REGLISSE

Review of European ground Laboratories and
Infrastructures for Sciences and Support Exploration

ESA Internal study

TECHNICAL NOTE 2:
Ideal Facility for Psychological Research

ESTEC Ref.: TOS-MCT/2001/3021/In/CL

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April,2002

Document Approval Sheet

Project:	Review of European Ground Laboratories and Infrastructures for Sciences and Support of Exploration
Title:	Definition of the Ideal Facility for Psychological Research
Subtitle:	Technical Note 2
Doc No:	REGLISSE-TN-02
Issue:	Final
Revision:	0

Prepared:	____________________ Dietrich Manzey	Date:	___
Concurred:	____________________ Christophe Lasseur	Date:	___

Document Change Record

Issue / Rev.	Date	DCN-No.	Pages Affected
Draft	29.08.2001		All
Final Draft	15.10.2001	1	All
Final Draft / Rev. 1	01.02.2002		All
Final	15.04.2002		Frontpage (new) Table of Contents (added)

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1. Scope

This document is part of the technical documentation produced in the frame of the "Review of European Ground Laboratories and Infrastructures for Sciences and Support of Exploration" (REGLISSE). This study is carried out under ESA contract and represents part of ESA activities in preparation of a potential European participation in human exploratory space missions to Moon or Mars. It is based on the previous "Study on the Survivability and Adaptation of Humans to Long-duration Interplanetary and Planetary Environments" (HUMEX) initiated by ESA which provides a critical assessment of the human responses, limitations, and needs with regard to medical, biological, psychological, and life-support issues during human exploratory missions into outer space.

The current study focuses on an identification of ground-test facilities which might be used for research in the areas of medicine, psychology, life-support and exobiology in order to prepare for a European participation in exploratory missions.

The present technical note (TN-02) presents the results of WP2 entitled "Definition of the ideal facility for psychological issues". It identifies some basic requirements, design characteristics (structures, architecture), instrumentation and methods which should characterise or be available in a ground-test facility in order to support in an ideal manner research on psychological issues related to long-term exploratory space missions. The results are intended to provide a basic input for designing a new ground-test facility for psychological research, or for evaluating already existing facilities concerning their suitability for such research.

2. Reference Documents (General)

RD1 ESA and the Mars Initiative, Final Report of the Interdirectorate Groupe de Reflexion. Sept. 15, 1998. D/MSM/98-248.

RD2 HUMEX - Study on the Survivability and Adapatation of Humans to Long-Duration Interplanetary and Planetary Environements. Technical Note 1. Definition of Reference Scenarios for a European Participation in Human Exploration and Estimation of the Life-sciences and Life Support Requirements. HUMEX TN-001, Issue: Final, December 2000.

RD3 HUMEX - Study on the Survivability and Adapatation of Humans to Long-Duration Interplanetary and Planetary Environements. Technical Note 2. Critical Assessments of the Limiting Factors for Human Health and Performance and Recommendations of Countermeasures. HUMEX TN-002, Issue: Version1, June 2001.

RD4 Human Exploration of Mars: the Reference Mission of the NASA Mars Exploration Study Team. NASA SP-6107, July, 1997. (http://www.spaceflight.nasa.gov/mars/reference/hem/hem1.html)

RD5 Reference Mission Version 3.0. Addendum to the Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team. EX13-98-036). NASA Exploration Office, Advanced Development Office. Houston, JSC, June 1998. (http://www.spaceflight.nasa.gov/mars/reference/hem/hem1.html).

RD6 Man-Systems Integration Standards (MSIS). NASA-STD-3000, Revision B, July, 1995.

RD7 ISS Program, ISS Flight Crew Integration Standard (SSP 50005). Revision B, May, 1995.

RD8 Human Factors. Volume 1 and 2. (ESA PSS-03-70), Issue 1, July, 1994.

Further references to specific literature are given in the reference list at the end of this technical note.

3. Introduction

Human exploratory missions to Moon and Mars will largely increase the importance of psychological issues to be taken into account as possible limiting factors for behavioural health and performance of astronauts. In order to prepare for such missions, psychological research is needed in different areas which have been reviewed in some detail as part of the HUMEX-study (RD3). Such research shall improve the assessment of possible risks associated with psychological issues during long-duration interplanetary missions, and shall lead to the development of effective countermeasures. In principle, it can include

- experiments and empirical studies during long-duration orbital spaceflight;
- experiments and empirical studies in other natural or technical environments which – at least to some extent – show similarities to space and spaceflight (e.g. Antarctic research outposts, submarines, or off-shore platforms);
- secondary analyses of existing data-bases from such analogue environments;
- experiments and empirical studies during ground-based simulations of spaceflight.

Experiments and empirical studies during actual spaceflight certainly represent the most direct approach to investigate psychological issues of long-duration spaceflight. In particular, they represent an inevitable condition for investigating any issues related to the prolonged exposure to hypogravity. However, the opportunities for this research are limited by both, the number of flights, as well as crew time constraints. Furthermore, the range of issues that can be investigated is naturally limited to those which do not conflict with operational demands or safety. Thus, it seems fair to say that spaceflight studies alone will not be sufficient to accumulate the knowledge needed for extrapolating psychological issues which might arise during long-term interplanetary flights. This holds even more, as psychological research during actual spaceflight often suffers from several methodological and technical constraints - e.g. small numbers of subjects, difficulties to control experimental conditions, lacking possibilities to replicate experiments under same conditions -, which renders a clearcut interpretation of results difficult.

Consequently, research in analogue environments on Earth and during ground-based simulations represent important elements in order to prepare for future exploratory spaceflights (Kanas, 1997). In particular, Earth-bound research can be used to investigate behavioural effects of prolonged co-living and co-working in small crews under conditions of confinement and isolation. As a matter of fact, most of our present knowledge concerning human behaviour and performance under long-term confinement and isolation in hostile environments has been derived from research in Antarctica (e.g. Palinkas et al., 2000), secondary analyses of existing data-bases and anecdotal information (e.g. diaries) available from polar expeditions (e.g. Palinkas et al., 2000; Stuster, 1996), and research during submarine missions (e.g. Weybrew, 1991). Yet, the analogy between these unusual environments and spaceflight is far from perfect – e.g. with regard to crew size, crew selection, crew tasks (Suedfeld, 1991) -, and almost none of the research in these environments has explicitly been dedicated to issues of spaceflight. Therefore, even though the experiences and observations derived from these analogue environments undoubtedly provide an interesting data-base from which possible psychological issues of long-duration spaceflight might be extrapolated, the applicability of this knowledge to space, nevertheless, appears to be somewhat limited.

The currently best methodological approach to investigate possible psychological issues of exploratory spaceflight represent specific ground-based simulations of prolonged spaceflight which offer the highest degree of experimental control, flexibility, and provide the opportunity for investigations of a sufficient number of subjects under standardised environmental conditions. Examples of this approach reach back to the 1960s and 1970s (e.g. Rockwell et al., 1976), and include also several dedicated confinement and isolation studies which have been conducted during the last decade under full or partial sponsorship of ESA (ISEMSI 1990, EXEMSI 1992, HUBES 1994/1995, SFINCCS 1999/2000). In order to prepare for crewed exploratory missions to Moon and Mars, this approach needs to be continued and expanded. For this purpose, ground-test facilities are needed which do not only provide a best analogue to space habitats which in all probability will be used for such exploratory missions, but which also provide opportunities for psychological research in all the different areas which have been identified as relevant. In the present report, general requirements, basic design characteristics, instrumentation, and organisational aspects of a ground-test facility are described which ideally would support research concerning psychological issues of human exploratory missions to Moon and Mars. This description is largely based on currently available information from different reference scenarios (RD2, RD4, RD5), as well as a foregoing review of critical psychological issues associated with such exploratory missions as part of the HUMEX study (RD3).

4. General Considerations

Two general aspects have to be considered in defining the ideal facility: (1) the objectives of psychological research which should be served by the facility, (2) the level of fidelity required that makes a ground-test facility an appropriate analogue for the circumstances of exploratory spaceflight.

4.1 Objectives of psychological research to be served by the facility

A comprehensive review of possible psychological issues of exploratory spaceflight and the current state of knowledge have been provided as result of the HUMEX-study (RD3). Based on this review, a number of recommendations for research and countermeasure development have been defined which cover a broad range of different topics. Only few of these topics involve issues of (hypo)gravity-related effects on human behavior and performance and, thus, require the conditions of real spaceflight to be investigated. Yet, far most of the psychological research identified as relevant to prepare for crewed planetary and interplanetary missions address issues which do not necessarily require research during actual spaceflight, but research that can also be conducted in an appropriate ground-test facility. The most important of these issues include effects of long-term confinement and isolation on individual well-being and performance, and interpersonal interactions within small (multi-cultural) crews, as well as appropriate countermeasures which might help to maintain behavioural health and performance under these conditions. In particular, four different areas of psychological research needs have been identified as relevant (a comprehensive list of single research issues within these different areas can be found in Technical Note 2 of the HUMEX study (RD3) and shall not be repeated here):

- fundamental research concerning mental performance, i.e. effects of confinement and isolation on cognitive performance and perceptual-motor skills;
- fundamental research concerning maladaptive individual reactions, i.e. impact of prolonged exposure to life-support systems, and confinement and isolation on sleep, circadian rhythm, mood and mental health;
- fundamental research concerning interpersonal issues, i.e. impact of confinement and isolation on crew interactions and communication with the outside (including research on different aspects of crew-composition, e.g. effects of differences in personality, motivation, cultural background, gender);
- applied research and development concerning psychological countermeasures (e.g. research on crew selection, training, monitoring, and support, as well as selected aspects of habitat design).

Thus, a first basic requirement of a ground-test facility for psychological research can be defined as to provide the opportunity for studying small crews under conditions of prolonged confinement and isolation analogue to those which are to be expected during exploratory space missions (see below for a more detailed discussion of the problem of analogy). In addition, instrumentation must be provided in the facility which is needed to investigate the broad range of psychological issues described above. Focusing on research topics related to confinement and isolation does not mean to deny the need for other preparatory psychological research addressing, e.g., specific psychological issues of the design of man-machine systems used in space or other specific human engineering/human factors issues of psychological relevance (see RD3). However, most of this research does not need a specific ground-test facility, but can be done with standard human factors laboratory equipment and tools.

4.2 Level of fidelity required: Importance of similarity of experience

At the date of this writing, any ideas about the architectural design of future planetary habitats are highly speculative. So far, the most detailed description of a possible transfer and surface habitat for an exploratory mission has been provided as part of the NASA Mars reference mission (RD4). In this scenario it is assumed that the crew habitat “will consist of a structural cylinder 7.5 meters in diameter and 4.6 meters long with two elliptical end caps (overall length of 7.5 meters). The internal volume will be divided into two levels oriented so that each ‘floor’ will be a cylinder 7.5 meters in diameter and approximately 3 meters in heigth” (RD4, p. 3-78/3-79). Such a habitat would provide approximately 265 cubic meters of pressurized gross volume for the assumed crew of six astronauts (including space needed for stowage). Yet, on the surface of Mars it is assumed that this volume will be considerably increased by the use of a second habitat sent by a separate cargo flight, or the attachment of an inflatable "TransHab" structure (RD5). Figure 1 presents an artists view of this possible structure.

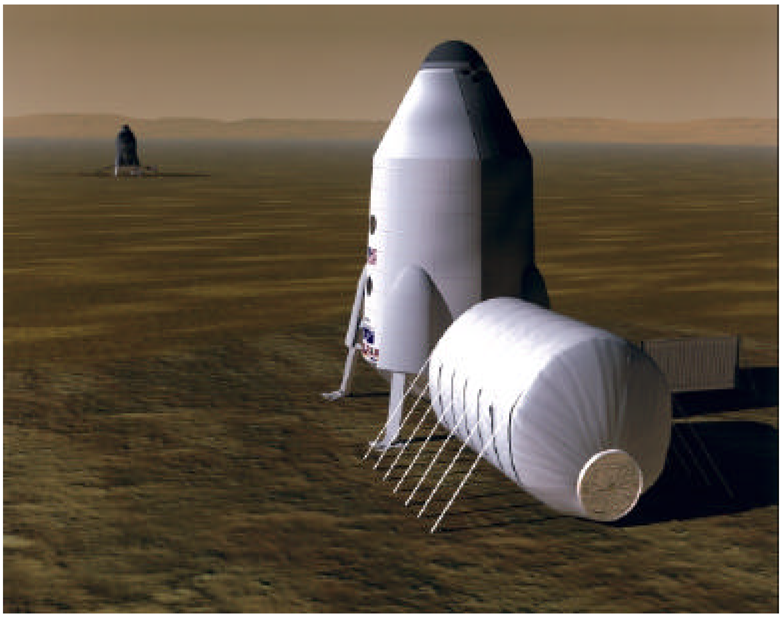

Figure 1: Artist's view of a possible planetary habitat based on ideas developed in the NASA reference mission of the Mars exploration team (RD4, RD5).

One could argue that a ground-test facility for psychological research should be as physically similar as possible to such a kind of structure, in order to represent a good analogue environment. Such an approach, e.g., has been chosen when the Mars Society built its first ground-based simulation facility referred to as Flashline Mars Arctic Research Station (FMARS), which has been placed in a crater in the Canadian high arctic, and was put into service in summer 2001. However, just the physical similarity of environments neither represents a necessary nor sufficient condition for being analogous in a psychological sense. Much more important is that the experiences and feelings of humans, living and working in the ground-test facility, are similar to those during an exploratory missions (Suedfeld, 1991). Therefore, a ground-test facility must not necessarily share all physical characteristics with a real planetary habitat (which are currently not known in detail, anyway). Instead, other aspects than pure physical similarity seem to be much more important, in order to simulate the psychological conditions of living and working confined in a space habitat. These factors can be summarised in two requirements - functional similarity and organisational similarity – and will be described in some detail below. The only exception in this respect represents the gross habitable volume available for a crew. This physical feature can be expected to have direct impact on the psychological meaning of confinement and isolation, and, thus, should correspond as best as possible to the volume of a real space habitat (see section 5.1.2).

4.2.1 Requirement of functional similarity

Functional similarity means that the ground-test facility should provide about the same functional possibilities and constraints which can be expected to characterise a planetary or interplanetary space habitat (e.g. during mission to Mars, RD4, RD5). This kind of similarity shall ensure that the ground-test facility – independent of its particular physical shape – provides a psychological environment which is as similar as possible to the situation in a real space habitat.

Most important functional possibilities which should be provided by an ideal ground-test facility include :

- support of an autonomous life of a crew of six in a sealed environment over a prolonged period of time, i.e. provision of:
    - an environmental control and life-support system
    - sanitary/hygienic facilities
    - facilities for autonomous food production (including sufficient stowage capacity for food)
    - waste management system
    - health care facility

- private crew quarters
- opportunities/facilities for crew meetings
- opportunities/facilities for meaningful work
- opportunities/facilities for recreational activities
- opportunities/facilities for physical exercise
- support by an outside control team.

Most important functional <u>constraints</u> of an ideal ground-test facility should include:

- permanent dependence on a life-support system
- restrictions of interpersonal face-to-face contacts to at most five other crew members
- restrictions of personal space and privacy
- restrictions of communication to the outside
- restrictions of environmental cues
- restrictions of hygienic facilities
- restrictions of variety of food and no possibility of re-supply of fresh food during the mission.

Most aspects of functional similarity can be met by appropriate structural and functional design features of a ground-based facility and its placement within an appropriate environment. These features are described in section 5.

Yet, the level of functional similarity which can be achieved will principally be limited. The main reason for this is that ethical standards prohibit to implement any functional constraints which are in conflict with the Declaration of Helsinki and with principle human rights, even though such constraints will characterise life and work on an interplanetary space mission and will determine the psychological burden of such a mission to a considerable degree. This regards, for example, the lacking possibilities to return to Earth during a Mars mission which also means that no evacuation will be possible in case of emergency. Such a feature can never be implemented in a ground-based simulation. In addition, ethical as well as practical considerations prohibit to confine and isolate crews for as long as 1000-days which would be required for a complete simulation of a Mars mission scenario on ground (see below section 7).

4.2.2 Requirement of organisational similarity

The requirement of 'organisational similarity' expands the conceptual view of a ground-test facility beyond considerations of purely environmental, architectural and functional characteristics. It is known for a long time that stress effects arising in a particular environment do not only depend on the environmental (physical and social) characteristics alone, but on its psychological meaning to the individual, i.e. represent the result of a complex interaction between person and environment. As has been described by Lazarus & Folkman (1984), the strength of stress effects is largely due to the subjective appraisal of a stressor by an individual. This appraisal has been shown to depend on both, personality characteristics as well as competencies, i.e. how the individual perceives the quality of stressor (e.g. threatening vs. challenging), and whether s/he thinks to have efficient strategies available to cope with it. Consequently, any organisational feature which can be expected to affect the way an astronaut perceives and copes with the challenges of an exploratory space mission, should also be taken into account in designing an overall concept of a ground-test facility. This aspect of "analogy" has rarely been addressed in evaluating results from so called analogue environments, and discussions of what makes an environment or ground-test facility an analogue of spaceflight all too often have remained limited to comparisons of different environments on a (superficial) structural or functional level. Yet, organisational similarity seems to represent another important condition for extrapolating findings from any ground-test facility to space.

From a psychological view, the most relevant organisational features in this respect include the provision of meaningful work for the crew, the promotion of a mission mentality and the provision of psychological countermeasures, i.e. selection, training, and support. For example, it appears to be highly questionable whether results from a ground-based confinement study using subjects who have not been specifically selected, trained or who have not got any psychological support during their 'mission', can really be extrapolated to real space missions with highly motivated, qualified, trained and supported astronauts. These aspects are described in more detail in section 6.

5. Basic Design Characteristics and Instrumentation of the Ideal Facility

In this section, basic design characteristics of an ideal ground-test facility for psychological research are described. According to the discussion above and the results of the HUMEX-study (RD3), the main focus is put on a facility which will be conducive for investigating effects of long-term confinement and isolation on mental performance, individual well-being and behavioural health, and interpersonal interactions.

Three aspects are addressed: firstly, some general features of the facility are described (i.e. basic elements, size, seclusion and life-support, surrounding environment, flexibility of interior architecture and décor). Secondly, important elements of a crew habitat are described which are needed as central part of the overall facility to support personal, operational and work-related functions during a ground-based simulation of a long-term space mission. Thirdly, specific equipment and features needed for conducting psychological investigations are described.

The general concept of a ground-test facility outlined in this section is largely based on presently available ideas and considerations about future space habitats, particularly those considered for exploratory missions to Mars (RD4, RD5, Winisdoerffer & Soulez-Lariviere, 1992). It is not only meant to provide a basic input for designing an ideal facility for psychological research, but also to provide some kind of checklist for evaluating existing facilities concerning their functional suitability as a space analogue ground-test facility from a psychological point of view. Since the main focus of the current concept is on functional similarity, however, no detailed architectural or human engineering specifications will be provided (see for such specifications RD6, RD7, RD8).

5.1 General features

5.1.1 Basic elements

The facility should consist of two basic elements:

- a *crew habitat* including individual and common crew quarters, service facilities, a laboratory for work-related activities, and several other specific facilities all of which will be described in more detail below;
- a *control centre* which allows for 24-hours coverage of crew operations and provides facilities for technical monitoring of the crew habitat's main functions (e.g. life-support system) , for medical and psychological support, and for scientific investigators.

The only link between crew habitat and control centre should consist of technical communication lines (see section 5.2.5), i.e. neither direct visual nor acoustical links should exist between both basic elements of the facility. From a psychological point of view, the crew habitat represents the most important component of the ground-test facility. Thus, the following description mainly focuses on this component.

5.1.2 Size of crew habitat

According to most reference scenarios for exploratory missions to Mars and Moon, there exist agreement that the crew will optimally consist of four to six astronauts. For example the 'Mars Direct' plan introduced by Zubrin, Baker and Gwynne (1991; see also Zubrin 2000) suggest to send a crew of four astronauts directly to the Martian surface. The most recent version of the NASA reference mission (RD4) which in large parts is based on the 'Mars Direct' plan, provides for six astronauts departing to the Martian surface. And a recent ESA-reference-scenario for a Mars mission (RD2) proposes that a crew of six astronauts are sent to Mars, yet, only four of them are assumed to depart to the Martian surface, whereas the other two crew members stay in the Martian orbit, in order to assure the functionality of the transit habitat for the return flight to Earth.

The gross volume of the transit/surface habitat available for the four to six crew members will represent a decisive factor that will considerably contribute to the psychological meaning of confinement during the mission. Thus, the crew habitat of a ground-test facility should not substantially exceed the volume which in all probability will be available in an interplanetary transit/surface habitat. However, reliable figures of what this volume will be during crewed missions to Mars (or Moon) are still lacking and represent a matter of speculation. Neither is valid information available about how much personal space is needed under confinement to maintain individual behavioural health and well-being (Fitts, 2000). Relevant research in this area dates back to the 1960s, and recommendations at this time suggested to provide a minimum of about 12 m^3 of habitable volume per person for long-duration missions under confinement (Connors, Harrison & Akins, 1985). However, such a volume appears to be inappropriately small for missions lasting more than a couple of weeks. Consequently, Winisdoerffer & Soulez-Lariviere (1991) suggest to provide at least 100 m^3 of volume per crew member for an exploratory mission to Mars.

According to the NASA Mars reference mission, which provides the most detailed information so far, the gross volume of pressurised space available in the transit habitat for crew accommodation (6 crew members), service facilities, laboratory, and storage capacity can be assumed to be around 260 m^3, and it can further be expected that this volume will be considerably expanded on the Martian surface by another habitat sent by a separate cargo flight (RD4) and/or by means of inflatable structures (RD5). Yet, more volume might be available even during transit if other launch alternatives are chosen (e.g. establishing and launching a transit habitat in/from low Earth orbit). No detailed information about the possible volume of a crew habitat has been provided for the different HUMEX study scenarios, but it can be assumed that the volume of transit and surface habitat will not be much smaller than those suggested in the NASA reference mission. Thus, the figure of 260 m^3 seems to represent the currently best (minimum) estimation of the gross habitable volume available during interplanetary transfer flights, and volumes up to 500/600 m^3 seem to be a more reasonable estimation for a habitat on the Martian surface.

Considering these figures as a guideline for a possible ground-test facility it might be taken into account that the microgravity conditions during transfer flights may considerably enlarge the *usable* space within a three-dimensional habitat of a given volume, compared to the space that can be used in a habitat of comparable size on Earth. However, exact calculations of what volumes in space and on ground are psychologically equivalent are difficult to obtain, and there are no empirical data available where such calculations could be based on. Therefore, any speculation about such figures (e.g. Connors et al., 1985) appears to be somewhat arbitrary. Yet, it seems at least fair to say that the above presented figure of 260 m^3 of habitable volume just represents a minimum size that must not necessarily be matched exactly by a ground-test facility. Even facilities which are larger to some extent can still serve as a useful psychological analogue for a transfer habitat. Based on these considerations the ideal ground-test facility should provide accommodations for up to six crew within a gross habitable volume of about 300-600 m^3 which can optionally be enlarged up to 600-1000 m^3, in order to serve for simulations of both, confinement conditions during transfer flights and during stays on a planetary surface. Of course, also ground-test facilities which are smaller can principally be considered. Although, they possess the risk of overestimating possible confinement effects, this risk seems to be more tolerable than a possible underestimation of effects in much larger facilities.

5.1.3 Seclusion and life-support

A psychologically important characteristic of each space mission represents a long-term dependence on environmental control and life-support systems (ECLSS). Thus, the ideal facility should provide a complete sealed environment equipped with an ECLSS, in order to achieve as best a functional similarity to a space mission as possible. In order to simulate the crew autonomy of an interplanetary mission, monitoring, maintaining and controlling the different sub-systems of the ECLSS should primarily be performed from inside the habitat. Control station functions should be limited to remote monitoring and control of systems and include a simulation of the typical delays of data transmission to be expected during interplanetary spaceflight.

5.1.4 Surrounding environment

Ideally the ground-test facility is placed in a natural surrounding environment characterised by harshness and hostility. Earth-bound environments best suitable for this approach include areas in the high Arctic or in Antarctica which - in a psychological sense – provide environmental conditions most similar to those on the Martian surface. In addition, dependent on the season, they provide opportunities to simulate a naturally weak structure of external Zeitgebers for the human circadian system which has been identified as an important possible stressor during interplanetary transit flight. Second best alternatives which also might be considered are deserts, high altitude regions in mountains, or any other remote areas with a comparatively monotonous landscape. All of these environments would not only be ideal to simulate the psychological conditions of confinement and isolation of an exploratory space mission as best on Earth as possible, but would also provide the opportunity for studying the effects of extra-habitat activities which will characterise the life and work on another planet's surface and might lessen possible effects of confinement. This marks an important difference to a third alternative, i.e. pressurised underwater habitats, which would not provide comparable possibilities for such activities because of the surrounding hyper-pressure environment and associated compression problems (to use a *saturation* diving chamber might solve this issue; yet, depending on the sea level and the necessity to breath special gas mixtures, a stay in such a chamber is associated with specific physiological and psychological effects not directly comparable to those of spaceflight). Thus, even though underwater habitats undoubtedly provide several interesting functional similarities to space habitats (e.g. the immediate dependence on life-support systems; the impossibility to leave the chamber at any time), the underwater environment presents only the third preferred *natural* environment to place a ground-test facility for psychological research in.

However, if an appropriate natural surrounding environment cannot be provided for some reason, also a sealed confinement chamber complex placed in a laboratory appear to be principally suitable as crew habitat of a ground-test facility. In this case however, a simulation of extra-habitat activities is generally not possible, and specific care must be taken to create the experience of living and working in a remote place by means of:

- efficient acoustical shielding against any noise from the outside;
- efficient visual shielding against the outside, i.e. if windows are provided (a highly preferred feature, see below) they should simulate an outlook on a monotonous landscape by means of appropriate 3D simulation technology.

5.1.5 Flexibility of interior architecture and décor

Even though, there is anecdotal evidence that the kind of interior décor (e.g. colour, paintings, pictures) can have an effect on individual well-being under prolonged confinement and isolation, only few empirical research has ever addressed this topic (Stuster, 1996). The most detailed research dates back to a NASA-Ames research program which has become known as "functional esthetics", and which has provided first recommendations concerning the topics and layouts of paintings and photographs most preferred under conditions of confinement (Clearwater & Coss, 1991). In order to support further research in this area, the general design of the crew habitat should allow for a high level of flexibility of internal illumination and décor. In addition, also different aspects of the interior architecture of the crew habitat (e.g. size of individual and common crew compartments, size of habitable volume) should be flexible to a certain degree. This would make it possible to address psychologically relevant research issues of habitability (RD3), as well as to adjust the ground-test facility for a simulation of the specific circumstances of different mission phases (e.g., transfer versus surface habitat).

5.2 Specific facilities and design features of the crew habitat

In order to support autonomous crew life and work over a prolonged period of time, the ground-test facility must provide several specific facilities. The most important ones include individual and common crew quarters, different service facilities, recreational facilities, exercise facilities, and a laboratory. Other design features which should be given to achieve functional similarity to interplanetary space missions regard the design of windows and interior décor, as well as the provision of outside communication lines with constraints characteristic for interplanetary expeditions (e.g., long transmission delays). In addition, the ground-test facility should provide the option to attach an hypobaric facility which might be used to simulate the physiological and/or psychological consequences of extravehicular activities. All of these different elements and features of an ideal ground-test facility are shortly described in the following. A schematic illustration of the different specific facilities is provided in the attachment.

5.2.1 Crew Quarter

5.2.1.1 Individual crew compartments

The ground-test facility should provide individual crew quarters for up to six crew members. These crew quarters should be designed to support the privacy and territorial needs of the crew members and to provide a personal place to withdraw.

The size and equipment of the private quarters should support the following functions (in priority order):

- visual shielding,
- undisturbed sleep, i.e. sufficient acoustical shielding
- private communication via audio/video transmission and e-mail (see below section 5.2.7),
- donning and doffing of personal clothes,
- stowage of personal items,
- individual environmental control (e.g. adjustable lighting, temperature),
- individual work and recreation (i.e. availability of a computerised workplace and compact entertainment devices),
- decor which allows for variability and individual preferences (e.g. paintings/pictures presented on screens; adjustable colour of lighting),
- view outside the habitat.

Minimum functional size requirements for some of these functions (sleeping facilities, stowage of personal items, donning and doffing of personal clothes) are provided in habitability standards compiled by NASA and ESA (RD7, RD8). Given these figures, a size of about 3-4 m^3 can be regarded as the minimum size of each individual crew quarter under microgravity. For the design of a ground-based facility, again differences in usable space between a microgravity and a gravity environment (e.g. with respect to the space needed for sleeping) have to be taken into account (see above section 5.1.2). Thus, a size of about 8-10 m^3 for each individual crew compartment seems to be appropriate on ground. However, since the optimal size of individual crew quarters needed to support territorial and privacy needs during long-term confinement still represents a matter of research, the size and general design of the individual crew quarters should be as flexible and easily adjustable as possible (see above section 5.1.5).

5.2.1.2 Meeting facility

A multi-purpose meeting facility should be available that provide opportunities for common meetings and interactive discussions, meals, and leisure activities (e.g. interactive games, movies) of the entire crew. In order to support these functions, the meeting facility should be equipped with a table where up to six crew members can be seated comfortably. It should be further equipped with communication devices which allow for two-way video/audio communications with the outside (see below section 5.2.7), and entertainment devices which can be used by the whole crew (e.g. video screen, see section 5.2.3). In addition, it should provide stowage capacity for items and equipments needed for these different purposes.

5.2.2 Service Facilities

5.2.2.1 Galley

The galley should provide all facilities needed to prepare food for the crew without outside assistance. In addition it should be equipped with a waste management system.

5.2.2.2 Laundry

In order to allow for a reuse of clothes, towels, bedding and to reduce the needed storage capacity, a laundry facility should be provided.

5.2.2.3 Sanitary and hygienic facilities

Sanitary and hygienic facilities include toilets and whole body cleaning devices (e.g. showers). Since these devices have to be shared during space missions, the same should hold for the ground-test facility. Thus, as an optimum, two toilets and two showers should be available within the ground-test facility for autonomous use by the six crew members.

5.2.2.4 Health care facility

The health care facility should support autonomous diagnosis and treatment of diseases occurring during confinement (unless an evacuation of the crew member is inevitable to meet ethical requirements). For this purpose it should be equipped with standard medical equipment and medication. In addition, telemedicine support should be available (within the constraints given by the long transmission times typically for interplanetary space flights). More details concerning these medical aspects are given in Technical Note 1.

5.2.3 Recreational and exercise facilities

In order to achieve a high level of functional similarity to the circumstances of real space missions, the ground-test facility should provide about the same facilities for recreation and physical exercise that will be available during exploratory flights. This is particularly important for psychological research since recreational activities and physical exercise can be regarded as countermeasures for boredom, monotony and stress arising during long-duration confinement. In addition, daily physical exercise represents an important medical countermeasure requirement for hypogravity effects during long-term space missions, and, therefore, should also be part of any ground-based simulation. In order to support recreational and exercise functions, the following facilities/supplies should be provided in the ground-test facility:

- at least two different kinds of physical exercise equipment (e.g. treadmill, bicycle ergometer),
- library of paperback and electronic books,
- personal entertainment devices and supplies (e.g. music instruments, DVD-players, computer games),
- crew entertainment devices and supplies (e.g. device for movie projection, card and board games)

Whereas the personal entertainment devices and supplies should be available in the individual crew compartments, the crew entertainment devices and supplies should be available in the meeting facility.

5.2.4 Work facility

From a psychological point of view, an important aspect of a ground-test facility is that the crews have some meaningful work to perform (beside participating in psychological experiments). This represents an important condition for ensuring a high level of functional and organisational similarity to the circumstances of a real mission. Thus, the ideal ground-test facility should consist of a work facility (e.g. laboratory module) which provides opportunities for real and meaningful research in different areas. In order to provide some flexibility in this regard, it should be equipped with standard industry racks where different hardware can easily be implemented, dependent on the experimental program of different 'missions'. The size of the laboratory should allow at least four crew members to work simultaneously.

5.2.5 Storage facilities

The ground-test facility should provide sufficient storage capacity to support missions of six crew members up to a duration of six months without any need for re-supply (e.g. of personal items, food, water etc.). However, if a re-supply is needed due to a shortage of storage capacity, the technical design of the crew habitat should allow to perform the re-supply without any direct contact to the crew. In addition, care should be taken that no items will be delivered which could not have stored for the same time within the habitat (e.g. fresh food). The importance of this requirement has been demonstrated by experiences from a recent 135-day confinement study (Kanas et al., 1986), where an opening of the isolation chamber for re-supply of food, equipment etc. midway of the seclusion turned out to have dramatic (positive) impact on the psychological state of the confined crew even though they were not allowed to leave the chamber.

5.2.6 Hypobaric facility (optional)

During missions to Moon or Mars, extravehicular activities (EVA) will have to be performed on a regular basis (e.g., 2 astronauts every 3 days, cf. RD2). Dependent on the general pressure level in the space habitat, these activities can be associated with problems of depressurisation. Even though depressurisation issues are primarily of medical concern, they also present several psychological problems, e.g. with respect to the impact of such EVA's on mental functions and its time-course of recovery (RD3). In order to provide the possibility to investigate these effects, the ground-test facility should be equipped with an air lock and an altitude chamber attached, for simulating work in a depressurised state. The size of the airlock and the altitude chamber should be large enough to accommodate two crew members. The altitude chamber should provide work facilities similar to those in the working facility of the crew habitat. However, this facility is regarded as an optional facility, i.e. it is not necessarily needed to conduct psychological research in a ground-test facility, but only represents an element which would be nice to have for addressing specific EVA issues. Furthermore, this feature of a ground-test facility becomes superfluous if transfer and surface habitats of interplanetary spaceflights will generally represent hypobaric environments that keep the crew members in a hypobaric state all the time, thus making any depressurisation for extra-habitat activities unnecessary.

5.2.7 Communication Lines

Communication between the crew habitat and the outside should be restricted to technical communication lines. These should include:

- audio transmission,
- video transmission,
- electronic mail transmission.

Audio/video transmissions and electronic mail transmission to the outside should be possible from every individual crew compartment, the meeting facility, the work facility, and the health care facility. Provisions should be made to allow private (i.e. protected) communications with family and friends via these lines from the individual crew compartments. In addition, the health care facility should be equipped with technical infrastructure needed to provide telemedicine support. Providing all of these communication lines, transmission delays such as those expected during exploratory missions (i.e. up to 20 minutes for one-way transmission to or from Mars) should be implemented, in order to fulfil the requirement of "functional similarity", and to investigate the effects of these delays on communicational behaviour.

5.2.8 Windows

Windows play an important role in confining habitats, and can be expected to have a significant impact on the psychological meaning of confinement (Haines, 1991). Since it can be expected that transit and surface habitats used for exploratory space missions will possess windows, the same should hold for a ground-test facility. Thus, windows which are accessible by the crew members and which provide a *real* (in case that the habitat is placed in an appropriate natural environment, see above section 5.1.4) or a *virtual* outlook (in case that the habitat is placed in a laboratory), should be present in different areas of the habitat (e.g. meeting area, working area). However, for research addressing issues of circadian rhythm arising during a long-term transfer to another celestial body, it must be possible to seclude the windows completely, in order to shield the crew habitat against any external Zeitgebers.

5.3 Specific instrumentation of the crew habitat needed for psychological research

Psychological research issues relevant to prepare crew interplanetary space missions have been identified and defined in the HUMEX study (RD3). Based on these study results, the ground-test facility should support psychological research on:

- effects of long-term confinement and isolation on cognitive and perceptual-motor performance,
- effects of long-term confinement and isolation on individual well-being and mental health
- effects of long-term confinement and isolation on interpersonal interactions within a confined crew and between a confined crew and the outside

In addition, it should also be used to develop, validate, and improve psychological countermeasures. Most of this research requires standard PC equipment or can even be done by means of paper-pencil tests and questionnaires. Consequently, only few specific instrumentation must be provided in the crew habitat for psychological research in different areas.

5.3.1.1 Fundamental research on cognitive and perceptual-motor performance

In order to investigate effects of confinement and isolation on cognitive and perceptual motor performance, an integrated psychophysiological performance-assessment-device (IPP-PAD) should be available which consist of

- a high-performance PC with a variety of input devices (i.e. keyboard, joystick, trackball, touch screen, microphone) for flexible implementation of different cognitive and psychomotor tasks,
- an interface to a device for recording and storing of (non-invasive) physiological data (e.g. EEG, ECG, EMG, EOG).

The IPP-PAD could permanently be implemented in the work facility and used for both, experiments addressing specific performance-related issues, as well as routine performance-monitoring applications.

5.3.1.2 Fundamental research on maladaptive individual reactions

Most research in this area can be done by means of tests and questionnaires which do not need specific instrumentation within the crew habitat. The only exception regards research addressing issues of sleep and circadian rhythm. For this kind of research a *mobile multi-channel recording and storing device* should be available for *each crew member* which can be used for:

- sleep-EEG recording,
- continuous recording of activity data,
- continuous recording of body temperature.

5.3.1.3 Fundamental research on interpersonal issues

In order to provide the opportunity for recording objective data on interpersonal interactions within the confined crew, the meeting facility should be equipped with video-cameras and microphones which allow for a complete recording of all verbal and non-verbal interpersonal interactions, either during selected regular crew meetings or during specific group-exercises.

No specific equipment, however, is required for investigations of interpersonal interactions between the confined crew and the crew of the control-centre. For this purpose, it is sufficient to analyse the communication between crew habitat and control-centre along the different communication lines available (see section 5.2.7).

5.3.1.4 Research and development concerning countermeasures

No specific instrumentation of the crew habitat beyond that which has already been described is needed for countermeasure research.

6. Organisational Aspects of the Ideal Facility

Preparatory research for exploratory missions should lead to results and conclusions that can be extrapolated to real space missions. As has been discussed in some detail above, this requires that the ground-test facility does not only provide a physical and social environment that is psychologically equivalent to the environment in a space habitat, but also fulfils the requirement of organisational similarity. According to this requirement, the most important organisational features which can be expected to affect the motivation of an astronaut, and the way an astronaut perceives and copes with the challenges of an exploratory space mission, must also be taken into account as best as possible in defining the overall concept of a ground-test facility. This should contribute to raise the psychological analogy of the ground-test facility, and should prevent research outcomes which, even though they might reveal interesting effects of confinement and isolation on humans in general, nevertheless lack external validity for the specific circumstances of space missions.

In particular, three different aspects appear to be of primary importance in this respect: provision of meaningful work, promotion of a mission mentality, provision of psychological countermeasures.

6.1 Meaningful work

Astronauts on exploratory missions will have to perform much operational and experimental work. To perform meaningful work has been identified as a very important factor in coping with confinement and isolation. This has been reported from astronauts on long-duration space missions, as well as participants of expeditions in the Antarctic. According to these reports, boredom is one of the most worst and demoralizing stressors in a confined and isolated environment (Stuster, 1996). Consequently, the concept of a ground-test facility for psychological research should take this factor into account, i.e., provisions should be made that subjects have meaningful work to perform during their stay in the ground-test facility.

6.2 Promotion of a mission mentality

The generally feeling to take part in an important mission represents a significant psychological factor of maintaining morale and motivation during spaceflights in general, and will be of high importance during exploratory missions, in particular. Even though it will never be possible to evoke a mission feeling of comparable strength in simulated missions on Earth, the organisational context of the ground-test facility should promote the development of a mission mentality as best as possible in both, the control centre personnel and the confined crew participating in a ground-test. This has successfully been done by ESA during several confinement studies in the past (ISEMSI, EXEMSI, HUBES), and has also been identified as an important factor in the long-duration missions of the NASA Lunar-Mars-Life-Support Project (LMLSTP, Holland & Curtis, 1999). Mission mentality can be assumed to arise automatically in crews participating in expedition-like ground-tests (i.e. if the ground-test facility is placed in a remote extreme environment on Earth), but must specifically be created if the ground-test facility is placed in a laboratory environment.

6.3 Implementation of psychological countermeasures, i.e. selection, training, and support

Psychological countermeasures represent a key aspect of long-duration space missions. Usually they include (1) a psychological screening of astronauts based on assessments of operational capabilities, personality and biographical experiences, (2) a psychological training addressing aspects of self-management, interpersonal communication, team-work, and leadership, and (3) psychological support during the mission in order to counter possible detrimental effects of boredom and social isolation (RD3). That is, astronauts sent on long-duration missions usually are specifically selected, prepared, and supported to cope with the psychological challenges they are exposed to. Consequently, similar countermeasures should also represent an integral part of the overall concept of an ideal ground-test facility. This would not only increase the external validity of effects, but also would provide the opportunity that the countermeasures itself can become an object of research. A positive example in this regard, has been EXEMSI, where the participants were psychologically selected according to the psychological standards defined for ESA astronaut candidates, where the crew were specifically composed based on behavioural assessments, and where the participants further got some psychological training in preparation of their 60-day confinement (Manzey et al., 1995).

Psychological screening should include standardized testing of the candidates based on performance tests, personality questionnaires, and a biographical interview. The results of this testing, on the one hand, should be used to select-out candidates who do not meet minimum psychological requirements concerning performance, personality, and motivation. In addition, it should be used to establish a data-base across different missions which can be used to identify individual predictors for optimum adaptation to conditions of confinement and isolation. Of course, limiting the psychological screening for a mission in a ground-test facility to a *select-out* approach does not compare to the more restrictive *select-in* approach recommended for exploratory missions (RD3). Yet it represents the best compromise between the need to apply at least some kind of selection, on the one hand, and the wish of keeping sufficient individual variety between candidates in order to enable research on individual predictors of adaptation, on the other hand.

Psychological training should address issues of human communication, team-work, and self- and stress-management under conditions of isolation and confinement.

Finally, psychological support should be provided during the stay in the ground-test facility which should include measures similar to those which in all probability will also be provided during exploratory space missions. At least, these measures should include

- provision of a variety of recreational supplies (see above, section 5.2.3.),
- provision of news from “Earth” (home) on regular basis,
- provision of contacts to family/friends via e-mail or audio-/video-transmissions on regular basis,
- psychological counselling and guidance if required.

In order to provide training and support before and during a ground-test mission, a psychological support group must be established as part of the control-centre team.

7. Additional Recommendations: General research strategies, mission durations, and a network of facilities

7.1 Recommendations for a general research strategy

Psychological research in the ground-test facility shall contribute to both, systematic investigation and understanding of psychological risks arising during interplanetary space missions, as well as development of efficient countermeasures for these effects.

In order to achieve this, a high degree of comparability between different studies must be ensured. This has often been a flaw of confinement and isolation studies in the past. For example, ISEMSI, EXEMSI, HUBES and SFINCSS, all represent interesting single studies which have produced a large amount of empirical data. However, a comparison of the different results which would be needed in order to draw general conclusions from these studies is hardly possible, mainly due to differences between studies with respect to crew size, crew mixture (all male versus mixed), mission duration, different functional and organisational aspects, and – last but not least – the kind of psychological data collected.

In order to facilitate an integration and interpretation of data, the concept of a ground-test facility should ideally include:

- Definition of a long-term research programs including at least 10 “missions” each, with a priori defined general mission parameters, e.g. fixed duration and work-rest schedules for all missions, but systematic variation of crew mixture (e.g. five missions each with same-gender and mixed-gender crews). This number of missions is suggested by the comparatively small crew size per “mission”, and would allow to accumulate data of about 60 subjects.

- Definition of a common set of measures which are used to select and train participants for a “mission” in the ground-test facility, as well as to monitor their performance, well-being and crew interactions during confinement and isolation. These common measures are meant to represent a “core set” of measures which would ensure the comparability of results across different missions, and which could primarily be used to address issues which need a considerable large data base to be investigated. Yet, in order to ensure sufficient scientific flexibility, the core set of measures could be complemented by new experimental measures in each new mission which then would allow to investigate specific questions of fundamental or applied (operational) interest.

7.2 Duration of missions in the ideal ground-test facility

As has already been mentioned above (section 4.2.1), a simulation of a full three-years Mars mission on ground appears to be an unrealistic option. One reason for this are ethical concerns which might be raised against isolation and confinement of humans for such a long time just for experimental purposes. However, also practical reasons argue against such a long-term simulation. Although it would certainly be the most realistic scenario to investigate possible psychological risks of an interplanetary mission, the time to be invested most likely would not justify the outcome, i.e. the sampling of data of only some few subjects which might be questioned with respect to conclusiveness and external validity (i.e. to what extent the results can be generalised). This is particularly an issue for psychological research which usually has to deal with stochastic phenomena and to rely on statistical evaluations based on a sufficient number of subjects. Therefore, mission durations for missions in a ground-test facility has to be chosen which present the best compromise between being long enough to investigate the interesting psychological effects, and being short enough to provide data from a sufficient number of subjects within a reasonable time-frame. Based on these considerations, a stepwise approach appears to be the best solution:

In the first step, systematic research programs as the one recommended above should be defined and conducted with comparatively short mission durations of two to four months. The exact mission durations should be tailored to the specific issues to be addressed in the research. For example, mission durations of three months appear to be a good compromise for most psychological research in areas where a large number of subjects are needed, or where research questions involve the comparison between crews of different structure. In particular, this holds for systematic research on individual differences in coping with long-term confinement and isolation, for research on psychological compatibility effects, for research on specific aspects of crew composition (e.g. multi-cultural crews, mixed- versus same-gender crews). Even though, a duration of only three months is considerable less than durations expected for real interplanetary mission, it appears to be long enough to provoke important effects of confinement and isolation on individual well-being and crew-interactions. Therefore, it can be used to establish a data base within a reasonable time-frame which can be used to describe important psychological issues of interpersonal co-living and co-working under confinement and isolation in some detail and to derive predictions about risks for exploratory missions of longer duration, as well as concepts for possible countermeasures.

In a second step, some single missions of longer duration (from six months up to one year) should be performed in order to test the predictions derived from the three-months missions research programs, and to empirically evaluate their validity for missions of extended duration.

7.3 Network of ground-test facilities

Even if one accepts the idea that a mission duration of three months is appropriate as a first step for most preparatory psychological research for exploratory space missions, the sampling of data of a sufficient number of subjects will include some years of research. For example, based on a realistic scenario where two three-months missions are run per year, each single research program involving ten missions in order to provide data of some 60 subjects must be planned to include a time-frame of at least five years.

This time could be considerably reduced if there would not only be one ground-test facility available, but a network of two or three facilities which could be run in parallel. Following this idea, the best comparability of studies will be achieved if all of these facilities are physically identical. However, even a given functional equivalence (see section 4.2.1) of different facilities might be sufficient for this approach. In any case, specific care should be taken that the environmental and organisational conditions under which the different facilities operate are comparable. To ensure this kind of comparability will present a particular difficult issue if the different facilities are placed in different environments and are run by different organisations/institutions, i.e. under different administrative responsibilities. In this case, different environmental effects can make an interpretation of results difficult, and a large amount of organisational and administrative work can be foreseen to coordinate the activities in the different ground-test facilities. This additional work most likely will produce costs that outweighs the possible benefit of this approach, thus rendering it an unrealistic and inefficient option. However, considerably synergism effects can be expected from a small network of facilities placed in a comparable environment which are run by a common European control centre. In this case, major organisational tasks (e.g. selecting, training and supporting of subjects; implementing experiments) can efficiently be coordinated which in turn will lead to a considerable reduction of operational costs per subject. In addition, it would reduce the time needed for completion of a certain research program by a factor two to three.

8. Interfaces to Other Fields of Research

8.1 Research on medical issues

The ideal ground-test facility for psychological research will also provide interesting opportunities for medical research on physiological effects of long-term confinement and isolation. In fact, both medical and psychological research pre-supposes a facility where a crew can live autonomously for a given time under conditions which are as functional and organisational comparable to those in a space (transfer or surface) habitat as possible (cf. Technical Note 1). Even though the most interesting aspect from a medical point of view certainly is hypo-gravity which can only partially be simulated on ground (e.g. by head-down tilt bedrest), other issues associated with confinement – e.g. effects of hypo-activity or hypo-stimulation, or medical support - can easily be investigated within a ground-test facility as the one described above. The most direct connection between both fields regards the health care facility which has been defined as an important element to support autonomous crew life. Beside using this facility for developing efficient support of autonomous health care activities (e.g. strategies of telemedicine support), it will also provide several options and instrumentation for medical research. In any case, conducting medical and psychological research within the same facility using the same subjects will provide a unique opportunity of systematically describing responses of the human organism to confinement on different levels, ranging from a molecular to a behavioural level.

8.2 Research on life-support issues

As has been described above, the ideal ground-test facility for psychological should be equipped with an ECLSS. The main reason for this is the realistic simulation of long-term dependence on an automatic life-support system which is assumed to represent an important psychological factor of exploratory space missions. In addition, it will provide the subject with a realistic operational task, i.e. monitoring and maintaining the ECLSS with only limited support from the control centre. Thus, the ground-test facility outlined in this Technical Note will also present interesting options for studies on different aspects of life-support systems in a ground-test facility as the one described above. One objective of this research, of course, are studies focusing on engineering-related questions associated to different ECLSS philosophies and solutions under realistic circumstances. Yet, also psychological effects of such systems could be addressed. One important psychological aspect, e.g., concerns the level of automation of an ECLSS and its impact on human capabilities to react appropriately in case of malfunctions. A second interesting aspect is related to the use of higher plants as part of bio-regenerative systems. Raising higher plants under confinement and isolation can be expected to have a positive impact on the psychological well-being of confined crew members, both by providing “living systems” which need care and present some kind of Earth-related stimulation in an otherwise monotonous and strange environment, as well as by providing a highly welcomed variety of diet. However, systematic research on these possible effects is lacking, so far. In order to allow for such research, it should be considered to attach a higher-plant chamber to the ground-test facility. Such a chamber could be used for both, specific research on bio-regenerative life-support systems, as well as psychological research on the impact of “living” higher plants on the mood and psychological well-being under long-term confinement and isolation.

8.3 Exobiological Research

As has been described above (section 6.1) the provision of meaningful work to confined crew members is regarded as an important element of a ground-test facility used for psychological research, in order to achieve a sufficient level of functional and organisational similarity to real space missions. To conduct exo-biological research could be such kind of work. However, this pre-supposes that the ground-test facility is placed in an extreme and (from an exo-biological point of view) interesting environment on Earth (see section 5.1.4.). On the one hand, such research clearly would provide “meaningful work” to crew members which is highly similar to the real work during an exploratory space mission. On the other hand it could contribute to address some of the research needs in this area which are defined in detail in Technical Note 4.

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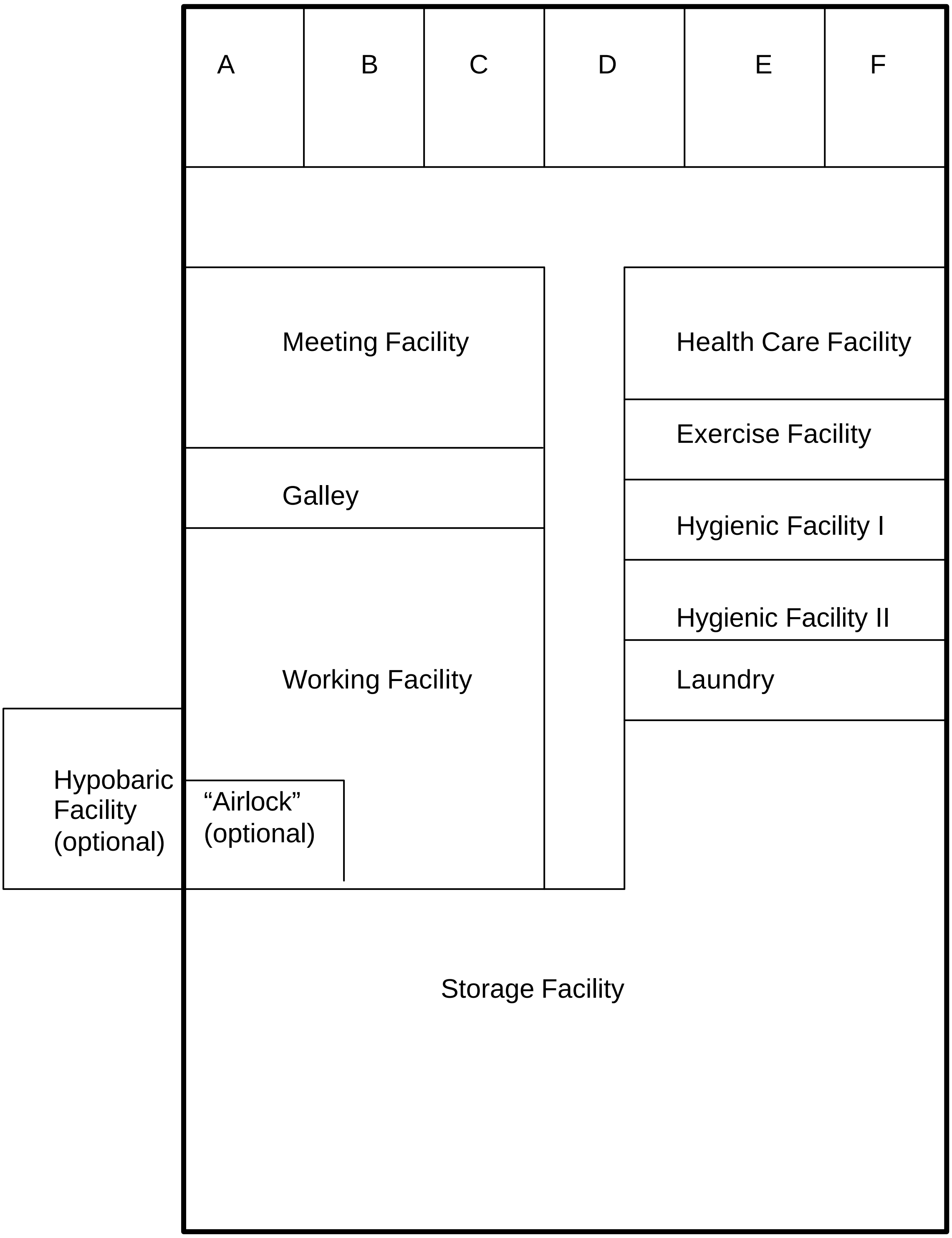
Attachment: Functional layout of a ground-based facility for psychological research*



* Note that this sketch shall only present a schematic illustration of the different specific facilities described in the text. It is not meant as an optimal design layout, neither does it imply that the ideal ground-based facility necessarily should be designed on one level only. (A-F = individual crew compartments).