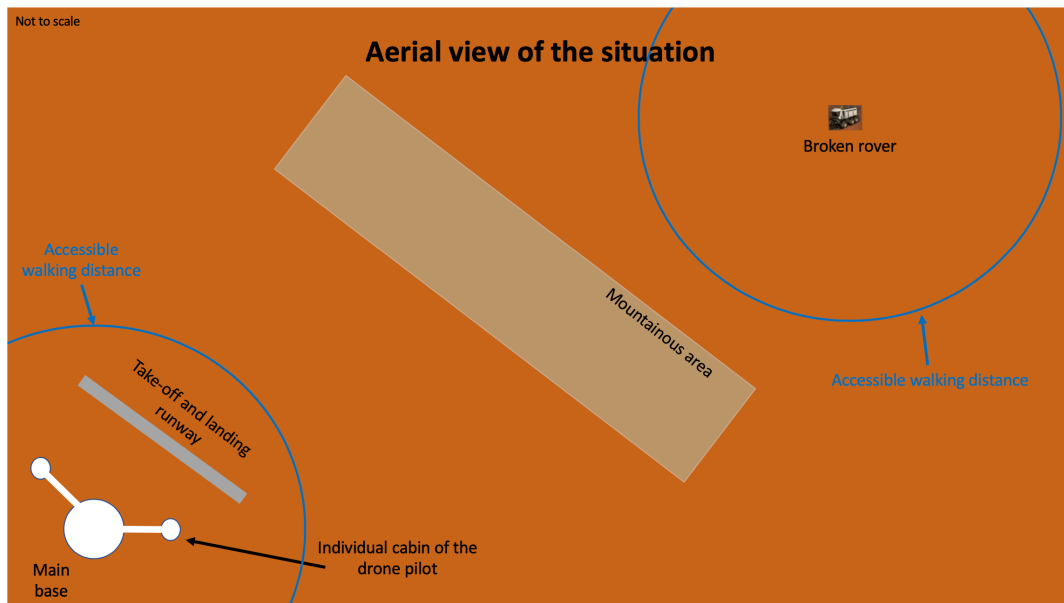
- The relevance of the drone pilot's skills and knowledge established. A relevant skill for this mission can be evident and/or banal just like complex,
- The number of answers.

Then, the more relevant answers you have, the better is your performance.

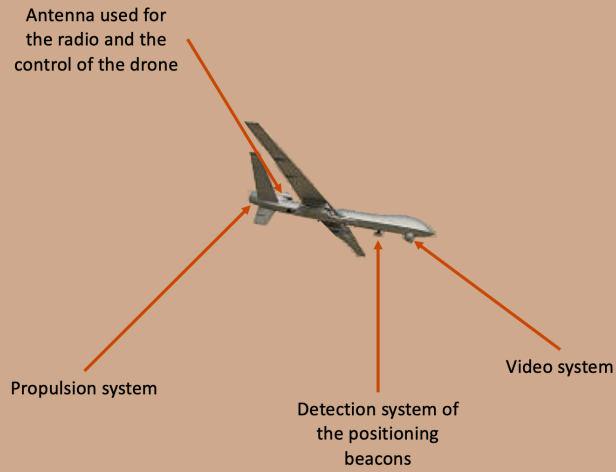
Caution, you are not to select a teammate to pilot this drone.

You will write your answers on an answer sheet. You have 30 minutes maximum.

ANNEX 16: CONTEXT PRESENTATION

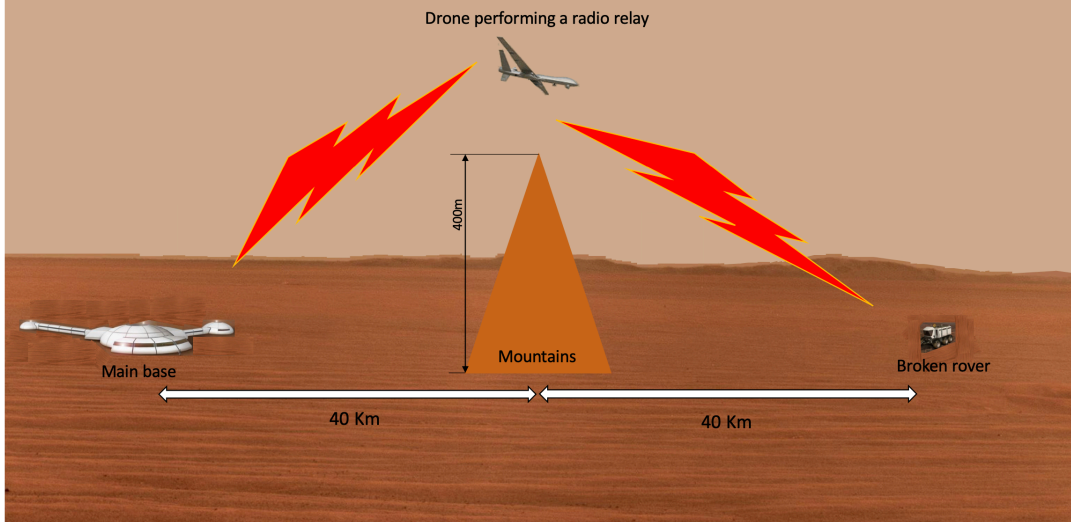


The research drone available for your mission on Mars



Not to scale

Situation during a radio relay



Technical manual of the research drone:

- No automatic pilot,
- Fixed-wing aircraft (like an airline aircraft),
- Flight autonomy: 24 hours,
- Average speed: 80 Km/h,
- Receiver/transmitter radio range: 50 Km,
- Classical take-offs and landings on a runway (like an airline aircraft, not like a catapult on an aircraft carrier),
- Detection of the beacon of the rover from the drone: the direction to follow and the distance are displayed up to a range of 100Km (even if mountains are between the rover and the drone),
- Detection of the beacon of the main base from the drone: the direction to follow and the distance are displayed up to a range of 100Km (even if mountains are between the main base and the drone),

Technical manual of the research drone:

- The pilot's cabin is exclusively individual. When the drone is in flight, the pilot is isolated from the main base. He/she cannot communicate with the rest of the crew located in the main base. This isolation enables the drone pilot to be focused on his mission.



ANNEX 17: DETAILS OF THE WEIGHTING

As explained in the chapter presenting the exercise called Mars drone pilot skills and knowledge, three performance levels are used to calculate the operational performance. The first performance level is divided into four items:

- Execute the mission,
- Guarantee the persons' safety,
- Guarantee the preservation of the equipment,
- Optimize the mission.

For each first level item, the items of the second performance level are presented in the tables 5 to 8.

Weighting of the mission execution: 80%	To execute the mission
100%	Sum of the below second performance level items
15%	To take off the drone
15%	To use the radio relay and communication devices
13%	To pilot mission related maneuvers in normal situation (establish a radio relay, avoid the masking effect of the mountains, etc.), not including basic maneuvers described below
10%	To use the detecting sensors to localize the beacon of the rover
10%	To pilot basic drone maneuvers in normal situation (basic maneuvers: straight and level flight, level turns, climb, descent, etc.)
6%	To establish priorities
6%	To be self-confident
5%	To be able to manage the stress of the crew in the rover
5%	To land the drone
4%	To pilot the drone in abnormal situations
4%	To be enduring
3%	To adapt the pursuit of the mission to a failure
2%	To use navigation maps
1%	To know the technical documentation of the drone
1%	To know the theory of the sensors, calculators and software (exclusive of the rover detection)

Table 5. second performance level items for "to execute a mission"

Weighting of the guarantee of the safety: 15%	To guarantee the persons' safety
100%	Sum of the below second performance level item
100%	To pilot in security during all the phases of the flight so as to protect persons

Table 6. second performance level items for "to guarantee the persons' safety"

Weighting of the material preservation: 3%	To guarantee the preservation of the equipment
100%	Sum of the below second performance level items
40%	To safely pilot during all the phases of the flight to protect the material (not to brush a cliff for example)
25%	To pilot the drone according to the technical limitations
15%	To treat failures according to the operational manual
10%	To update regularly the parameters of the mission (fuel, autonomy, covered areas, etc.)
5%	To monitor the functioning of the drone
5%	To know the induced effects produced by a type of failures

Table 7. second performance level items for "to guarantee the preservation of the equipment"

Weighting of the optimization: 2%	To optimize the mission
100%	Sum of the below second performance level items
20%	To communicate effectively (transmission of ideas)
20%	To adopt a coherent piloting according to the research mission (wings-level flight, navigation coherent with the relief, analyses of the relief to search relevant places where the rover could be, no aerobatics, etc.)
13%	To adapt himself/herself (behavioral flexibility / situational intelligence / emotional intelligence)
10%	To communicate with efficiency (with few words)
7%	To be reliable
5%	To anticipate
5%	To manage his/her workload in order to perform a satisfying control of the mission (plan, anticipate, etc.), manage his/her own attentional resources
5%	To have good psychomotor skills
4%	To analyze
4%	To pilot in 3 dimensions (including space orientation)
3%	To take into account the meteorology on Mars
2%	To divide his/her own attention
1%	To be comfortable with glass cockpits (computers, screens, and computer friendly for example)
1%	To adapt himself to the lack of sensation thanks to a remote piloting with instruments

Table 8. second performance level items for "to optimize the mission"

ANNEX 18: GUIDELINES OF THE DOCKING PORT RELOCATION EXERCISE

Computer virus detected in the central computer of the International Space Station.

Automatic action performed: reset of all the onboard systems.

Three consequences of the reset:

- Computer virus deleted,
- Short circuit in the computer controlling the “ZVEZDA” docking point, definitive stop of the “ZVEZDA” docking point in 30 minutes. Your Soyuz vehicle, used for the return on Earth, is docked at this point and then, it will be blocked in 30 minutes. Only one Soyuz is available on the International Space Station.
- Reset of the Soyuz vehicle and then start-up with the “factory release”: the displays and the controls of the engines in the “factory release” are unknown to your crew.

To prevent the blockage of the Soyuz vehicle to the “ZVEZDA” docking point, your crew must transfer the Soyuz from the “ZVEZDA” docking point (in yellow) to the “PIRS” docking point (in green). Look at the schema of the International Space Station available to visualize the situation (several slides available).

Automatic download of the Soyuz simulator with the “factory release” executed and available on the tablet. Download executed in order to get familiarized with the “factory release”.

The annex document presents the instructions to configure the Soyuz simulator according to the position of your Soyuz (look at the schema of the International Space Station): transfer from the “ZVEZDA” docking point to the “PIRS” docking point.

You have 22 minutes maximum.

Only the pilot is authorized to manipulate the tablet.

The sole goal of the exercise is to give the **function of the displays and the commands** of the Soyuz simulator of the tablet on an answer sheet. The performance is measured according to the precision of each response; if a doubt exists, the answer is false.

ANNEX 19: CONFIGURATION OF THE SOYUZ SIMULATOR

Use of the simulator

Simulator in free use

To launch a simulation corresponding to the transfer from the “ZVEZDA” docking point to the “PIRS” docking point:

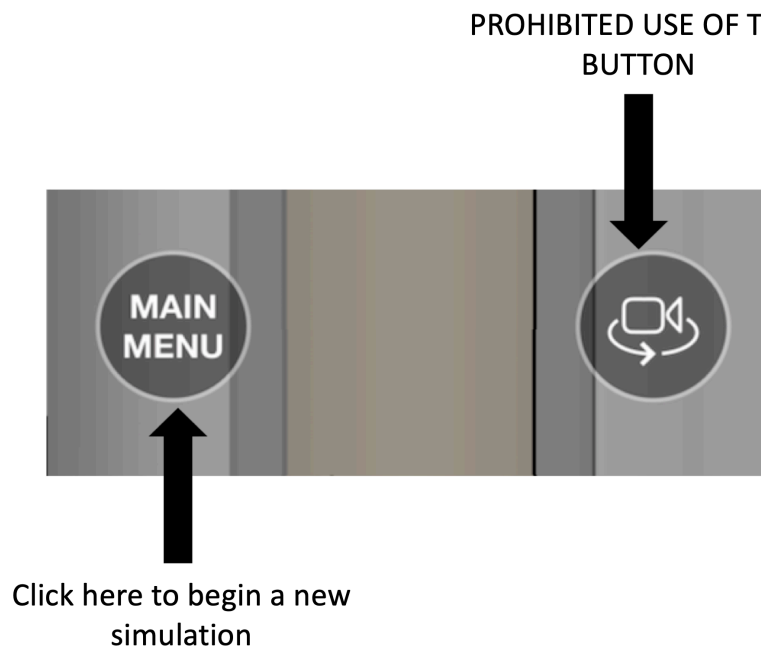
- Click on “NEW SIM, docking port relocation”, to the bottom right,
- Click on “OK”: the simulator asks you if you want to begin a new simulation,
- Click on “FROM PORT @ ZVEZDA”, at the bottom of the screen, ZEVZDA gets yellow,
- “TO PORT @ PIRS”, at the bottom of the screen, PIRS is already green,

You get this configuration:

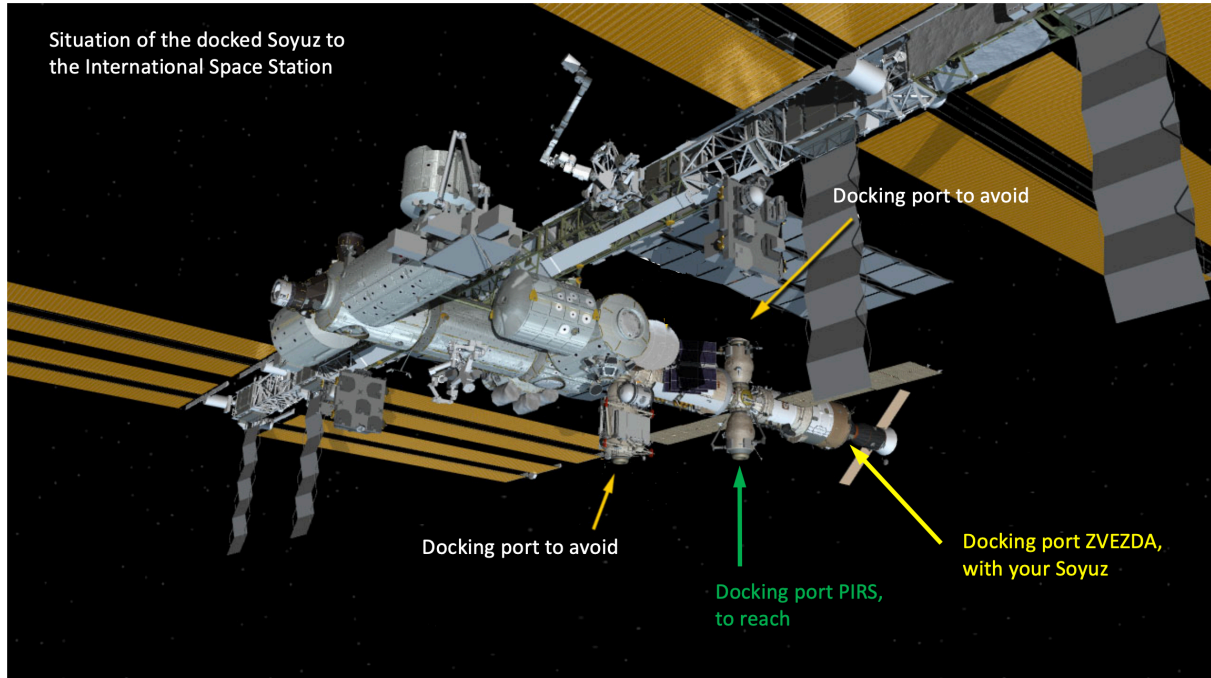


- Click on “START”, at the bottom right corner of the screen.

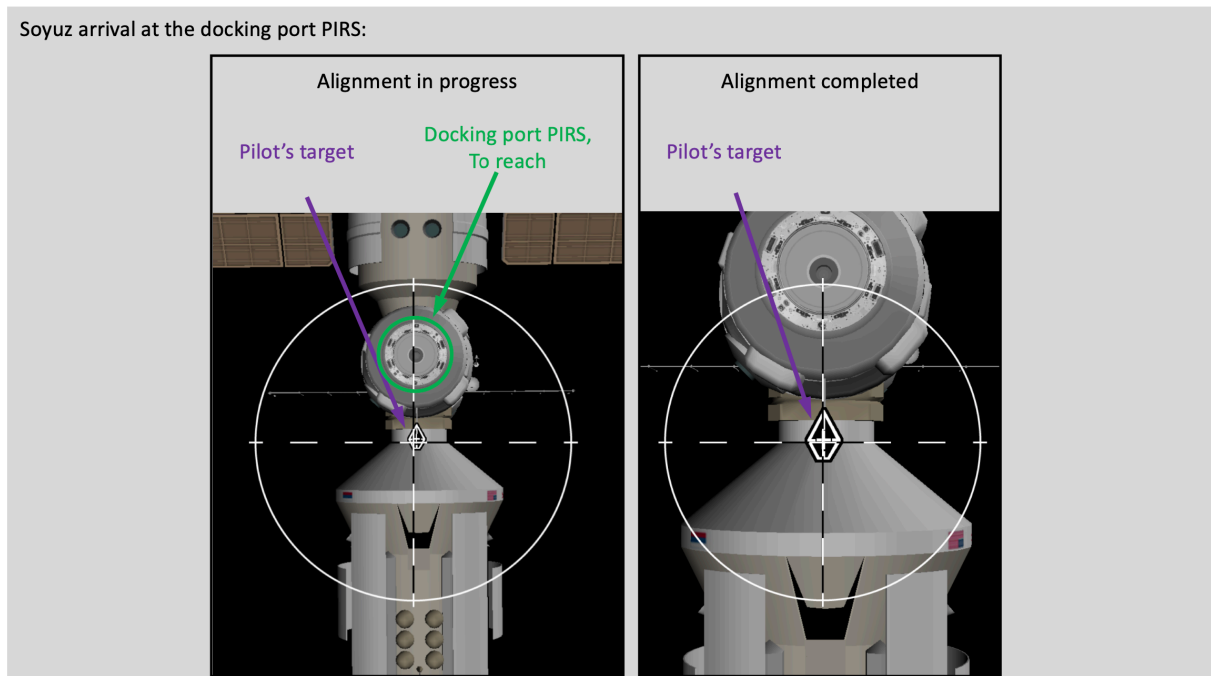
During the simulation, at the bottom center of the screen, you have two buttons:



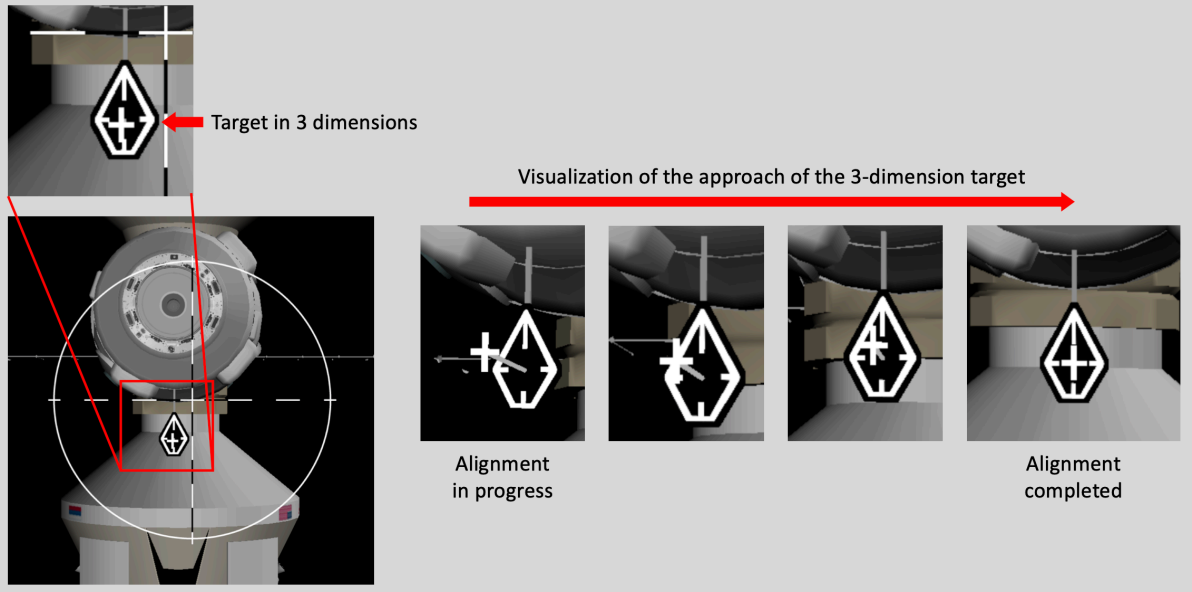
ANNEX 20: SOYUZ PRESENTATION



Soyuz arrival at the docking port PIRS:



Soyuz arrival at the docking port PIRS:



Trajectory of the transfer from ZVEZDA to PIRS :

