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THE PERFECT BORING SITUATION – IN VIEW OF DESIGNING ONBOARD COUNTERMEASURES TO MONOTONY & ISOLATION DURING TRANSFER STAGES OF EXTENDED EXPLORATION MISSIONS

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In contemporary orbital missions, workloads are so high and varied that crew may rarely experience stretches of monotony. However, in historical orbital long duration missions, experiences of monotony were, indeed, reported anecdotally by crew. Remedies appeared to be at hand, including a constant visual connection to Earth providing a rich source of stimulation and past-time activity, regular direct audio contact to the ground, visiting crew, and designated 'surprise' packages containing novelty items, correspondence and fresh produce delivered with cargo. However, all these countermeasures – which were relatively successful in addressing what is essentially an operational issue – are not feasible in the remote context of an extended mission scenario. Particularly in- and outbound cruising stages are characterised by longer, comparably uneventful stretches of low workload, coupled with confinement and unchanging vehicle surroundings. While the challenge of monotony has been pointed out as critical in taxonomies of exploration-related further research needs, it has received less explicit attention from a habitation design perspective than other human behaviour and performance issues. This paper aims to address this gap through an introductory overview on the theory and application of design-based mitigation strategies. Following an introduction of key concepts surrounding the phenomenon of monotony as such, a summary of the existing body of literature from the orbital experience is given and models of mitigation strategies outlined. Based on a situational characterisation of a typical transfer stage scenario, monotony is conceptualised as a threefold model of sensory, social and spatio-temporal isolation that may exacerbate other psychological stressors of the setting and negatively affect human behaviour and performance. In view of translating currently available orbital evidence into design recommendations for an autonomous setting, a review conducted of published primary anecdotal evidence of crew on orbital and simulator missions in relation to their experience of monotony is summarised, highlighting three themes of design-based countermeasures.

I. INTRODUCTION: MONOTONY AS CRITICAL ISSUE IN EXTENDED SPACEFLIGHT

Somewhat in contrast to the contemporary image of the busy astronaut or cosmonaut, monotony and boredom are routinely listed as one of the main psychological stressors and high-level behavioural challenges in extended space missions.[1, 2] This may be particularly severe in deep space missions and their likely situational constraints of low workload, hypostimulation, limited social interaction and isolation from loved ones.[3, 4] Extreme monotony leads to increasing boredom and motivates coping attempts, some of which may be risky and impede safety[2]. The issues is classified as priority research and development need on par with technical challenges and biomedical issues such as radiation in contemporary taxonomies of current biomedical evidence, exploration studies and policy document.[5, 6, 7] Nevertheless, has received comparably little explicit attention from both a human factors or design perspective.

Particularly the transfer phases to and from a mission destination such as Mars or Near Earth Asteroids are described as incubators for low morale[6] and, in certain mission scenarios, might be worse for those crewmembers remaining in an orbiting vehicle while their peers work on the planetary surface. Activities such as housekeeping, physical exercise, skill maintenance, leisure and scientific activities may fill a portion of onboard time. Crew selection and training will identify individuals less prone to boredom or impart coping strategies. Ideally, though, these measures would be additionally augmented by the design of the vehicle interior system itself to provide in-situ, autonomous mitigation or prevention.[8, 9]

This paper aims to provide an introductory overview on monotony in transfer stages of autonomous exploration class missions from a conceptual and applied perspective. After an introduction of theoretical concerns of monotony as emotional state, the criticality of monotony particularly in the cruising stages of deep space missions will be outlined. Monotony will be conceptualized as a threefold phenomenon of isolation that is fundamentally distinct from the orbital setting and but could be addressed by design-based countermeasure strategies. A review of published user accounts from orbit and ground-based simulation identifies three main themes, based on which a set of high-level strategies for in-flight support measures for prevention and mitigation are suggested.

Monotony and Boredom as Emotional States

The phenomenon and condition of monotony is often cited in conjunction with – or, indeed, as synonym for – boredom. Boredom is described as a current 'emotional state, ranging from mild to severe discontent that people describe as a feeling of tedium, monotony, ennui, apathy, meaninglessness, emptiness, lack of interest, and disconnection with the current environment'.[10] It has practical importance, as it is related to both social problems and problems living in prison settings, elderly or mental care and the military, aside from other, more prominently addressed problems associated with such settings such as depression or anger.[10] DeChenne and Moody[11] describe a model of boredom that is controlled by four variables relating to stimulus variety and intensity (not content), to proneness to boredom (extroverts or introverts), individual needs (the content of the stimulus related to a person's interests, values, needs), and skills (the adequacy of personal capabilities to 'farm' an environment for stimulation).

Compared to other emotional states, boredom is a relatively recent phenomenon of industrialised societies.[12] Philosophically, it has been characterised by a sense of dullness or emptiness[13] that may be 'accompanied by mad pursuit of and/or waiting for trivial, insubstantial stimulations and distractions'[14] and that can lead to destructive tendencies.[15] The acute 'void' or 'uncanny sense of nothing'[15] that ensues may – figuratively speaking – not be incomparable to the situational setting of a deep space transfer scenario. Seaburn echoes the sense of 'emptiness' described in philosophy from an applied perspective.[16] He points out that boredom arises when a person is unable to successfully navigate a developmental or situational change. The resulting 'transitional vacuum' is caused by an underlying sense of loss, expressed by apathy, alienation and behaviour that to others may appear as frivolous, irresponsible, vaguely self-destructive.[16] It constitutes one step on the continuum to melancholy and serious depression[17], and is paraphrased by asthenia,[18] a possible condition identified in the space setting[19]. Concretely in light of its conceptual sense of 'massiveness and lack of distance',[20] Allo links boredom to the contemporary 'dislocation' of the individual in relation to the accelerated pace of technologically mediated life. Julier[21] qualifies this notion of technology and dislocation with the increasing de-skilling of the user due to automation – a point of critique lucidly made for the aerospace context both by Connor[22] for test pilots and Krikalev, Kalery and Sorokin for cosmonauts.[23]

Extroverts are more susceptible to boredom.[24] A 'very high readiness to withstand deprivation' and medium motivation and creativity will be an essential quality of crewmembers if they were to cope positively to a confined and isolated setting.[25] However, for highly motivated and energetic groups such as explorers, the forced inactivity that is part of the mission 'can generate more acute distress and frustration than fighting for survival'.[26] This 'personality paradox' was described by both Sandal[27] and Suedfeld and Steel,[2] who point out that those volunteering for missions in capsule habitats often display a keenness for thrills and novelty, and high motivation with a 'strong need for change and thrive toward adventure, strength and mastering difficult tasks'[27] – only to find themselves grounded in a monotonous environment in an unvarying group with a routine schedule.[2] Thus, the people who are 'most likely to be unhappy on site are recruited'.[2] Finally, training can exacerbate the 'dangers of boredom'[8] as the anticipation of an exciting mission may not offset monotony, and that work design and intrinsic motivation will become even more important.

Models for Prevention and Mitigation Strategies to Monotony

Klapp's (1986) Model of Redundancy and Variety

In his analysis of informational overload, Klapp[28] proposes a matrix of factors contributing to boredom. Klapp describes boredom as the 'loss of meaning' that results from an overload of information that includes either too much redundancy or too much noise. Emergence of, and coping with, the state highly depend on the individual. Boredom, as result of understimulation, is most acutely produced by sensory deprivation or a severe loss of information, and can be experimentally induced by a monotonous and artificial environment, cutting off communications, variety and activity. Klapp's matrix is made up of two axes (variety-redundancy and meaning-entropy) and four quadrants of *good redundancy* on the quadrant meaning-redundancy; *good variety* on the quadrant meaning-variety; *boring redundancy* on the quadrant entropy-redundancy; and *boring variety* on the quadrant entropy-variety. Klapp's interpretative model of how boredom arises may also hold the key to approaching countermeasures to it in an extreme operational context:[29] While too much 'boring redundancy' (banality, tedium, monotony, restriction, formalism) is disadvantageous, good redundancy (codes, customs, rituals, traditions, tinkering, continuity, resonance, and 'social placebo' activities such as watching sports) mitigates boredom as much as 'good variety' derived from discovery, adaptation, invention, games of chance or bantering.

Csikszentmihalyi's (1975) Model of Flow State

The balance of variety and redundancy suggested in Klapp's model can be further extended by the model of 'flow state' proposed by Csikszentmihalyi.[30] Csikszentmihalyi explored the relationship of boredom and anxiety, where anxiety is induced when a situation demands more of the person than their capabilities can stand up to, and boredom when it demands too little; the ideal balance between the two represents flow. Flow is a state described as sense of mindfulness in the moment; Csikszentmihalyi distinguishes 'micro-flow' derived from pleasurable or meaningful everyday settings categorised in social, kinaesthetic, imaginative, attentive, oral (such as snacking or smoking) and creative context on one hand, and 'deep play' on the other. Deep play is achieved when an activity involves a sense of risk and a inherently complex environment, where flow is achieved through a sense of immersion, focus on a single stimulus field, unambiguous feedback, control, a feeling of competence and autonomy. These can occur in off-duty or work settings such as in rock-climbing or surgery that, he argues, 'connect brain and hand'; in the space context, this could for instance apply to a successfully accomplished extravehicular activity (EVA). However, he also stresses that such highly qualified professionals want to make use of their skills *to the fullest extent.* Without this, monotony occurs and no state of flow can be achieved. Even brief deprivation of flow can cause negative changes in physical feelings, cognitive functioning and self-perception, and can result in disruptive behaviour; Csikszentmihalyi infers that the affordance of flow in an activity can mediate those symptoms.

II. MONOTONY AS PHENOMENON OF SOCIAL, SENSORY AND SPATIO-TEMPORAL ISOLATION DURING DEEP SPACE TRANSFER

Rasmussen[31] points out that the impact of isolation and confinement on individuals in extreme environments varies with situational and contextual factors. Sells[32] describes these factors in his model of isolation that includes social deprivation, spatial confinement, and reduced sensory variety. Suedfeld and Steel[33] later refine Sell's vehicle concept, adding a temporal relationship by distinguishing a relatively stationary orbital or planetary surface habitat and the itinerant spacecraft during transfer. Of the three main stressors that adversely affect mood states in space, Manzey, Schiewe and Fassbender[34] relate two directly to monotony: reduced sensory stimulation due to the uniformity of the environment and daily life and restricted social contacts and separation from family and friends. They point out that the negative effects of monotony, such as reduced communication, may in turn reinforce feelings of 'isolation and monotony' of individual crew members. The Humex report[6] points out that currently there exist no general models for monotony and boredom space, but suggest splitting the phenomenon into three strands of social, environmental and occupational monotony. Finally, also Klapp describes what he calls the 'perfect boring situation'[28] as a triad of the sameness of the environment, people and their conversations, and seeing and doing the 'same stuff day after day'.

Spatio-Temporal Isolation: The Earth Out of View

Spatio-temporal isolation in deep space missions is related both to the great duration, associated extreme remoteness and spatial confinement onboard the vehicle. One of the main characteristics that set deep missions apart is their great remoteness and isolation that might lead to the phenomenon of 'break-off'[35] and 'Earth-out-of-view'.[36] Considering the positive value of off-duty Earth observation for astronauts well-being, it seems almost certain that seeing the Earth reduced to a distanced dot in space will impact negatively on the psyche of Mars-bound crew.[1]

The interior space around the individual, and its layers of intimate, personal and social space[37] then become important. Conflict may result in territoriality, hostility and tension.[38] The human ability aspect of imagining distant spatial settings[39] is important in a remote spacecraft environment, as it affords the individual an additional layer of 'space' that can be either directed at the immediate present (proximal), or at distant locations, such as home, or the future mission destination (distal), as outlined by Rivolier and colleagues.[40] This concept can be compared to what Whitely and Bogatyreva[41] describe as the 'virtual shell' in their radial taxonomy of spatial and personal layers for individual crewmembers with their values and attitudes. Fraisse[42] suggests that spatial isolation may involve temporal isolation if no times cues are given, for instance in caves. During depressive mood states, time appears to run less swiftly than it is usually perceived to.[43]

Sensory Isolation: Lack of External Cues and Variety in Internal Stimuli

There are two central to sensory isolation in deep space transfer: On one hand, crew are deprived of their usual stimuli from Earth, but also the stimuli available in situ (inside the vehicle and in its surrounds) lack in variety. Sensory stimulation and environmental cues are vital to the satisfaction of basic human needs.[44] Schultz points out it is not only the input of stimulus, but also its meaningfulness and quality that elicit an effect.[45] This is of interest in the deep space setting, as it suggests the general reduction of situational stimuli (especially external cues) may not be as challenging as the repetitive pattern or lack of variation in available stimuli inside the craft if we assume a similar vehicle interior paradigm as in operation today.

An associated main challenge is the absence of environmental cues such as daylight that regulate sleep-wake cycles. These cues are some of the most pervasive features on Earth that humans have evolved along,[46] and disruption of this fundamental can result in performance decrement and depressed mood states.[47]

Social Isolation: Alone Together

Kanas and colleagues[19] list isolation, separation from family and friends, a feeling of 'insignificance' in light of a vast setting and resultant loneliness and homesickness as stressors in space. Social isolation or monotony includes the extent of restrictions of members of a group to communicate with others outside the group through physical or socially prescribed boundaries.[48] Aside from the lack of usual company such as relatives, partners and friends, social monotony is caused by the restriction in the range (i.e. variety) of social contacts, and exacerbated through confinement that enforces togetherness where withdrawal from the presence of others is almost impossible.[6] Although crew are most likely to know and train with each other for a long time before the mission, forced over-familiarity with each other in confinement can amplify the negative impact of even minute and mundane habits on others.[49]

From an architectural perspective, the social aspects of space capsule environments have been examined both in terms of spatiality[50] and human interaction.[51]

III. DESIGN OF HABITABILITY SYSTEMS AS IN-FLIGHT COUNTERMEASURE TO MONOTONY

Design as In-flight Support

Aside from taxonomies describing concrete biomedical risks of a future deep space mission, much less has been written about the infrastructure that support users in extreme environments,[52] or the concrete strategies that may mitigate psychological challenges in space.[53] The general stress associated with a space capsule environment can be addressed by avoiding or reducing a stressor, or by addressing the negative consequences of exposure to a stressor.[54] Prevention and mitigation strategies associated with the behavioural challenges of long duration missions are grouped under concept of psychological countermeasures.[55] They are increasingly formalised in human behaviour and performance medical strategies.[56] The key mitigation paradigm for psychological stressors is the concept of psychological countermeasures that foresees the adaptation of either the user or the system to reduce stressors and stress.[1] From an applied psychological side, environmental aspects such as habitat design are recognised as countermeasures[8] and considered critical in high-level medical overviews.[57]

Strategies for Orbital In-flight Countermeasures against Monotony

Like other countermeasures, also measures to prevent or alleviate monotony can be implemented on the person, the task or the environment.[10] Monotony and boredom have been the designated subject of only a small number of dedicated systematic studies to date from a technical, operational or human factors-design perspective in space[58, 59] and the military.[29] In the following, these are outlined and contextualised by other literature that included considerations on monotony as part of wider or related topical scopes.

Eberhard & Hooper (1967): Utilise Excessive Off-Duty Time

One of the first studies addressing low workload and environmental monotony on a potential Mars mission was conducted by Eberhard and Hooper for NASA.[58] They aimed to determine the amount of 'excessive off-duty time' available to the crew particularly during transfer phases by reviewing reports from conceptual, simulator and space analogous studies, and to suggest effective utilisation of time in support of contextual psychological challenges. They found that in confined environments, work was the most frequently sought activity and concluded with recommendations particularly for work design, including a proposal of a 'data bank of [meaningful] work opportunities'. They also suggested the affordance of discretionary activities that allow the 'observation of the passage of time', a concept comparable to other taxonomies of habitual events in long duration missions.[60] Due to the date of this study, Eberhard and Hooper were of course unable to take into account data of actual long duration missions; however, a wide range of countermeasures today do centre on work design, off-duty time and the provision of adequate leisure activities, their equipment and facilities.[1, 61] Measures in operation today were found to be similar to preferences of cosmonauts when asked on their opinions for a Mars mission.[62]

Fraser (1968) and Stuster (1986): Variation of the Environment – But by Consensus

A year later, Fraser reviewed similar data in a section on recreation as part of his report on the intangible aspects of habitability.[63] By definition, this was not as extensive as Eberhard and Hooper's designated study on monotony; however, Fraser stressed the importance of variability of 'basic' or 'subtle' habitability requirements such as atmosphere, temperature, questioning the paradigm of environmental neutrality as 'ideal state'. Bromfield[44] had pointed out earlier the importance of continually varying a sensory stimulus for the maintenance of intelligent and adaptive behaviour; Fraser's suggestion for variation was echoed by recent taxonomies.[19, 6] Aside from music and lighting suggested by the latter, other carriers of variety in space may be food[64] and supplementing fare with produce from regenerative systems,[65] through alternating tasks,[43] by providing higher degree of autonomy in scheduling for the individual,[66] or by allowing personalisation of the environment.[67]

Stuster[49] systematically analysed empirical literature of analogue conditions and proposes a range of evidence-based recommendations that resonate with the earlier approaches to environmental variation. Crucially, however, he emphasises that any modification of the off-duty vehicle setting should be achieved by group consensus: 'There are many who appreciate the works of Jackson Pollack [sic], Norman Rockwell, or the photographers of Playboy, but it would be unfair to inflict those tastes on others on a regular basis unless it were mutually agreeable' (p. 68).

This notion of individual preference is further qualified by Suedfeld and Steel, who recommend that modification in crew quarters be designed flexibly also in relation to respecting political correctness and avoiding to offend others.[2]

Connors et al. (1986): Value of the Unexpected

Connors and colleagues highlight the 'novel approaches' to recreation by the Russian space programme at the time, such as 'videotheques' (movie databases where particularly 'unfamiliar and eccentric' films were found to be effective in alleviating depressive moods), or grab bags with novelty items such as fresh food, letters or toys.[8] A detailed description of these is provided by Bluth and Helppie.[68] The delivery of surprise presents and food through cargo vehicles represents one of the main means to counteract monotony,[19] a practice that appeared effective in acute occurrences of isolation and low mood states.[69] Today, these packages are supplied by operational psychological support.[70] Connors stresses importance of the unexpected and its utilisation a positive force in spaceflight. Over a decade later, her call is echoed by Suedfeld and Steel who refer to 'providing novelty and surprises' as yet open item in research and development needs of countermeasures.[2] Today, there still appear to be no further proposed operational concepts, although Fiedler and Harrison suggest that such 'crew care packages' can be put together using help of astronauts' families (as they were in the Russian space programme), and, when delivery would be infeasible, could be stored on board to be accessed on special occasions.[52]

Statler & Billings (1989) Meaningful Work & Flow

In the only other study specifically addressing 'boredom' and design in space after Eberhard and Hooper's work, Statler and Billings approached the issue from a productivity perspective, trying to identify design aspects that would purposefully maintain a level of workload for the crew as countermeasure.[59] They, however, conclude that design of the physical setting may not be able to alleviate these psychological issues, and concentrate their activity on work design issues. Similar to Eberhard and Hooper, they recommend 'a variety of scientific experiments that challenge the astronauts' judgment and creativity, that exploit the unique environment of the Mars spaceship, and that impose minimal constraints with regard to duty and accomplishment' (p. 5), similar to Eberhard and Hooper's proposal. This is echoing an earlier point made by Connors to leave a portion of non-crucial task training for the cruising phase.[8] Today, onboard skill maintenance is regarded as an essential component of training,[71, 72] and could include activities such as surgery, manual landing or telerobotics.[6] Other studies point out that, aside from providing crew with meaningful work in the first place,[36] astronauts should also be encouraged to pursue their own scientific interests in their work and free time.[34] In fact, not having such individual 'pet-projects' can cause the loss of a sense of ownership of the mission.[73] Other meaningful activities include formal duties that are anecdotally reported to become pleasantly immersive, such as maintaining plant growth facilities.[74]

Suedfeld & Steel (2000): Improvisation

Suedfeld and Steel highlight mitigation approaches to instances of low workload by capsule dwellers in polar and space contexts,[2] relating to expressive and active pursuits that resonate with Klapp's concept of redundancy and variety. Aside from measures echoing those outlined earlier, these include celebrating mission milestones, dressing up smartly, or performing plays for special occasions, replications of home-reminiscent situations, theatrical performances, parties to celebrate events, sports competitions, or the relishing of special music and foods. Similar pursuits such as 'creative endeavours such as writing, painting, playing music' have been reported to be stress-relieving in ground-based isolation experiences.[75]

Mæland & Brunstad (2009): Acceptance of situational constraints

In view of the lack of more recent designated literature and thought on monotony in a space context, it is useful to take into account other isolated, confined or extreme environmental settings. The only study addressing this issue explicitly appears to have been conducted in the Norwegian military by Mæland and

Brunstad, who interviewed and observed novices in the navy and experienced submarine officers with regards to their experience of boredom during deployment.[29] The main caveat in comparing this to space missions is one of the key assumptions the investigators lay down as cause for boredom, which is the lack of motivating reasons for individual personnel to be on certain military deployment, in particular those that are drawn out and long term, or where general goals are abstract or unclear to the individual. This is contrary to the space setting, where programmatic concerns, i.e. the reasons to embark on certain activities, are a key political and social notion, and astronauts are highly motivated by both the overall endeavour and their specific mission objectives. However, the acute nature of the phenomenon of boredom is comparable to aspects of long duration missions as both share settings of small or close groups, confined locales or itinerant vessels, dangerous exterior environments, separation from familiar contexts, a form of command structure or hierarchy, and limited access to certain resources and activities.

Mæland and Brunstad found that diversion, action, excitement or fun helped fend off boredom, but also that a vital part was also sleep, relaxation, and rest. Exhaustion was billed as the 'gateway to boredom'. Another point was the ability to 'escape' to a place, such an observatory on a mast on a ship, where – even in monotonous settings such as during weeks on the high sea – meaning could be derived from the surroundings through an individual interpretative effort. Subjects were able to take advantage of small variations in an otherwise constricted situation, or derive diversion and stimulation from other interesting work-related tasks such as challenging manoeuvres. The authors framed these findings by pointing out that acceptance of constraints was vital: 'if you can't get what you love, love what you get' (p. 124). This resonates with the idea of preparing crews to foresee a situation they will experience for a long period and is applied in human behaviour and performance training today.[76] Boredom on submarines, billed as the 'perfect place to get bored' by Mæland and Brunstad, was not as adverse as expected since the crew had coping strategies. Among those, 'focus on details and procedures' for the automatic *mastering* of details was highlighted. The suggestion that routine tasks should be trained to be automatic contextualises both the earlier finding that interesting manoeuvres are challenging, and Connors' earlier point that interesting tasks should not be over-trained.

Paradigm Shift from Orbital to Autonomous Setting

Many of the remedies that have proved successful in orbit will not be feasible in deep space due to the long distances involved that make resupply, crew visits and direct audio and close visual contact to Earth impossible.[6] Crew will have to rely solely on onboard provisions and facilities.[19] A detailed baseline concept for psychological support in this autonomous support setting has been described by Whiteley.[77] It proposed the integration and embedding into the spacecraft of a toolset comprising of preventative, monitoring, detection, and resolution technology. Specifically with regards to monotony, Whiteley suggested that the phenomenon was ambiguous from evidence and anecdotal reports, and that to address the issue it would need to be broken down to be of use for both psychologists and design-engineers.

IV. THE MONOTONY EXPERIENCE IN ORBIT: A REVIEW OF PUBLISHED USER ACCOUNTS

Aside from space analogues, the main body of evidence that exists in relation to monotony hails from orbital long duration missions. To understand the monotony experience of users in relation to the built environment with the aim of developing possible mitigation and prevention strategies, a close look was directed at primary anecdotal evidence from orbital and ground simulation settings.

Case Selection

Publicly available onboard user accounts were identified from five operational space stations with long duration missions and, as control in view of the deep space mission setting, a ground-based Mars mission simulation. Contemporary formats, including blogs and twitter, were taken into account. One account was selected for each habitat, aiming for a culturally balanced sample in terms of user nationalities (Russian, American, Belgian, French, German) and professional backgrounds (engineers, armed forces, test pilots, medical doctors and commercial pilots). The resulting gender bias could not be removed, as only retrospective biographies rather than onboard diaries by female users were available for review at the time.

- Salyut 7: Valentin Lebedev[78] (daily diary): 211d
- Skylab: Alan Bean[79] (weekly diary): 59d
- MIR: Jerry Linenger[80] (daily letters): 132d
- ISS: Frank DeWinne[81] (weekly blog posts): 187d
- ISS: Clayton Anderson[82] (weekly blog posts): 152d
- Mars500: Oliver Knickel & Cyrille Fournier[83] (fortnightly alternate blog posts), 105d

Writing styles and lengths, frequencies of entries and purpose of the log entries varied. They ranged from informal and apparently only vaguely edited detailed posts to a wider public; personal messages or entries directed originally at close relatives; to relatively formal sporadic accounts. All accounts were written electronically or in long hand in-flight, some supplemented or edited later. No ethical issues were identified; all accounts were unclassified and contained no explicit or implicit disclaimers that discouraged from a review or required confidentiality.

The relative candour or restraint with which some of the users expressed their experience can both be attributed to the fact that they actively self-censored depending on the degree of publicity or intimacy of their entries. In some cases, publicly available material such as outreach videos suggests that the diarist is generally more reserved, respectively open, in relating their experiences to the public. In Lebedev's case, the editors of his published account unfortunately omitted a long serious of entries that were deemed 'repetitions' of his mood states in the third and final quarter of the mission; these would, in fact, have been very insightful as they appeared to refer directly to the monotony experienced by Lebedev. Finally, accounts might have to be read taking into account the fact that long duration missions have become a norm and today, technical capabilities and provisions are more advanced. We can also assume that the user experiences and their narratives have become more public, their challenges are expected (i.e. users have a growing body of evidence to personally prepare for their experience), and with less hardship caused by organisational and operational teething problems that seem to have contributed to earlier difficult experiences.

Review & Analysis

The accounts were read in full and annotated according to aspects from the concepts outlined in the literature, i.e. in relation to leisure time activities, to the three-fold model of isolation, state of flow and Klapp's matrix, and in connection to keywords such as 'monotony' or 'tedious'. Thus, experiences were marked both in form of descriptions of the experience itself, and descriptions of the quality of an experience (i.e. whether the user found something pleasant or frustrating). In scoring, emphasis was placed on description, rather than establishing the occurrence of experiences.[84]

The entries were transcribed in chronological order, and then coded and subsequently grouped with regards to the quality of the experience according to Klapp's fourfold matrix. Interpretation was informed by Czikszentmihalyi's concept of flow state, which can be situated on the border of meaning-redundancy (i.e. when flow experience is created by routine, application of skills etc., such as during long stretches of professional Earth observation) and meaning-variety (i.e. when flow experience is created by playfulness or excitement, for instance during playful acrobatics in microgravity conditions or during a strenuous but successful spacewalk).

V. EMERGING THEMES FROM THE ORBITAL AND GROUND-BASED SIMULATION EXPERIENCE

The experiences of the users were varied. All diarists, with the exceptions of a limited period of low workload on Skylab were busy. Workload was high, and this was found uniformly as beneficial – unless it was repetitive, monotonous or too controlled by ground. However, even those users who portrayed their stay as entirely positive or also otherwise 'never boring' (most notably Anderson and Linenger), did point out explicitly that they missed certain aspects of life on Earth that would usually alleviate or prevent entirely feelings of isolation or monotony. Linenger, whose mission was placed under extreme strain through multiple system failure, longed for 'boring' times in the sense that they would provide an antidote to high workload and emergencies, but also acknowledged in great detail how, at times, he felt he needed to 'do something, go somewhere'.[6] Despite workloads, it was the off-duty aspect that proved monotonous. Off-duty design provisions specifically brought on board – a priori, or at points in the mission to respond to specific requests – were helpful and effective, from letters, media equipment and food. When provisions failed to materialise or work, frustration appeared to ensue to a greater extent than if no provision had been made. This appeared to be equally frustrating as the tedium of having to repair faulty or broken work equipment on a regular basis.

In terms of mitigation and prevention of monotony and isolation, three salient countermeasure themes in relation to design and the built environment were identified, including activities or habitat provisions that afforded redundancy and variety for individuals and across the user group were identified.

Personal Science Projects, Hacking and Pranks

Two of the most important edifying activities described by the users included either pursuing personal science projects or improvisation by re-appropriating onboard materials and hardware (such as printers, cameras, supplies etc.) to produce entertaining, experimental or useful artefacts. With no resupply-ship to come to them, and echoing the importance of work and necessity to repair, the Mars500 crew displayed an active DIY (do-it-yourself) attitude, that served to upgrade or decorate their habitat, and provided them with entertainment or mutual presents. They also practiced their improvised language of 'Ruslish' (a hybrid of English and Russian). However, some of the modifications of the shared spaces were initiated and implemented singlehandedly by an individual crew member 'in… his own style!';[83] the associated comment neither included neither approval nor dismissal of this occurrence.

Expectedly, all users reported to derive great satisfaction from successful completion of work-related or voluntary science projects, payload calibration or habitat maintenance, even if this was carried out in leisure time. Many of the onboard provisions that were introduced as payload, such as plant-growth facilities, became a central restorative measure. However, when professional or off-duty equipment such as furnaces or video players failed repeatedly and time had to be spent on constant repair, this was received with increasing and deep frustration, both in terms of wasting valuable work time on but also forgoing precious leisure time – which, limited as it is in the first place, was often seen as a treat. A set of categories for interaction with hardware was identified. These posited different interventions on a Klapp's spectrum of tedium/ entropy and diversion/ meaning. This can be contextualised from a design perspective by Jordan's three-tired model of categories of functional, usable and pleasurable products:[90]

- Constant repair due to equipment failure, tear and wear, or minor incidents;
  → frustration, duty
- Necessary adjustments and calibration of payload, routine system upkeep and maintenance;
  → duty, satisfaction
- Hacking and modification, personalisation of quarters;
  → satisfaction, delight
- Bespoke decoration, tinkering, practical jokes, voluntary science;
  → delight, intrigue

On the periphery of environmental modification sit practical jokes by astronauts, especially those that involve the production or rigging of an artefact. Especially Bean's account is peppered with references to jokes, 'kidding' and play in comparatively great detail, but also most of the other diarists recount episodes of jokes. Often these jokes served to dissipate tension and acted as comic relief in a confined or dangerous setting, or mediated latent or acute interpersonal issues such as personal taste in music, aspects of hygiene such as flatulence or facial hair, or crew hierarchy issues. In other cases, jokes and pranks were even subversive or sinister. Nevertheless, they seemed to edify even high-performance individuals especially in long duration missions.[85] In many cases, the pranks were thoroughly 'engineered' both logistically and technically. The repertoire included spontaneous pranks, elaborate pranks that were pre-planned with accomplices on the ground or pre-constructed hardware, or those were equipment was rigged in situ. Unless jokes backfired – which was sometimes the case, to the disappointment of the prankster, especially when long lead-times for preparation were involved – they served the lubrication of relationships to fellow crewmembers, loved ones on the ground or mission control. From the diary entries, and consulting secondary literature that refers to other diaries (for instance in Zimmerman[74]), we can identify roughly 8 distinct categories of jokes:

- Hygiene and health jokes;
- Jokes about risk, safety, mission success;
- Manipulating a system to startle others;
- Playful bets and competitions;
- Rigging equipment in situ;
- Bringing ready-made props into orbit.

Humour or producing artefacts for others from scratch will be invaluable in a remote, inaccessible location – not only to extend the operational lifecycle of equipment and solve maintenance problems,[86] but to entertain, edify and pass the time.

<u>Relationship to the Nature: Windows and Plant-Growth Facilities</u>

Perhaps expectedly, astronauts did not always draw on man-made support to pass the time or feel stimulated and surprised. One of the greatest sources of edification, wonder and occupation were the natural surroundings around the spacecraft, and the unique situational conditions of reduced gravity inside the vehicle. Together with generic design features such as windows, or existing equipment to be found on board, these situational qualities were the focus of much directed inquisitiveness, curiosity and interest. Engaging with them appeared to create a sense of flow, situational awareness and connection to the local setting for the user. Such sensitivity would, no doubt, be a crucial asset in a remote and unknown setting. Many of the 'good variety' experiences of the users were related to their experience of the outside of the craft, and the thrilling experience of the inhospitable black outdoors, whether observed passively from inside, or experienced directly during sorties outside the habitat. The astronauts report both types of interaction with the outside entirely positively (i.e. as 'good variety' and 'good redundancy'). These related to the active experience of the outdoors (EVAs, fly-arounds) that instilled a sense of thrill and wonder in an often radically disorienting environment, often reconciliating the returning astronaut or cosmonaut with their homely, if idiosyncratic or failure-prone habitat; and the passive observation of the natural Earth environment through the porthole, which was a continuous and almost fail-safe source of ever-changing stimulation.

But interaction with natural material also occurred indoors. The experience of interacting with plant growth facilities was reported restorative, and products of the greenhouses were used as tokens of appreciation to other crewmembers or relatives, or as supplement to onboard diet. With no outside observations of Earth, the Mars500 crew cherished their greenhouse as much as their orbital colleagues did, both to pass the time with experiments, as source of relaxation and edification (both in tending and watching plants grow), as a source of a variety of fresh produce to enjoy during meal times, and even – like Lebedev, who bestowed a flower to their first female onboard guest, and Linenger, who had pre-arranged a flower-delivery to his wife – as remotely presented gift dedicated to a ground-based relatives via photograph.

Resupply Ships, Visitors and Communication

The third central countermeasure theme involved surprise provisions. The personal items brought up by cargo ships or with visiting crew were a central theme throughout all diaries but those of the Mars500 participants, who did not receive resupply. Nearly all users wrote about resupply ships and the 'goodies' they brought in great length, great detail, and repeatedly. Entries were both in anticipation of the cargo highlighting the sense of excitement they brought, and in retrospective – often for days afterwards – pointing out what was received and how much consuming those gifts was cherished. But resupply-ships were not the only source of novelty. There were a host of other surprise channels, ranging from transmissions from the ground, surprise guests on communication sessions, or the company of visiting guests on board. Other sources were 'organised' surprises or rewards after special tasks or certain periods of time, such as communal special dinners. Crewmembers also derived surprise through serendipitously retrieving lost items during housekeeping.

An overview on categories and qualities of surprise provisions is given below in a matrix that pinpoints where both redundancy (control) and variety (novelty) can be leveraged (some provisions fit more than one category):

Occurrence Unexpected

- Email wishes
- Relatives at press interview
- Celebrity greetings
- 'Special delivery' photos
- Birdsong/ melodies
- Gifts from visitors
- Children's letters
- Discovery of additional provisions
- Smell of fresh fruit

Occurrence Expected

- Birthday presents
- Resupply goods
- Special food items or rations
- 'Psychological support' packs
- Wake-up songs

Content Unexpected

- Bonus packs
- Wake-up songs

Occurrence Expected

- Bonus packs
- Email access
- Resupply goodies
- Visitors
- Food variety

It should be noted that while variety is one antidote to boredom, when too much choice is presented, meaning is lost and monotony induced,[87] particularly when the available choice baffles through a lack of distinctive values.[88]

VI. IN VIEW OF TRANSLATING THE ORBITAL EXPERIENCE INTO THE DEEP SPACE SETTING

Overall Rationale: Utilising onboard and in-situ materials

In order to work effectively in an autonomous setting, the overall rationale for countermeasures must involve the approach to work with material and conditions available in situ. From a systems perspective, this means integrating mitigation strategies seamlessly and without significant additional cost into existing habitation systems. From an environmental perspective, this means working with local conditions rather than against them.

On one hand, this is essentially a programmatic and cultural issue. Why export earthly paradigms into a radically different setting – deep space – that is the subject of exploration and enquiry in the first place? There is certainly validity and need in providing comfort through the familiar (i.e. provide Klapp's qualities of meaningful redundancy). In addition to that, however, from a user perspective it appears meaningful also to accept the local setting with all its implications, and learn to understand, even savour it (Klapp's good variety). This programmatic issue then extends into psychology and can be seen in the context of positive or salutary factors of spaceflight[89]. While it is necessary and meaningful to provide rich content that reminds the individual of the home environment, it would be a missed opportunity not to leverage the subtleties and spectacular attractions of the local setting. Monotony and isolation should be addressed through facilitating a meaningful 'connection' to the immediate, local present (Rivolier's proximal concept, Csikszentmihalyi's flow), rather than only by projection of thoughts towards the home and past (Rivolier's distal concept, Klapp's redundancy).

Design Recommendations

Habitat design can support both of those approaches. Based on the findings from the diary review in relation to the literature, the following design recommendations can be made:

Restorative Payload: Users experienced some payload provisions as restorative off-duty provisions; it is recommended to afford scope in existing generic design features, such as plant growth facilities or portholes, for crew to conduct personal projects without impeding work-related experimental set-ups. Basic maintenance activities (including hygiene and habitat upkeep) are time-consuming but represent an opportunity to instil qualities of 'flow'. It is recommended to invest a majority of the interior, product or interaction design effort not necessarily into additional provisions or gadgets to counteract monotony, but to foolproof existing hardware from toilets or stowage to entertainment equipment to ensure reliable, smooth operation and provide opportunities for modification. This would reduce the tedium of repair, free up time, and even enable pleasurable

Relationship to Local Setting: Users enjoyed experiencing local phenomena, whether Earth-related or in view of other physical or astronomical aspects. They got finely attuned to their situational surroundings. It is recommended to provide opportunity to experience the outside natural environment and the interior unique physical conditions; if necessary amplify impressions so that they can be experienced also in a shirtsleeve environment (through cupolas, viewports or retractable lightweight modules for instance). This facilitates restorative past-time, but also enhances situational awareness.

Surprise Provisions: Users enjoyed tremendously the different forms of novelty available in their setting. It appears there are many dimensions to novel provisions or interventions. In an autonomous setting, the challenge is to integrate surprise in a quasi 'closed' system that is, by default, completely familiar to the user. It is recommended to integrate novelty in the existing habitat system by instilling meaningful complexity in the habitation system and by providing sensory redundancy.

Caveat of Ambiguity of Mitigating Provisions

Any of these strategies will only find leverage to an extent. One point that particularly Lebedev's diary highlighted was that, at the dire end of the mission, the countermeasures that worked so effectively until then lost their positive impact. Contact to ground control and relatives was tense, the crew ceased socialising, the station fell silent, there was a lethargy and apathy that induced indifference towards portholes with great views, indifference towards the greenhouse and tending to plants – only, finally, remedied by a return to the ground. One crucial point for long duration exploration missions is, finally, the taking into account or anticipation of possibly changing personal interests in relation to passing off-duty time.[19]

In relation to this, the proposed mitigation strategies ought to be seen and applied in the overall context of psychological, biomedical and operational support. When approaches in one area cease to work, redundancy needs to be provided by other areas of support, and also be handled with the awareness and acceptance that these experiences will form a vital part of an extended mission. Such consideration can only be instilled in the individual through careful selection, training and preparation, in addition to integrating support measures on different operational levels in the context of overall in-flight support.

VII: CONCLUSION & RECOMMENDATIONS FOR FURTHER RESEARCH

The situational setting of a deep space mission not only echoes the psychological challenges of orbital missions but also extrapolates these experiences to a degree we can only anticipate today. Despite careful and systematic prevention and mitigation through user training, familiarisation and environmental design, there is reason to assume that crew on extended missions will inevitably face the stressors and stresses of isolation and monotony, just as astronauts and cosmonauts in orbital missions experienced them despite proximity to Earth and a range of countermeasures. The implications of these experiences, coupled with the extreme remoteness and autonomy represent a critical operational human behaviour and performance issue with a close relationship to vehicle interior and systems design.

This study aimed to provide an introductory overview on the issue of monotony in deep space transfers from a theoretical and applied design perspective, drawing on and translating orbital evidence into strategies for onboard countermeasures in an autonomous transfer scenario. It revisited in depth a small set of accounts from historical and contemporary space and space analogous habitats to provide a picture of the user experience in long duration missions in relation to the built environment.

Astronauts and cosmonauts did, indeed, experience monotony and isolation, even boredom, in orbital missions to different degrees. Their experience highlighted a range of countermeasures, whose translation into a remote setting in deep space was captured in the form of a set of design recommendations with the overall rationale of autonomous, in situ support. These included affording the opportunity to modify and intervene in the system as off duty activity and avoid the need for constant repair of hardware; to strive to reinforce the positive factors of the local conditions rather than trying to merely counteract stressors; and utilising existing equipment to cater to psychological needs through design that leverages the restorative and stimulating potential of generic habitation systems. This strategy of integration and use of in-situ conditions reconceptualises and extends existing mitigation strategies while acknowledging the ambiguity of those measures, and the need to be integrated in a contextual network of support in relation to other psychological stressors.

Future research should consider widening the sample of user diaries, and conduct an additional comparison to data on experience available from the longer 520-day study of the currently ongoing Mars500 simulation. Specific topical concerns associated with the implementation and applied testing of design strategies across particular habitation systems should be probed in depth as to their feasibility, efficacy and, if promising, their technology readiness level. Finally, in view of understanding the relationship of the individual user preference and personality, mediation through the built environment and mission length or segment (i.e. 3rd quarter phenomenon), would be advantageous to both user selection and system design; particular the aspect of ambiguity in countermeasure provision should be investigated with regards to this.

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