Sex in Space: Consideration of uncontrolled human conception in emerging space tourism

Authors: David C. Cullen[*,1]; Matthew C. Hudnall[2]; Sheela Ali[3]; Steve S. Behram[4]; Egbert Edelbroek[5]; Alexander Layendecker[6]; Rafael Elias Marques[7]; Sumbal Mushtaq[8]; Angelo C.J. Vermeulen[9]

Abstract

The next ten years (2023 to 2033) are expected to see growth in orbital space tourism, with flights lasting from days to weeks. The motivations for spaceflight and the expected inflight behaviours of participants are likely to differ from those of professional astronauts. It is unrealistic to assume that all space tourism participants will abstain from sexual activities while exposed to microgravity and increased levels of ionising radiation during spaceflight. This raises the possibility of uncontrolled human conception in space, which poses a significant risk to the emerging space tourism sector. Our knowledge of the effects of these space environments on the early stages of human reproduction and the long-term consequence to human offspring is in its infancy. This lack of knowledge underpins the risks within the evolving orbital space tourism sector. The possible detrimental outcomes include those of a biological nature – *e.g.* developmental abnormalities in human offspring, and those of a societal and commercial nature – *e.g.* litigation, reputational damage, and financial loss. Currently (2023), the sector does not appear to be discussing this risk and context in an open forum or communicating any risk mitigation. Given the breadth of actors and stakeholders that seem applicable, this means many relevant voices are not engaged in discussions and influencing outcomes. The authors of this paper consider this to be an inappropriate situation that needs to be urgently addressed.

To encourage and contribute to a broad actor and stakeholder engagement and discussion, this green paper defines the term "*uncontrolled human conception in emerging space tourism*" and outlines the actors and stakeholders that should constitute the community or sector. Various issues and topics relevant to the actor and stakeholder engagement and discussions are outlined. These include the biological context and risks of human conception during spaceflight and postflight; the sociological context of human conception in space; space tourism and other business models relevant to human conception in space; spacecraft engineering context; moral, ethical, legal and regulatory considerations; examples from other relevant and analogue situations; and the present status of discussion and risk mitigation within the space tourism sector.

As part of this green paper, the authors make a series of recommendations for the community: (i) organise a series of consultations and meetings to bring together the actors and stakeholders for debate, discussion, and dialogue concerning uncontrolled human conception in space tourism; (ii) establish the current status of discussion, risks consideration and risk mitigation within the community; and (iii) propose routes forward to result in a community/sector approach to (a) regulation, (b) risk mitigation, (c) development and sharing of best practices, and (d) open communications. Several topics for further research are also suggested, including (i) exploring questions concerning likely tourist motivation for, and sexual activity during, spaceflight and (ii) considering the efficacy of, and approaches to validate the use of, existing human contraceptive approaches during spaceflight.

Keywords

Space tourism; human reproduction; sex; sexology; microgravity; risk mitigation; spaceflight behaviour

Introduction

Earth-orbit and beyond Earth-orbit space tourism is becoming a reality and is expected to grow in the coming years. The growth will increase the number of human space tourists exposed to diverse space environments and expand the range of underlying motivations to be in space. A specific assumption as the basis for the current paper is that "*it seems unrealistic to assume that all space tourism participants will abstain from sexual activities whilst in space and exposed to space environments*". A consequence of this is that early stages of human reproduction – *e.g.* gametogenesis, fertilisation and zygote formation, blastocyst development, and implantation – may occur in the very near future during spaceflight and whilst exposed to space environments. There is little knowledge and understanding concerning the effects of space environments – principally weightlessness and increased levels of ionising radiation – on the early stages of human reproduction and the subsequent long-term consequences on any resultant human offspring. The previous points describe a scenario that could result in various detrimental outcomes for the actors and stakeholders involved in space tourism. Potential detrimental outcomes and risks include those of a biological nature such as maternal complications related to conception and embryo, foetal,

[*] Author for correspondence – d.cullen@cranfield.ac.uk

[1] Space Group, School of Aerospace, Transport and Manufacturing, Cranfield University, Cranfield, Bedfordshire, MK43 0AL, United Kingdom

[2] Cryobio, Columbus, OH 43214, USA

[3] Progenesis Inc., La Jolla, CA 92037, USA

[4] Congressional OB GYN, Rockville, MD 20850, USA

[5] SpaceBorn United B.V., Graaf Adolfstraat 32, Eindhoven, The Netherlands

[6] Astrosexological Research Institute, 8700 Astronaut Boulevard, Suite 69, Cape Canaveral, FL 32920, USA

[7] Brazilian National Biosciences Laboratory - LNBio, Brazilian Centre for Research in Energy and Materials - CNPEM. Giuseppe Máximo Scolfaro, 10000, Campinas 13083-100, Brazil

[8] Diversity and Gender Equality Group, Space Generation Advisory Council, Vienna, Austria

[9] Faculty of Technology, Policy and Management, Delft University of Technology, Postbus 5, 2600 AA Delft, The Netherlands & SEADS (Space Ecologies Art and Design) Network (https://seads.network) & SpaceBorn United B.V., Graaf Adolfstraat 32, Eindhoven, The Netherlands

neonatal, and later abnormalities, and those of a societal and commercial nature such as litigation, reputational damage, and financial loss. At the time of authoring this paper (2023), this scenario and its implications have not been adequately and openly discussed among the wide range of actors and stakeholders involved in and relevant to the space tourism sector. The authors of this paper consider the lack of discussion, given the underlying risks and little obvious risk mitigation by the space tourism sector, poses a broad and un-mitigated risk to the space tourism sector.

This consultative green paper aims to highlight, expand, and communicate the issues to benefit the relevant actors and stakeholders in the space tourism sector. This can form the basis for further discussions among this community. To this end, this paper will:

- Provide an overview of relevant parts of the space tourism sector.
- Propose a definition of the term "uncontrolled human conception in emerging space tourism".
- Propose, discuss and list the relevant community in the form of actors and stakeholders.
- Overview the biological context and risks.
- Consider the sociological context, including general society, space tourists, and relevant organisations.
- Consider the space engineering context.
- Consider the moral, ethical, legal, and regulatory context.
- Review other relevant or analogue sectors where lessons and established practice can be observed.
- Review the present status of discussion and risk mitigation within the space tourism sector.

The scope of this paper will focus on considering short to medium-term space tourism expected within approximately the next ten years – *i.e.* spaceflight duration of days to weeks – and therefore only considers biological risks associated with the early stages of human reproduction.

The authors hope this paper will help to promote open debate, discussion, dialogue, and other considerations of the issues highlighted and the resulting risks among the relevant actors and stakeholders in the space tourism sector. The authors conclude this paper with several recommendations for the sector, actors, and stakeholders to aid this engagement.

This green paper will be used to gather further community inputs to produce a white paper version and then further disseminated via publication in a peer-reviewed journal.

Overview of relevant aspects of the space tourism sector

Space tourism can be viewed as a broadly defined term in the context of the present paper. Cater (Cater, 2010) overviewed the sector and categorised three sub-sectors that comprise the following. (i) Terrestrial space tourism and which includes tours of ground-based space facilities, dark skies astronomy, and other ground-based activities. (ii) Atmospheric space tourism and which includes weightless parabolic aircraft flights and stratospheric balloon capsules. (iii) Astro-tourism includes sub-orbital flights beyond the Kármán line, Earth-orbital flights, and beyond Earth-orbit flights. This paper focuses solely on astro-tourism as this is the only sub-sector that exposes participants to space environments of interest and for appropriate durations. Although the term astro-tourism is well-defined, it is not widely used within the relevant actor and stakeholder communities where space tourism is typically used instead of astro-tourism. Therefore to aid in communication to a broad audience, the term space tourism will be used in the remainder of this paper to represent astro-tourism. For further context, (Zhang & Wang, 2022) recently performed a systematic literature review of the existing body of space tourism literature.

The aspects of space tourism that are the focus of the current paper are those that expose human participants to space environments for time durations that could be expected to affect the early stages of human reproduction. While sub-orbital flights with an apogee of around 100 km and a free-fall or weightless period of a few single minutes may not have a significant effect on early stages of human reproduction, longer-duration space flights could potentially have an impact. As such, the remainder of this paper will focus on Earth-orbital and beyond Earth-orbital flights as they expose participants to weightlessness and increased levels of ionising radiation for durations of days to weeks. Such periods are similar to the timescales of the early and formative stages of human reproduction surrounding conception.

The Earth orbital and beyond Earth orbit space tourism sector is still in its infancy. Still, it has attracted considerable interest from various actors and stakeholders, who will be reviewed later in this paper. It is difficult to predict how the sector will evolve in the coming decade, as evidenced by several market survey reports that differ significantly in their predictions. Example reports have a predicted market size of $8.7b by 2030 (Grand View Research, n.d.), $12.7b by 2031 (Allied Market Research, 2022), and $92b by 2030 (Precedence Research, 2022), although these reports include both orbital and sub-orbital activities.

To date, examples that could be considered orbital space tourism are the following. The seven private astronauts flown individually by Roskosmos and its predecessors on Soyoz-TM/TMA spacecraft to the ISS from 2001 to 2009 (Stimac, 2020). In 2021, the privately funded three-day Inspiration4 orbital space mission operated by SpaceX flew four private astronauts in a SpaceX Crew Dragon spacecraft (Dutfield & Stein, 2022). In 2022 the privately funded seventeen-day Axiom Mission 1 orbital mission flew four astronauts for a sixteen-day stay on the ISS via a SpaceX Crew Dragon spacecraft (Howell, 2022).

The immediate future of orbital space tourism spaceflights can be anticipated as extensions of those that have already occurred. The team behind the Inspiration4 flight have proposed a series of three further flights as the Polaris program (Browne, 2023), with the first two flights using the SpaceX Crew Dragon spacecraft and the third the SpaceX Starship spacecraft and with the latter having the potential for more than four crew members. Axiom Space has proposed additional privately funded flights using a SpaceX Crew Dragon spacecraft to the ISS (Wall, 2022).

Space tourism flights beyond low Earth orbit are being considered using the SpaceX Starship spacecraft under development. The dearMoon project is a privately funded mission that proposes to fly nine crew on a six-day free-return trajectory to the Moon. The selected crew announced in late 2022 has a wide range of backgrounds and none of which have a professional astronaut background (Howell, 2022). A previous private astronaut, Dennis Tito, has announced an agreement with SpaceX for seats on a second private circumlunar Starship flight (Pearlman, 2022).

Another type of space tourism being considered is the private Earth-orbiting space station akin to the space hotel concept. A number have been proposed and subsequently abandoned. Currently, the company Orbital Assembly Corporation (USA) has been promoting Earth-orbiting commercial space stations with gravity-simulating on-orbit habitation environments for leisure, commercial and industrial activities. Two concepts have

been described: the Pioneer-class space station (Orbital Assembly, 2023) with a maximum occupancy of 28 people and the Voyager-class space station (Orbital Assembly, 2023) with a maximum occupancy of 440 people. The ability to generate artificial gravity via space station rotation would not necessarily be operated at a 1g level, rather fractional gravity levels such as lunar or Martian levels would be expected. Their promotional materials suggest implementation well within the next ten years. A number of companies are developing orbital space station concepts as part of the NASA Commercial Destinations in Low-Earth Orbit programme (NASA, 2023) to prepare for post-ISS activities. Voyager Space (USA), as a subsidiary of NanoRacks (USA), is proposing the Starlab private space station and is partnering with the Hilton hotel group (Hilton Worldwide, 2022).

Definition of uncontrolled human conception in emerging space tourism

To aid the desired debate, discussion, and dialogue among the relevant actors and stakeholders, a definition of "*uncontrolled human conception in emerging space tourism*" will be helpful. Within the current paper, the term "*uncontrolled human conception in emerging space tourism*" is defined as the following: (i) Any activities that lead to human conception – *i.e.* gametogenesis, fertilisation and zygote formation, blastocyst development, and implantation – in a form that could be influenced by space environments encountered during space tourism. (ii) Activities include pre-meditated (planned) and non-pre-meditated (unplanned), as well as consensual and non-consensual activities. (iii) Uncontrolled refers to a context without societal approval for human conception – *i.e.* without regulatory approval from relevant bodies representing a broad societal consensus.

Consideration of the sector actors and stakeholders

To further consider the issues relating to uncontrolled human conception in space tourism, the range of actors (those directly involved) and stakeholders (those indirectly involved) should be defined. Once identified, the actors and stakeholders can be engaged to discuss the issues and risks of uncontrolled human conception in space tourism and to consider risk-mitigation approaches – see later recommendations in this paper.

A suggested list of actors and stakeholders is documented in Table 1. The approach taken to populate the table was to use the knowledge and views of the authors of this paper. It is proposed to refine and update the table contents as part of the broader community consultation the authors are planning via the publication of this green paper. The table contains a short description of the basis for inclusion and the role or roles of each identified entry.

Table 1: List of identified actors and stakeholders that could be involved in implementing space tourism with specific consideration regarding the potential for uncontrolled human conception in emerging space tourism. The term "actor" means any individual, group or organisation directly involved in the delivery of space tourism and the term "stakeholder" means any group or individual who can affect or is affected by the implementation of space tourism. Sometimes, a single individual, group or organisation could be represented in more than one actor and/or stakeholder capacity. The approach taken to populate the table was to use the knowledge and views of the authors of this paper. The table contents are expected to be refined, updated and validated by presentation to and discussion with a wider cross-section of the community as part of a broader community engagement the authors intend.

Space tourism actors	Comments
Space tourists	Persons being fare-paying customers (paying directly or indirectly) involved in spaceflight and not being viewed as professional crew or astronauts and noting the ambiguity of the term "private astronauts"
Offspring of in-space human conception	Given the "uncontrolled human conception" context of this table, the human offspring of in-space human conception should be considered as actors, including whilst *in utero*
Crew astronauts	Persons acting as professional and employed astronauts required as part of a spaceflight
Space tourism operators	Legal entities that directly provide space tourism services to customers – *e.g.* owners and operators of spacecraft used for space tourism
Space tourism brokers	Third-party entities that broker agreements between space tourists and space tourism operators
Technology, engineering, and infrastructure personnel and organisations	Those involved in the supply (design, manufacture, operation, safeguarding, rescue) of spacecraft and related space and ground support systems and infrastructure – *e.g.* sub-contractors, supply chain, service providers, …
Medical support personnel and organisations	Those involved in ensuring medical planning and medical fitness of space tourists during pre-spaceflight and providing medical support during spaceflight and post-spaceflight (including human contraception)
Training providers	Those involved in providing pre-flight training for space tourists and which could include a contribution to establishing expected and acceptable behaviour during touristic spaceflight
Legal support services	Those supporting the implementation of legal frameworks and agreements involved in implementing space tourism flights
Insurance services	To meet the insurance needs of space tourism providers, space tourists, and necessary third parties
Regulatory bodies and organisations	Those regulatory bodies that would contribute to the administration and enforcement of regulations in space tourism flights
Researchers	Those researchers that can utilise human space tourism to advance knowledge and understanding in a diverse range of topics – *e.g.* primarily using human space tourists as test subjects/test populations, to perform citizen science, and including specific research questions concerning sexology and biomedical aspects of human reproduction

(TABLE CONTINUED ON NEXT PAGE)

(TABLE CONTINUATION) Others to be determined	Placeholder to acknowledge this list is not closed, and additional actors may be identified and that the list will be updated in future versions of this table
Space tourism stakeholders	**Comments**
Financial, business and investment sector	Those involved in financially supporting, investing in, and commercially developing and exploiting space tourism
Tourism community	Space tourism can be viewed as part of this broader community or sector
Regulatory bodies and organisations	Those regulatory bodies that oversee the establishment and maintenance of regulations and that capture and represent broad societal views – *e.g.* would expect to include those relevant to or originating from space regulations, those from medical and human ethics regulations and those from the tourism sector
Research and expert community	A broad range of research and expert communities are expected to have roles in the consideration of risks, risk mitigation, and development of regulations – *e.g.* medical (inc. obstetricians, gynaecologists, and andrologists), ethics, legal, behavioural, human contraception designers and manufacturers, *etc*. communities
Politicians	Politicians guide and exert a significant influence on the overall societal framework in which space tourism operates
Various societal advocacy groups	Religious groups, reproductive rights groups, foetal rights groups, abortion and anti-abortion groups, environmental groups, …
General and specialist media	Space tourism will take place within a broad societal context; therefore, the general and specialist media can impact and influence the sector – *e.g.* a broad range of views could be expressed from overtly biased viewpoints – both negative and positive – and balanced viewpoints and all with an ability to influence the views and opinions of other stakeholders and actors
General public	Space tourism will take place within a broad societal context; therefore, the views of the general public can impact and influence the sector – *e.g.* would expect the general public to segregate into groups of those positive towards, negative towards, and ambivalent towards space tourism
Artistic and cultural communities	Space tourism can be expected to have a cultural impact on the broad wider "storytelling" (artist and cultural communities), and that can influence the sector
Others to be determined	Placeholder to acknowledge this list is not closed, and additional stakeholders may be identified and that the list will be updated in future versions of this table

Biological context and risks of human conception in space and postflight

Human reproductive physiology has evolved in the 1g gravity and ionising radiation environment present at the Earth's surface. The space environments to which early space tourists will be exposed will be significantly different with microgravity and increased levels of ionising radiation and changed ionising radiation composition, *i.e.* increased contribution from high-LET radiation. The concern is that our understanding of the exposure effects of microgravity and reduced gravity, space ionising radiation, and other components of the space environment on the human reproductive system and process is still very limited (Misra & Luderer, 2019) and therefore poses an unknown risk.

In the early stages of space tourism, where exposure to space environments will be limited to durations of days or weeks, the reproductive processes of interest are gametogenesis, fertilisation, embryogenesis, and implantation. This assumes that existing pregnancy, including a positive pregnancy test, would be an exclusion criterion for spaceflight and so later stages of pregnancy would not be subject to space environment exposure.

Before consideration of the biological aspects of conception during spaceflight, some consequences of gametogenesis need to be considered, specifically possible consequences of human conception involving space tourists in a period of up to a few months postflight. Male gametogenesis – *i.e.* sperm production or spermatogenesis – is a complex process which takes around 74 days in humans (Sharma & Agarwal, 2011). This process starts from primordial germ cells involving phases of cellular divisions including both mitotic and meiotic divisions. Coupled with the fact that testicular tissue is highly radiosensitive (Sullivan, 1996), germline consequences from microgravity and radiation exposures during sperm production may endure for up to around three months – *i.e.* due to the approximate 74-day production process – following the return to Earth. Germline mutations or chromatin structural malformations – *i.e.* epigenetic inheritance (Yoshida, et al., 2021) – resulting from radiation and/or microgravity exposure, may be heritable. Thus, there is a possible unknown risk that male space tourists if involved in conception for up to three months postflight could use sperm that has been affected by space environments. Concerning female gametogenesis and spaceflight. There are examples of female astronauts becoming pregnant post-spaceflight and delivering babies without any identified space-specific concerns (Jennings & Baker, 2008). The assumption is that in these cases conception would not have happened within a few months of return from space. Unlike males, females have a finite number of gametes which are present at birth. These primary or immature oocytes, arrested at the diplotene stage of meiosis I, are present within primordial follicles in the ovaries. The pool of primordial follicles and primary oocytes remain in an arrested state until puberty is reached. After puberty, individual primordial follicles from the pool continually enter further development with the potential to go through various stages of follicle development over a period of around 120 days and leading to preovulatory follicles. Within the 120-day development the oocyte undergoes growth and in the last few days, completes meiosis I and starts meiosis II. With each menstrual cycle, typically a single dominant preovulatory follicle will ovulate releasing a secondary oocyte. Female astronauts who later gave birth, are expected to

have conceived with oocytes which were in an arrested stage during space travel. In the context of space tourism, the scenario may be different. The motivation for spaceflight and the reproductive status of female space tourists may be different to female professional astronauts. An example may be the desire to conceive shortly after returning from spaceflight. This results in a scenario that conception, if occurring within around four months of spaceflight, may happen with oocytes that were developing during exposure to space environments with the unknown risks this entails. Therefore, in addition to concerns about human conception during spaceflight, there are also possible risks associated with human conception for a short period postflight. Furthermore, immunosuppression is frequently developed by astronauts on and after missions (Rooney, et al., 2019) and pregnant females are known to develop a transient immunosuppressed condition (Abu-Raya, et al., 2020). Therefore the combined immunosuppressive pressures may pose additional risks if conception occurs during or shortly after spaceflight as summarised in (Szocik, et al., 2018).

For conception during spaceflight, following gametogenesis and after copulation, the process of *in vivo* human fertilisation, requires the sperm to travel through the cervix and uterine cavity followed by fertilisation of an oocyte in the fallopian tube. To achieve this, sperm must undergo hyperactivation and attain increased motility. While mammalian studies are limited, in 2018 NASA's "Spaceflight-Altered Motility Activation and Fertility-Dependent Responses in Sperm" (Micro-11) investigation on the ISS studied the effects of microgravity on human sperm motility and capacitation for fertilisation (NASA, 2018) although the results of this study are not yet available to the public. Studies on mice have shown *in vitro* fertilisation can be achieved under simulated microgravity but early stages of embryo development are detrimentally affected (Kojima, et al., 2000; Wakayama, et al., 2009; Jung, et al., 2009).

If fertilisation can occur in a space environment, subsequent embryo development poses a further set of challenges. Forty-nine two-cell mouse embryos were sent into space on board the Columbia Space Shuttle, which resulted in the developmental arrest in all cases (Schenker & Forkheim, 1998). Ten years later, 100 four-cell mouse embryos were sent to the SJ-8 orbital platform. Once again, developmental arrest occurred and all 100 embryos failed to develop to the blastocyst stage (Ma, et al., 2008). (Lei, et al., 2020) was successful in culturing mouse blastocysts on China's SJ-10 recoverable satellite. Blastulation rates and blastocyst quality, however, were detrimentally affected. Together, studies have yielded conflicting results.

Implantation of an embryo in the uterus is the next step after fertilisation to achieve an early intrauterine pregnancy. After *in vivo* fertilisation occurs, embryo transport from the fallopian tube to the uterus is facilitated by ciliated cells and tubal fluid. While research in this area is lacking, it may be possible that a microgravity environment could affect the ability of the cilia and tubal fluid to effectively transport the embryo to the uterine cavity. If this is the case, there is a potential risk of a higher rate of extrauterine (ectopic) implantation resulting in an ectopic pregnancy. Ectopic pregnancy is a dangerous and potentially life-threatening maternal condition which requires immediate medical or surgical intervention (Bachman & Barnhart, 2012).

In summary, the limited studies on mammalian reproduction in space environments indicate that such environments may have a signification effect on many steps in reproduction physiology. This emphasises the unknown risks of allowing human conception in such situations at present. This has ethical implications, in addition to human developmental and financial and liability implications, for industry sector stakeholders. A significant increase in knowledge is required to make informed decisions regarding human reproduction in space. One obvious mitigation approach to consider is for counselling on safe sexual practices for space tourists. This, among many other issues, should be discussed among the medical and scientific communities, the other actors and stakeholders, and the public as a whole.

Sociological context of human conception in space

The sociological context is a crucial consideration expected to influence the potential for uncontrolled human conception in space tourism. There is limited research published concerning sexual relations – *i.e.* sexology – in space and this has focused primarily on the context of past and current astronauts and a medium to long-term future involving future humanity exploring and living beyond the Earth (Dubé, et al., 2023; Layendecker, 2016; Noonan, 1998). None have focused on the rapidly evolving and short-term context of space tourism.

The current situation can be broken down into several different situations and consequences. Firstly, concerning humans having taken part in, or immediately about to take part in, orbital spaceflight. To date, spaceflight has been dominated by professional astronauts. It can be argued that a combination of the selection processes, career pathways, professional culture and peer expectation provides an environment that has not resulted in any documented human conception in space. This culture can be seen as emphasising mission-oriented goals, risk/reward profiles that minimise behaviour deemed inappropriate and a common and shared set of views and behaviour. The early orbital space tourists that have already flown and are about to fly are viewed by some commentators as private astronauts rather than space tourists (Tumlinson, 2022). This can be interpreted as a cohort that still preserves many of the characteristics of professional astronauts and, therefore, can be expected to exhibit similar behaviour. As the nature of space tourism is expected to evolve, the motivation, behaviour, culture, and peer expectations of orbital space tourists will also evolve.

To emphasise the likely difference in the motivation and expected behaviour of space tourists compared to professional astronauts, (Olya & Han, 2020) broadly considered the behavioural intention of space travellers – *i.e.* space tourists – and reviewed the existing literature. The broad range of considerations identified includes aspects of adventure, gratification, information acquisition, service experience, and social motivation. Also, the nature of space tourism is expected to attract behavioural types such as risk-takers and novelty seekers. It can be assumed that these behaviours also pose a risk associated with a willingness to disregard rules, regulations and societal norms. There does not appear to have been any study of the motivation or intent of space tourists for sexual activity during spaceflight. The conclusion is that the body of future space tourists is likely to have a much greater range and individual diversity of motivations and behaviour compared to professional astronauts and are less likely to be compliant with rules, regulations, and community/social norms.

An obvious question that needs to be considered is why the risks and consequences of uncontrolled human conception in emerging space tourism have not been discussed by the relevant community of actors and stakeholders in a public forum. Among the public, there is reoccurring evidence that the topic of human conception in space – *i.e.* sex in space – is of interest given

several general media articles published in the past and recently (for a recent example see (Sina, 2022)). Anecdotal evidence from this paper's authors suggests that such topics are discussed privately but not in public forums within the community. Given that at present most space tourism developments are occurring in a Western cultural context and one heavily influenced by the USA, one possibility is as follows. NASA has dominated the US spaceflight scene for decades. NASA was and is publicly funded primarily as an engineering-based organisation. The nature of the US political system in the regular approval of NASA funding is influenced by a significant culturally conservative viewpoint towards human sex. The resulting culture within NASA has been to avoid any signification overt and public discussion of human sexuality to avoid problems with political oversight and funding. It can be considered that within NASA, discussion and research into human sexual activities is a topic that is formally avoided. This culture has then contributed to the broader spaceflight landscape and space tourism sector and especially those elements coming from an engineering and governmental background. This view has been reviewed and commented upon in (Dubé, et al., 2023) and highlighted the general consideration of sexual interaction in space – *i.e.* space sexology – as "*the under-researched blind spot of space programs*".

A further consideration specific to this paper is that the authors represent a predominately Western cultural perspective. Whilst it can be argued that much of the technical development of space tourism and the growing regulatory environment is occurring within Western cultures, this may not be the case in the future. Also, the cultural background of end-users – *i.e.* space tourists – is expected to diversify. It is therefore important that if the community openly engages in debates, discussions, and dialogue, it should ensure that voices representing all cultural backgrounds are considered.

As part of any community considerations, all possible situations relating to uncontrolled human conception should be included. Therefore, the possibility of, and consequences of, non-consensual as well as consensual human conception should be considered. The need to address the potential for sexual harassment and assault in space-related contexts has recently been highlighted (Santaguida, et al., 2022; Dubé, et al., 2023).

Space tourism and other business models relevant to human conception in space

The space tourism business development community can contribute to driving or influencing the motivations and behaviour of individual space tourists in the context of uncontrolled human conception. Several proposals have been promoted that strongly suggest an expectation of sexual activity. The idea of "space honeymoons" has been promoted as a motivation for participants to take part in spaceflight. An exclusive or luxury dating agency has promoted a space dating service where two individuals can have "the first date in space" (Mitchell, 2021; Lusso, n.d.).

Although not orbital space tourism, several space tourism companies are planning stratospheric balloon flights in luxury environmentally controlled gondolas offering participants a journey to "the edge of space". The authors are aware anecdotally of enquiries for booking private romantic flights.

Again, although not specifically space tourism, the potential for uncontrolled human conception in space could occur through the activities of the adult film industry. The adult film industry has previously explored the possibility of video/film production in space environments. In 2000 a parabolic aircraft flight was used for filming a weightless scene (Wall, 2015), and in 2015 a major adult website organised a public fundraising campaign to fund a spaceflight for filming (Wall, 2015), however, this failed to raise sufficient funds and was abandoned. As future costs for human orbital spaceflight reduce and capacity increases, it is realistic to assume the adult film industry, given its significant financial resources, will exploit this opportunity. It is assumed that within the industry, existing good practices minimise the possibility of human conception. These good practices could be expected to be transferred into space environments subject to compatibility with space environments.

Spacecraft engineering context

Within the context of varying societal norms, the internal topology or layout of space of emerging spacecraft for space tourism can be expected to influence the willingness of participants to engage in sexual activities. It is assumed that if the habitable volume of spacecraft used for space tourism offers a degree of privacy, either by design or inadvertently, within a multi-person flight scenario, this may influence the prevalence of sexual activities among flight participants. The two obvious extremes are a single and therefore shared habitable compartment such as in the SpaceX Crew Dragon spacecraft and proposed concepts of orbital space stations with hotel-like modules offering private quarters. The under-development SpaceX Starship spacecraft is positioned between these extremes with a large habitable volume and some suggested configurations having private or separated personal living quarters.

Regulatory, legal, ethical and moral considerations

Current space activities take place within established regulatory frameworks at both international and national levels. Similarly, space tourism will need to be regulated through a regulatory framework but the details are not yet well established. The regulation of space tourism has recently been considered and reviewed by (von der Dunk, 2019; von der Dunk, 2013), although the focus was primarily on sub-orbital spaceflight. The view is that for orbital spaceflight tourism, international space law could be the primary basis for evolution to cover orbital space tourism. For sub-orbital spaceflight, air law rather than space law may be taken as the basis.

Similarly, human reproduction – *i.e.* sexual and reproductive health and rights – is overseen by reproductive rights frameworks and legislation at international and national levels (Pizzarossa, 2018). As part of a broader community engagement, a wide variety of advocacy groups are voices in the ongoing evolution of sexual and reproductive health and rights and associated legislation and include religious groups and foetal rights groups. Such voices should be acknowledged and considered. A further consideration could be the situation of a couple knowingly conceiving during spaceflight and with the knowledge of existing science indicating significant embryo, foetus, and child development risks (Lei, et al., 2019) (Lei, et al., 2020) (Wang & Yasuda, 2020). If so, should this be seen as foetal harm and related to similar behaviour involving drugs of abuse, alcohol use, and smoking during conception and pregnancy. The legal consequences are complex; for example, see (Harris & Paltrow, 2003).

In summary, the regulatory framework of space tourism is evolving, and the need to consider the possibility of human conception during spaceflight should be added to the issues that need to be considered.

Examples from other relevant and analogue situations

To help inform a space tourism context, other relevant and analogue situations with similar issues are highlighted as possible resources for best practices and lessons learned.

An obviously related context is current practice in professional astronaut spaceflight concerning guidance or rules concerning sexual activities during spaceflight. There appears to be a reluctance to have overt policies and for these to be discussed freely within and external to space agencies. Both NASA and ESA guidance appears to recommend that sexual relationships and interactions should not occur during spaceflight and to have existing pregnancy as a medical exclusion criterion for spaceflight. A recent article has quoted statements of this situation by a current ESA astronaut (Sina, 2022). A combination of crew professionalism, crew motivation, and the lack of privacy in current spacecraft design and operations are also likely to contribute to an environment that minimises the likelihood of sexual interactions.

An aspect of female astronaut health relevant to human conception in space is the common elective practice of medically induced amenorrhea among female crew members (Jain & Wotring, 2016; Stellar, et al., 2021). The motivation for menstrual suppression can include contraception during ground-based pre-flight activities, given that pregnancy is a contraindication of spaceflight, and to avoid a range of issues with menstruation within the operational and austere hygiene conditions of spaceflight. A range of off-the-shelf products is commonly used, including combined oral contraceptives and long-acting reversible contraceptives.

Over-wintering Antarctic crews are often used as an analogue for social anthropological studies of human spaceflight. A current concern is to address legacy and ongoing cultural problems associated with sexual harassment within fieldwork settings – *i.e.* including Antarctic base settings – and ensure best practices from other settings are implemented. Generic recommendations to organisations include (i) a clear statement that harassment is not tolerated, (ii) different types of sexual harassment are defined, (iii) the policy is disseminated to all employees, (iv) and the policy is highly visible to employees and the public to increase exposure. Such guidance could be adapted for space tourism as sexual harassment is a valid concern or possibility. As an example of organisational guidance specifically regarding pregnancy, The British Antarctic Survey has a "*Policy on Pregnancy in the Antarctic and Artic*" document currently in the public domain, which appears to have been authored in 2010 (Boon & Grant, 2010) and states that "*Anyone known to be pregnant should not serve in the Antarctic or the Arctic*" and "*Recommendation: Everyone serving in the Antarctic / Arctic has a responsibility to minimise the chance of personnel becoming pregnant. Every effort to ensure adequate contraception should be used*." If this policy was to be applied to orbital space tourism, the obvious concern is the lack of any studies or validation of the efficacy of human contraceptive approaches within space environments.

Military submarines offer an analogue for human spaceflight with isolation, artificially maintained physical environment, particular cultural environment, and mixed-gender crews. A review of medical implications of women on submarines published in 2001 (Kane & Horn, 2001) included consideration of female sexual health and pregnancy. Of specific relevance to spaceflight, the elevated atmospheric carbon dioxide level in submarine environments (up to ten times normal levels) was highlighted as an unknown risk to foetal development. This has resulted in some navies at some points in time excluding women from serving on submarines due to this risk. Similar levels of atmospheric carbon dioxide are found on the ISS.

Status of discussion and risk mitigation within the space tourism sector

Given the questions and objectives of this paper, it is evident that the current status of discussions and considerations of uncontrolled human conception among the actors and stakeholders of emerging space tourism needs to be assessed.

In an initial review of public domain information associated with those entities planning to provide space tourism flights, there appears to be no mention of the risks or mitigation of human conception during or immediately after spaceflight. Furthermore, from the limited anecdotal knowledge of the authors, this is not being discussed privately or mitigated to any meaningful level.

There are two areas with clear or implied evidence of the discussion of human sexual interactions in space. Firstly, in the general media, there have been reoccurring instances over many years of news articles and opinion pieces speculating on human sexual interactions during spaceflight. Secondly, some emerging business models of space tourism emphasise the marketing of personal relationships in the form of "space honeymoons" and "space dating". It can be assumed that this implies the increased chance of sexual interactions occurring during spaceflight. These latter examples show some actors and stakeholders are discussing the potential for human sexual interactions in spaceflight but not necessarily discussing human conception and the risks and consequences to any resultant progeny or the potential litigation, reputational damage, and financial loss consequences.

It is obvious that the current status of discussion and mitigation needs to be determined with greater certainty. It is therefore recommended that this is assessed further as a priority. The key entities to engage with are (i) the space tourism providers and (ii) the likely regulatory agencies.

Example use case

To help highlight the core issue of this paper and to suggest one possible solution, the following is a simple example use case for mitigating the risk of human conception in emerging space tourism.

The case could be based on a simple approach of (i) pre-flight counselling of participants concerning the risks of human conception in space environments, and (ii) participant signing of legal waivers. It would be expected that similar approaches would be used to address other medical risks associated with participant spaceflight. Thus, space tourism participants as part of their pre-spaceflight preparations and training would have a compulsory counselling session and then sign a legal waiver broadly stating that the participants are solely liable for the consequences if they do conceive during or shortly after spaceflight.

If this was deemed a possible route forward, the following are obvious immediate activities to pursue: (i) deciding on the content of the pre-flight counselling, the mode of delivery and to seek community approval, (ii) decide on the details of the legal waiver documentation and obtain community approval, (iii) test the robustness of the approach by detailed consideration of consequences of participants having counselling, signing waivers, and then still conceiving during spaceflight or immediately after spaceflight, and (iv) as part of the preceding, explore best practice and lessons learned from related situations

where parent behaviour is regulated/controlled by society due to risks to the offspring of conception.

Recommendations

Given the preceding considerations and discussion, the authors make the following recommendations:

Recommendation 1: A series of consultations and meetings (workshops, seminars, conferences, *etc*.) should be organised to bring together the relevant actors and stakeholders for debate, discussion, and dialogue concerning uncontrolled human conception in space tourism.

Recommendation 2: From the consultations and meetings, the current status in the sector of the consideration, discussion, risks, and mitigation of unplanned human conception in emerging space tourism should be established.

Recommendation 3: From the consultations and meetings, the sector should propose routes forward to result in a formulated approach to (a) regulation, (b) risk mitigation, (c) development and sharing of best practices, and (d) ongoing open communications.

Recommendation 4: One, or more, use cases should be explored to help understand the issues and possible solutions with one suggestion being a simple approach based upon pre-spaceflight counselling and waiving of liability by the participants.

Further recommended immediate research could be the following:

Research topic 1: Explore questions about likely tourist motivation and sexual activity.

Research topic 2: Consideration of sexology studies as part of future analogue space missions.

Research topic 3: Consolidation of existing knowledge about the early stages of human (and mammalian) reproduction in space environments and consideration of the ensuing risks to human progeny.

Research topic 4: Given the possible use of existing human contraceptive approaches during spaceflight for risk mitigation, there is a need for studies of and validation of their efficacy within space environments.

Conclusions

Given the preceding considerations of uncontrolled human conception in emerging space tourism, the authors conclude the following. (i) There are risks associated with uncontrolled human conception in emerging space tourism and comprising human developmental risks and sectorial reputational and liability risks. (ii) At present, the various actors and stakeholders relevant to space tourism do not appear to have publicly discussed the risks. (iii) There appears to be no mitigation of the risks surrounding uncontrolled human conception in emerging space tourism. (iv) The authors recommend that the relevant actors and stakeholders engage in appropriate debate, discussion, and dialogue to clarify and appropriately mitigate the risks and establish guidelines for best practices. (v) The authors have listed the possible stakeholders and actors and produced a definition of "uncontrolled human conception" to aid in debate, discussion, and dialogue. (vi) The authors have suggested further areas of research to help clarify current uncertainties.

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SpaceBorn United B.V. (www.spacebornunited.com) is an organisation based in the Netherlands. Its goals include advocating the present need for humanity to explore, understand, and address the multitude of issues surrounding a future with the need for human reproduction beyond the Earth. The role of SpaceBorn United in this paper has been to provide a networking environment to identify, assemble and enable discussion among the authors. All authors have advisory or other collaborative roles with SpaceBorn United B.V. at the time of writing.

Layendecker is a member of the Board of Directors of the Space Tourism Society (https://spacetourismsociety.org). The Space Tourism Society openly advocates for the development and expansion of the space tourism industry.

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