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FEASIBILITY STUDY OF NOVEL CREW WELLBEING AND ALTERNATIVE COUNTERMEASURES SOLUTIONS FOR RECREATIONAL SPACES IN FUTURE LUNAR PERMANENT SETTLEMENTS

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Abstract

With the successful conclusion of the mission Artemis I, a new era of space exploration has started with the aim to pave the way for humans to return to the Moon. It is therefore of paramount importance to develop proper solutions for permanent outposts, with a special focus on habitability, ergonomics, and long-term usability in hypogravity environments such as the lunar environment. By focusing on crew psychophysiological wellbeing, this work revolves around the conception of spaces for the practice of new fitness and leisure activities as countermeasure against stress in long-term mission. It is well known that by introducing game components into exercise routines psychological and physiological wellbeing can be significantly improved, resulting in the enhancement of crew's performance. Thus, the present study investigates how tennis, which has many proven health benefits, could theoretically be played under lunar gravity conditions focusing on how this game would change due to the lunar environmental factors in terms of regulation and equipment. A qualitative assessment is conducted through a comparative evaluation of the features of racket-ball sports practised on the Earth, to better adapt rules and playing of tennis to lunar conditions. Furthermore, the investigation addresses the study of the technical feasibility of a lunar tennis facility, in order to provide lunar settlements design with new elements to enhance habitability in long-duration human missions on the Moon.

Keywords: lunar settlements, psychophysiological wellbeing, tennis, LDSM stress countermeasures, lunar tennis facility;

Acronyms

ACTH	Adrenocorticotropic Hormone
ARED	Resistive Exercise Device
EE	Extreme Environment
GR	Glucocorticoid Receptor
HIIT	High Intensity Interval Training
HPA	Hypothalamic Pituitary Adrenocortical
ICE	Isolated and Confined Environment
LDSM	Long-Duration Space Mission
LEO	Low Earth Orbit
LBNP	Lower Body Negative Pressure Device
MDD	Major Depressive Disorder
SLS	Space Launch System
TLI	Trans-Lunar trajectories

1. INTRODUCTION

A new phase of lunar and exploration has begun under the human spaceflight program. In order to enable planetary exploration, space organizations created roadmaps that specify research priorities. Therefore, it is vital to understand whether long-duration spaceflight may have an impact on crew's psychological and physical well-being.

According to researchers, lunar missions will result in distinct needs from those in LEO orbit [1]. Although crew members experience psychological and interpersonal stress during orbital spaceflights, a lunar Long-Duration Space Mission (LDSM) may take significantly more effort to adjust to than an orbital spaceflight due to the higher stress level induced by prolonged exposure to stressors.

A stressor is "a stimulus that affects an organism in an arousing manner”, whereas stress "refers to the changes in an organism that are caused by a given stressor" [2, p. 457]. Stress is a physiological and psychological reaction to one or more internal or external stressors, such as a feeling of annoyance and high alertness [3], which can negatively impact on cognition and performance [4, 5].

Extreme Environments (EEs), such as the lunar one, and Isolated and Confined Environments (ICEs), such as extraplanetary habitats, can harm a person's physical and/or psychological well-being because they involve stimuli and/or stresses of high intensity [6] and both require a significant human adaptation to survive and perform [7, 8, 9].

The social, psychological, and spatial significance of adaptation to an extraterrestrial environment can be more clearly characterized by considering the challenges of living in such environments as there are many different sorts of stresses in EEs and ICEs that come from a wide range of sources and almost always work together rather than acting alone, including physical characteristics of the environment, crewmate psychological issues, habitability considerations, and interpersonal dynamics [10].

People who live and work in ICE environments (such as polar stations, offshore platforms, submarines, etc.) are subject to both physical (such as harsh climate and light-dark cycle) and psychological stressors (such as protracted isolation, confinement, lack of family contact, limited privacy, monotony, etc.). Cognitive functioning is hampered by somatic complaints, sleep issues, and negative emotions (fatigue, despair, anger, and anxiety), while interpersonal conflict and tension can arise [11, 12].

Such conditions place demands on both the living spaces and activities in such a way, that they can support human life and provide well-being. As the term habitability describes the suitability and value of a built living space for its residents in a specific environment [13], habitability in lunar ICEs calls into question all environment-inducted stressors and associated stress responses.

Research demonstrated that there are two types of countermeasures against stressors: those that improve the ergonomics of the habitats (such as design of the spaces) and those that enhance knowledge and behaviour to facilitate adaptability and well-being (such as scheduling activities and personal downtime) [14]. In a lunar expedition, both elements are critical, as it was proved that ICE's psychosocial stressors can cause performance decline and potential safety hazards (Fig.1) [15].

Research on the effective design of habitats for human health and well-being in EEs and ICEs is still in its infancy and is spread across multiple disciplines. The recent intersection of several critical research directions is beginning to develop several intriguing original approaches to implementing environmental design in ways that integrate place and use requirements as conscious elements that promote well-being and maximize adaptation through sport and leisure activities [16].

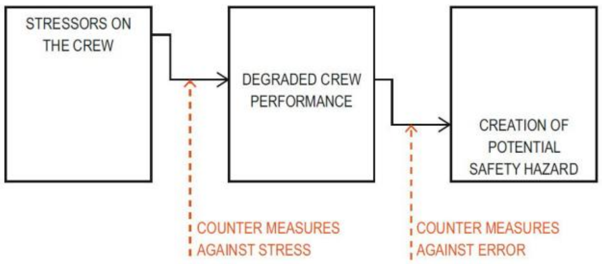

Fig. 1 The crew safety-human factors interaction model (adapted from [15] original image by Marc M. Cohen)

2. PHYSICAL ACTIVITY AS COUNTER-MEASURE FOR HEALTH DISEASES IN MICROGRAVITY ENVIRONMENTS

In general, the efficacy of physical activity in preventing health diseases is widely recognized. Physical activity is a key component of programs to prevent physiological changes brought on by microgravity in space missions such as musculoskeletal and psychological diseases.

In weightlessness, all physical activities are less strenuous since the musculoskeletal system is unloaded, unlike on Earth where it must maintain the body's weight and the postural bones and muscles are constantly burdened by gravity. Therefore, exposure to microgravity causes the loss of bone and muscle. After six months in space, osteoporosis symptoms in astronauts are comparable to those of old women on Earth. Bone remodelling and/or loss occur during spaceflight at a rate of roughly 1-2% per month.

After six months in space, osteoporosis symptoms in astronauts are comparable to those of old women on Earth. Bone remodelling and/or loss occur during spaceflight at a rate of roughly 1-2% per month. As a result of their increased risk of fracture, astronauts who return from lengthy space missions receive special treatment and care.

Muscle atrophy is brought on by the unloading of the postural muscles as well as a lack of demanding tasks (no more stair climbing, lifting, etc.). On short missions, muscle loss of 10% to 20% has been noted; on long missions, this loss could reach 50% if no preventative measures are taken. This could affect the astronaut's capacity to carry out physically demanding tasks throughout the flight (such as extravehicular activities) and after landing (such as emergency egress). Additionally, this causes discomfort: astronauts frequently express low-back pain, which is being researched as the effect of postural muscle atrophy [17].

Exercise countermeasures are the major method employed to protect astronauts from musculoskeletal deconditioning in microgravity and hypogravity, however, the quantity of exercise required to protect the musculoskeletal system from "small planet deconditioning", like the Moon, is not fully understood [18].

For a person to survive, the hypothalamic pituitary adrenocortical axis (HPA) and the cortisol it releases are essential. In order to respond to internal or external stressors, energy resources must be mobilized through catabolic pathways [19, 20]. Specific neurons in the limbic system of the brain become active and release hormones when exposed to a stressful experience. These neurons stimulate the hypothalamus to secrete more adrenocorticotropic hormone (ACTH) [19].

The hallmark of an acute stress reaction is a brief rise in both ACTH and cortisol level. Sustained stress leads to a dysregulation of the HPA axis activity, increasing the chance of developing major depressive disorder (MDD) [21, 22] and many other disorders involving the cardiovascular, gastrointestinal, and immunological systems [23]. HPA axis dysregulation and high cortisol levels have been found to be higher in astronauts following both short- and long-term space missions [24, 25, 26, 27, 28], highlighting the need to better understand the health concerns [29].

The body's stress chemicals, such as cortisol and adrenaline, are reduced by aerobic exercise with physiological and psychological advantages. Aerobic exercise promotes the production of endorphins, natural analgesics, and mood enhancers, which are the cause of emotions of tranquillity and optimism that frequently accompany challenging exercises.

However, studies suggest that type, duration and level of exercise can impact the amount of cortisol. According to a study, long-term cortisol exposure is much higher in endurance athletes, while short bursts of high-intensity exercise, such as High Intensity Interval Training (HIIT), which alternates quick bursts of explosive or intense anaerobic exercise with quick rest periods until exhaustion, result in less of a rise in plasma cortisol levels [30]. Thus, HIIT sports as hockey, football, basketball, and tennis, characterized by brief rest intervals and high labour levels are the most effective against depressive disorders. A significant amount of evidence produced on Earth suggests that methods, like high intensity interval training (HIIT), in conjunction with or without bouts of resistive exercise, may be able to be an efficient countermeasure against health diseases and stressors [31].

Adressing negative environmental factors and psychological stressors with sport activities have been advocated for decades in various space programs [32, 33, 34]. The Apollo astronauts exercised for about 10 to 30 minutes during their flights. They performed gymnastics with a device called the Exergenie [35]. Some astronauts jumped and sang between their experiments on the lunar surface [36].

Soviet cosmonauts had some freedom of choice in the types of exercises they conducted. Cosmonauts trained twice a day for about 1.5 hours. The training equipment at the Salyut stations included a stationary bike, a treadmill or track, pressure suits (Penguin suit) or vacuum pants (Chibis) and muscle training devices [37, 38]. On Salyut 7, the cosmonauts switched to a two-hour exercise period per day and were provided with an exercise bike, a treadmill, a running track, pressure suits, vacuum pants and muscle training machines. According to Bluth, the Russians recognized that leisure had a stimulating effect on the cosmonaut's mental state and fitness and would therefore contribute to the crew's work efficiency [37].

On the Skylab, a bicycle ergometer was located in the experimental area and it featured triangular shackles on the pedals for specially designed shoes [39], while, later, a treadmill was installed [40, 41]. Skylab astronauts were inventive in exercises and experimented with body movements that were only possible in weightlessness. They flew from side to side or ran centrifugally in circles on the track formed by the storage boxes.

Onboard the shuttle, exercise area was located on the middeck or flight deck. Available exercise equipment included a stationary bike, a treadmill and Dynabands. Astronauts on short-term missions were required to exercise 30 minutes per day. Astronauts in orbit used a waist belt to attach themselves to the device so they can walk in orbit [42]. A bicycle ergometer was installed, as well [43].

The Mir space station was equipped with a bicycle ergometer and a treadmill in the basic block. Returning to Earth, cosmonauts wore a negative pressure device for the lower body, the so-called Chibis vacuum pants to push blood into the lower limbs and make the heart work harder to pump blood and increase heart rate [44].

On the ISS, astronauts train for two hours a day using cardio and muscle resistance machines. The station has six different exercise options. A treadmill and ergometer for cardiovascular training are located in the Zvezda service module. The Resistive Exercise Device (ARED) for muscle strengthening is located in the Node 1 module (Unity). A second treadmill (COLBERT) is in node 3 (Tranquility) [45]. The Flywheel training device to combat muscle wasting and bone loss is in the Columbus module and is stored when not in use [46], while a stationary bike is in the U.S. Lab [47]. Other training equipment includes muscle trainers, exercise balls and Grip Master.

All the mentioned examples prove the relevancy of physical activity in space missions in order to mitigate the effects of reduced gravity on the crew’s physiology and achieve psychological well-being.

3. WHY TENNIS AS COUNTERMEASURE FOR LUNAR LDSM

Tennis belongs to the "racket sports" family, which include a variety of disciplines (badminton, racquetball, padel, tennis, table tennis, squash, etc.) characterised by being non-cyclical disciplines, involving repeated high intensity, short work bouts interspersed with regular rest periods [48] and characterised by changeable intensity and a variable match duration. Among racquet sports, the most widely practised and the most scientifically studied is tennis, the physiological and psychological characteristics of which have already been extensively covered in a large body of reference literature [49].

According to Kovacs [50], Tennis involves (i) tactical, (ii) technical, (iii) physical, and (iv) psychological areas.

From the physiological point of view, previous research suggests that tennis is associated with a wide variety of health-related physical benefits, ranging from improved physical fitness, cardiovascular, metabolic, and bone health to improved agility and coordination [49]. In particular, tennis practised on a regular basis may result in improved aerobic fitness, lower body fat percentage and decreased risks of diabetes and cardiovascular disease [51], and studies suggest that it may serve as a protective influence in the maintenance of aerobic capacity and healthy body composition specifically in adults 45 years and older [52].

The peculiarity that distinguishes tennis from other sports is that it both challenges and builds an individual’s different metabolic pathways: lactacid anaerobic that intervenes when the exchange begins to lengthen, with an aerobic support base that prevails in the recovery phases.

On a psychological level, participation in tennis has been linked to psychological benefits such as increased self-esteem and improved stress and anxiety management [49]. Tennis, as HIIT, appears to be a very efficient countermeasure against stressors in space missions [31]. Furthermore, according to analysis conducted since the 1990s [53], compared with other athletes and non-athletes, tennis players score higher in vigour, optimism, and self-esteem, while scoring lower in depression, anger, confusion, anxiety, and tension.

Research promoted by the United States Professional Tennis Association [49] claims that playing tennis contributes to the development of psychological capabilities such as the perception of control over one’s actions, work ethic, self-discipline, responsibility, stress management, adaptation, strategic planning, problem-solving.

Tennis combines technical and tactical variables, and it trains the ability to quickly react to contingent situations, constantly requiring the player to react to the opponent's actions and make immediate decisions to counteract. Moreover, being a game of winners and mistakes, it trains the ability to recognize and manage errors and emergencies. Tennis also develops social skills, sportsmanship, teamwork.

4. MOON TENNIS: ADAPTING EARTH TENNIS TO LUNAR ENVIRONMENTAL CONDITIONS

This section focuses on how to adapt and modify the sport of tennis by starting from earthly conditions and transposing them to the lunar environment, considering the adjustments necessary for the game to appear normal or at least playable in the moon's unique conditions.

This means identifying the fundamental characteristics of tennis that must be maintained and the significant parameters on which adaptation can be made. After all, Tennis is an ancient sport, practiced through the centuries under the names of pallacorda, wall ball, Jeu de Paume, Royal Tennis, Tenez, shuttlecock, racket game... each time readjusting its rules, the equipment used, and the playing spaces according to the environmental and cultural conditions of the society that played it.

And there are so many variations of tennis played today: badminton, table tennis (ping-pong), racquetball, padel, squash, pickleball, beach tennis, etc. Few sports in history have lent themselves to so many derivations, depending on changes made to one or more of the 3 basic variables: the court, the ball, the racket.

It is therefore highly likely that when tennis is transposed to the moon, it will give rise to a new lunar variant. The first step in adapting tennis for the moon was to eliminate as many parameters as possible. The first challenge was deciding whether to construct the tennis court outdoors or indoors. If an outdoor court were to be considered, numerous atmospheric parameters would need to be addressed, including moondust, static cling, and the absence of air, which alters the spin and rotation of the ball. Additionally, the bulky spacesuits would severely limit player’s movements. To mitigate these issues, an indoor facility within a pressurised sports dome, with breathable air, emerged as a viable solution.

Next, key parameters were identified to evaluate the adaptation of tennis to lunar conditions. The parameters were chosen by referring to the technical and approval regulations of the International Tennis Federation (ITF), the world-wide governing body of the game of tennis.

Every year, the ITF publishes the document "Rules of Tennis”, [54] which covers all aspects of the game and includes regulation on: the court (Rule 1, Appendix I, VIII) and its permanent equipment (Rule 2), the ball (Rule 3, Appendix I), the racket (Rule 4, Appendix II), the scoring system and rules of play (Rules 5 to 30), and player analysis technology (Rule 31, Appendix III). Rules are not established once and for all but are revised annually in order to incorporate new discoveries and improvements that scientific research is able to bring to the game. For a court, a ball, or a racket to be labelled

"ITF Approved" it must conform to a stringent set of approval tests as defined by the Rules of Tennis. Unlike other sports, there is no single type of court surface, racket, or ball to be respected, but a range of geometric and physical parameters that in each different case must be respected.

The following paragraphs delve into the current rules regarding the court, the ball and the racket, identifying and selecting the parameters that, according to the authors, will have to be evaluated primarily when moving tennis to the Moon.

The *shape* and *size* parameters of racket sports fields have undergone changes over time until they settled into the various official regulations. The playing surface has assumed various shapes such as oval, trapezoidal, and rectangular, each with quite different areas. Some variants were developed in spaces divided by a net (badminton, tennis, table tennis); in others it is mandatory to use a wall or fence (squash, racquetball); and in the case of padel, an hybrid sport developed in a space enclosed by walls and divided by a net where it is allowed to play with some side wall areas and with the back walls [48].

The shape of the tennis court was finally stabilised in 1875 to today's design and official Laws of Lawn-Tennis were adopted by the Marylebone Cricket Club.

The size of the court and the type of surface are factors that extremely influence the dynamics of play, the distances travelled, the breaks in each match and the type of effort made. The study by Cádiz Gallardo, Pradas de la Fuente and Carrasco Páez provides a review of the literature on the influence of court size of different racquet sports in the metabolic response of players [48]. The tennis court is a rectangle measuring 23.77×8.23 m for singles and 23.77×10.97 m for doubles [54]. In addition to the limits of the court, inside which the balls must bounce, it is also necessary to consider the outer space (run-back and side-run space) that players use to move and hit the ball: this brings the dimensions of the tennis court to be a minimum of 34.75×17.07m, which results in mainly lateral and "longer" distance movements. Padel is played on a 20×10 m court with side/back walls [55] that generate a better pace of play and more frequent actions without increasing physical intensity [56]. Badminton and pickleball are played in an even smaller rectangle (13.40×5.18 for singles and 13.40×6.10 for doubles) with space for run-back and side-run, but badminton has a higher height net [57]. Table tennis is played on a 2.74×1.525 m table [58], which causes short and fast movements that are very explosive and high intensity, although the final distance travelled a is short, but the intensity is extremely high [59].

Thus, it is proven that there is no optimal size but that it is a key parameter to be evaluated for moving the field to the moon. A future experiment on the body's metabolic response to playing tennis under lunar hypogravity conditions will be needed to determine court size. For example, players might move around the field differently, walking more slowly and taking higher jumps. Due to the lower gravity, the Froud number is higher, and the transition between walking and running (or better, jumping) occurs at a lower speed [60-64]. As a result, a smaller court size but with a higher net could be experienced. The space could then be scaled according to the physical effects that will occur.

The material that makes up the *court surface* also affects the dynamics of the players' movement. Tennis is played on many diverse types of surfaces, more so perhaps than any other sport (grass, clay, acrylic, carpet, concrete), each of which has different characteristics not only in terms of its interaction with the ball, but also with the player [65]. The ITF identifies key properties of a court surface as *friction*, *energy restitution* (ball rebound), *topography and dimensions* (evenness, slope, planarity, dimensions), and *consistency* (uniformity). Tennis courts are classified according to the combination of these properties, determining their type and speed [66].

The tennis ball has also undergone constant changes in size and especially material over time. The overall behaviour of the tennis ball on Earth is influenced by many factors (temperature, pressure, humidity, altitude) and the ITF has established rules for the approval and classification of balls based on parameters such as *mass [grams], size [cm], rebound [cm], pressurization [kPa], deformation [cm], durability and colour* [67].

In particular, it is considered relevant to dwell on the *rebound* value [68]. The ITF test required to homologate a ball is performed in a Controlled Environment and consists of dropping a ball vertically from a height of 254 cm (100 inches) onto a smooth, rigid and horizontal block of high mass and measuring its rebound heigh which must fall within a predetermined range [66]. Today there are already different rebound requirements for balls to be used at high altitude (lower rebound height) and also to adapt the game to the height of children in Under 10 tennis (deflated, depressurized ball, etc.).

Another element to be investigated is the trajectory of the ball in flight, which is measured by studying the horizontal (speed) and vertical (spin) components, expressed in terms of acceleration. The variables involved (under terrestrial conditions) are the *radius* of the ball, its *velocity, air density* and *drag coefficient*.

Extensive study and tests are needed to measure the dynamic reaction and the aerodynamic characteristics of the balls in the new environment. It is hypothesised that on the Moon, due to the lower gravity, the standard ball will travel through the air with a higher speed and have a higher and longer rebound than experienced on Earth. Moreover, on Earth the ball can be hit by giving it some spin, an effect that would be difficult to replicate on the Moon without atmosphere. To compensate for these effects, it will be necessary to change the composition of the ball and the readjustment of parameters.

The structure of a racket involves the presence of a rigid element, the frame (composed of a head, throat and handle) and a more flexible element, the stringbed.

Rackets have undergone constant transformation and refinement to accommodate evolving players and strokes. Research has developed enormously in this field leading to substantial changes in profile and frame shape and string material to act on handling, power, and static and dynamic stiffness. From the primordial wooden frames, the 1980s saw the introduction of frames made of graphite, carbon fiber, fiberglass, etc., which were much lighter and performed much better [64]. Strings have also evolved from natural gut to synthetic strings.

There are multiple parameters to be evaluated to adapt the tool to the lunar environment. The main parameters may refer to: *materials composition* of the frame, of the handle, of the strings; geometric parameters such as *head size* and *form*, *length*, *beam width*, *string pattern*, *size and shape of the handle*; physical parameters such as *weight*, *balance*, *swing weight*, *string tension*, *static stiffness*, and *dynamic stiffness* [65].

5. TECHNICAL FEASIBILITY AND CONSTRUC-TI-ON MANAGEMENT OF A LUNAR TENNIS FACILITY

The unique conditions of the lunar environment such as low gravity, extreme temperature variability, exposure to cosmic radiation, risk of impact of micrometeorites and the absence of atmosphere, strongly condition the architectural design of a structure on the lunar environment.

Similarly, the choice of the location of the settlement is of fundamental importance, due to the constraints, of different nature, deriving from the orographic conformation, the consistency of the soil and the availability of in-situ resources, such as frozen water under the lunar surface, of which it is supposed to be present large quantity in the south polar region.

It has long been suspected that lava tubes exist on the Moon, with several skylights recently detected in SELENE and LRO images [70]. In recent years, space agencies have developed many different mission scenarios for exploring these subsurface environments, showing that interest in these exploration targets is increasing. NASA has conducted a NIAC Phase 1 study [71], while JAXA is developing potential scenarios for extraterrestrial cave exploration under the UZUME program [72].

Scientific interest in these potential subsurface environments spans several aspects. It is therefore clear that lunar lava tubes could be important for future human exploration of the Moon, as they could provide protection from a range of harsh surface conditions. Lava tubes represent unique environments protected from cosmic radiation [73], characterized by less pronounced temperature fluctuations, protected from micrometeorite bombardment, and therefore are potential candidates for planet-based human settlements.

The scenario described in this study assumes to exploit the advantages offered by the placement of the module for practicing tennis in a lava tube. With the purpose to facilitate construction operations, following a mapping and an assessment of the site, a lava tube with direct outlet to the lunar surface must be opted, so as to not to have to dig a vertical access pit.

All habitation modules in the lunar environment must be pressurized to support human life. All habitable structures in the harsh environment beyond Earth must be able to withstand internal pressure loads of 0.6 to 1.0 bar (without leaks). Consequently, space habitats generally are primarily modules of circular cross-section, incorporating spherical, tubular or toroidal geometries (regardless of the materials used).

Although the structural possibilities are associated with a number of constraints, research has developed different options for the construction of planetary habitats such as prefabricated, inflatables, hybrid and in-situ 3D-printed and a class terminology has been proposed (Tab.1) [71, 75, 76].

In the proposed scenario the constructive typology of the sports facility for LDSM on the Moon is hybrid solution, class 4, resulting by the connection of two prefabricated rigid modules, which contain airlocks, changing room, equipment storage, control room and facilities for crew's hygiene, with a pre-integrated central module consisting of a deployable and inflatable hemicylindrical shell (thermally insulated by an inner layer of aerogel) in which to practise tennis (Fig. 2).

This typological solution provides the sports facility with two emergency exits at its opposite ends and the possibility of integrating with other modules by connecting through a locking ring at the tips.

Foreseeing further development of Artemis program, the whole module, in its deflated payload configuration (22m X 9m), could be stowed in the cargo fairing of the launch vehicle SLS 10m PLF, whose total mission volume is 1800 m^3 (9,1m diameter X 27m) and design payload is approximately 42 tons.

The Space Launch System (SLS) is a super heavy-lift expendable launch vehicle which NASA is likely to develop no earlier than in 2028. It is designed for trans-lunar trajectories (TLI) to offer more payload mass, volume, and departure energy than any other single rocket, supporting a wide range of mission objectives, while reducing mission complexity.

Assuming that in the identified site a human settlement has already been built and there is availability of energy sources and teleoperated machines for the execution of construction work and for the hauling of loads, it is possible to summarize the phases of installation of the module as follows:

Tab. 1 Different approaches to habitat design. Adapted from [71].

	Class 1	**Class 2**	**Class 3**	**Class 4 (combinations)**
Construction	Pre-integrated modules from Earth	Prefabricated components that are assembled onsite	In-situ resources are used for building structures	Combination of classes 1, 2 and 3
Examples	Apollo Lunar Module (1969–1972, NASA)	Inflatable or deployable structures: deployable Voshkod 2 airlock (1965, USSR), geodetic satellites, Genesis I and II prototypes (2006, 2007, Bigelow) space hotel	3D printing using surface material (regolith) Developing concrete and "bricks" using regolith as a major ingredient	Reconfiguration of hard shell "conventional" modules with pre-integrated interior elements and attached deployable (e.g., inflatable) volumes. Class 3 structures may be used for exterior protection

Preparatory phase:

- Construction of the bedding layer in sintered regolith for the installation of the module: teleoperated rovers transport regolith into the lava tube, compact it and sinter it by laser, creating the bedding layer for laying the module.

Hauling and anchorage phase:

- Transport of the module in the lava tube: a teleoperated hauler transports the module, which is in the payload and deflated configuration, into the lava tube and places it on the regolith bedding layer;
- Module extension: a teleoperated hauler extends the module by spacing its parts in order to develop the central part (inflatable balloon). The whole extension of the module is 36.6 meters;
- Anchoring of the structure to the bedding layer: the module is connected to the energy supply system, the legs of the module are extended, the inflatable balloon is anchored to the bedding layer by means of pegs.

Installing phase:

- Plant connection: the module is connected to the air or inert gas supply system and to the water supply system;
- Inflatable balloon mounting: the inflatable balloon is inflated with air or inert gas;
- Internal atmosphere pressurization: the internal environment of the module is pressurized with breathable air;
- Locking of the internal stiffening structure of the inflatable balloon: the stiffening arcs and the bracing structure of the inflatable envelope are extended and locked in their final position.
- Laying of the flooring and the tennis court: inside the balloon a flooring is made of ribbed tiles in polymeric material and the tennis court in synthetic material is deployed.

6. CONCLUSIONS

Lunar environment is little less harsh than space environment for what regards low gravity. While the effects on human body of microgravity is well known, there are no studies on the effects of reduced gravity, like that on the Moon. However, it is reasonable to expect that most effects of microgravity (loss of bone, of muscular mass, displacement of body fluids, etc.) are present although on a reduced scale.

Experience gained in LEO, shows that physical activities are important not only to counter the effects of microgravity, but also to improve the general physiological and psychological wellbeing of the crew.

While on space stations reduced space compels to limit the activities to using a treadmill, exercise bicycle or similar gym equipment, on the Moon it is possible to practice a more enjoyable sport activity.

The activities which involve short burst of heavy effort and brief rest intervals have several advantages and are the most effective against depressive disorders. Among these sports (hockey, football, basketball, etc) "racket sports" are perhaps the most adaptable to the Lunar environment.

Tennis, practised on a regular basis, may result in improved aerobic fitness, lower body fat percentage and decreased risks of diabetes and cardiovascular diseases.

On a psychological level, increases optimism and self-esteem, improves stress and anxiety management and contributes to the development of psychological capabilities such as the perception of control over one's actions, work ethic, self-discipline, responsibility, stress management, adaptation, strategic planning. It appears to be a very efficient countermeasure against stressors in space missions.

Tennis rules and specifications for the court, the ball and the racket must be adapted to the lunar environment which may result in a different kind of racket sport.

The present paper presents a feasibility study for a facility to practice tennis on the Moon.

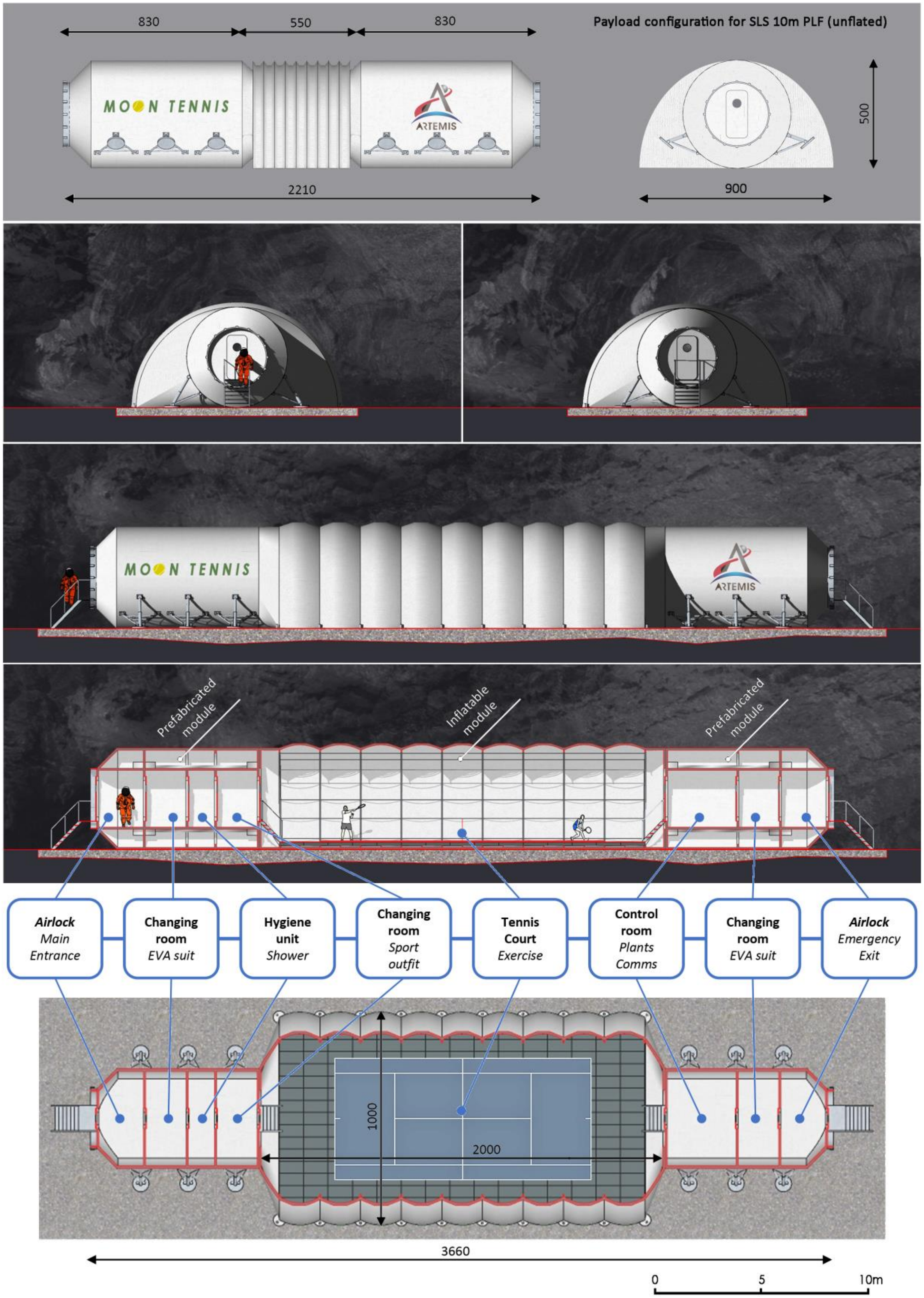

Fig. 2 Concept of a tennis facility for LDSM on the Moon

The court can be located in a pressurized building in a lava tube, so that it is protected from radiation and the players do not need to wear a heavy space suit.

The building can be made by two class 1 (pre-integrated from Earth) modules, on a class 3 (built using lunar regolith) foundation, while the central part, hosting the court, is an inflated structure (class 2). The parts carried from Earth can be transported in a single launch using the SLS launcher in pre-assembles conditions. The assembly work is not complex and can be done in a relatively short time.

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