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SPACE FLIGHTS A NEW OPTION FOR INTERCONTINETAL TRAVEL – SOLUTION DESING

Dominik Mrňa
Air Transport Department
University of Žilina
Univerzitná 8215/1
010 26, Žilina
dominik.mrna@stud.uniza.sk

Abstract

This paper describes problem of space flight intercontinental flight with passengers or cargo via suborbital orbits. It describes the necessary monitoring network as well as the operating procedures with connection of flights in airspace and in space itself. Paper takes into account existing models of spacecraft (space vessels) and concept designs to introduce possible solutions to this type of travelling. Last section deals with the issue of ground infrastructure – spaceport, for a given type of transport and focuses on the existing spaceport in USA and presents it as a model for future spaceports around the world.

Keywords

space flights, spacecraft, monitoring, spaceport

1. Introduction

Nowadays, a lot of start-up companies which would like to use space, in particular altitude above 100 kilometres, which represents the imaginary boundary between airspace and space (Zahari, Romli, 2019), for flights between continents with passengers or cargo. International legislation about the use of space allows to each country use space for socio-economic purposes with condition that space will be used only for peaceful purposes (Outer Space Treaty, 1967). Some companies, mainly in the USA, have started operating aircraft for space tourism. Some of these companies would like to start intercontinental flights in future. This technology would significantly speed up connections between destinations. Most of long-distance flights would be completed in less than half an hour (Musk, 2017).

Many subsystems will be needed for the whole system to work smoothly without problems. Advantage is that a similar system is using for the needs of satellite operations. Therefore, certain procedures could be implemented, and certain devices could be applied to the space travel segment.

2. Methodology

The used methodology consists in introducing basic components for traveling in suborbital orbits around the Earth. The gradual development of concepts, physical equipment and infrastructure seems to be suitable for updating the proposed concepts in the past. Content of this paper is presentation of the possibilities for surveillance and monitoring networks, means of transport and ground infrastructure.

2.1. Surveillance network and monitoring

To ensure safety environment, a new surveillance network will be needed to ensure tracking and surveillance of spacecraft during space flight. Operators have to take into account surveillance and tracking network for flight phase in airspace. For these purposes, operators or navigation providers could use existing surveillance network for aviation. Data sharing within these two spaces will be needed. Air traffic control would ensure control and safety in airspace and new centres of space traffic control would ensure control and safety of space. Experts in the field suggest a transition Flight Level of 650, circa 22 kilometres. In case of economic efficiency, space navigation providers could use a surveillance network from Space Traffic Management system, which is used for monitoring and tracking of objects for collision warnings of satellites. Nowadays, USA owns the most developed surveillance system called Space Surveillance Network (SNN), which is displayed in Figure 1. This system consists from ground based and space radars with 3 types of sensors placed around the world. Space-based sensors are not included in Figure 1.

Composition of the SSN system:

1. Conventional radars,
2. Phase-array radars,
3. Electro-optical sensors GEODSS (Ground-Based Electro-Optical Deep Space Surveillance),
4. The Midcourse Space Experiment (Sgobba, Allahdadi, 2013).

Figure 23: Location of all ground based sensor of SSN. Source: https://www.economist.com/briefing/2019/07/18/attacking-satellites-is-increasingly-attractive-and-dangerous

Hovewer extensive and developed this system is, it is not perfect and cannot predict the exact objects locations during a conjunction. As a result, there is a predicted location for each object. Reality is that object could actually be anywhere within an oblong bubble surrounding that predicted location (Peterson et al., 2018). It means that tracking object has many possible positions around the actual/real position. The bigger this bubble is, more false alarms of crash are produced. At present, experts in the field are trying to minimise this bubble to the smallest possible size by the ideas how to minimise the future population growth or by improved/additional data and processing (Peterson et al., 2018).

2.1.1. <u>CNS</u>

If we take into account the CNS – Communication, Navigation and Surveillance, the communication segment would be identical to the current concept and procedures. It means, that participants could use standard radio communication or digital communication (Tullmann et al., 2017).

Navigation would need to be standardised for space travel and similar to today's RNP (Required Navigation Performance) used in air transport is recommended. It is expressed by the distance to the intended position that an aircraft must comply with in at least 95% of the total flight time (Tullmann et al., 2017). Based on the navigation accuracy of spacecraft equipment and on the manoeuvrability of this vehicle, separation standards in airspace and space will be established. Operators have to take into account that certain concepts of spacecraft, especially those with limited manoeuvrability (rockets). Those will be not fully integrated into airspace, as concepts with horizontal take-off and landing.

RNP only applies to airspace, specifically to FL650. As others physical laws apply in space, it will be necessary to develop new navigations systems and its standards. New space vehicle would have to use two different navigation systems. This navigation system designed for the space environment could take the example and best practices from the operations of the Space shuttle. According to the technical specifications given in the NSTS New reference manual (1988)[a], Space shuttle navigation system was composed of three inertial measurement units, three tactical air navigation units, two air data probe assemblies, three microwave scan beam landing systems and two radar altimeters. For a detailed example, this system consisted of inertial measurement units, star trackers, crewman optical alignment sight, TACAN, air data system, microwave scan beam landing system, radar altimeter, accelerometer assemblies and orbiter gyro assemblies. Solid rocket booster rate gyro assemblies were used for navigation during launch.

For the proper function of surveillance, a concept should combine the data from sensors and radars used to monitor air traffic and space traffic on orbits. When the spacecraft will pass a FL650, it will be necessary to ensure a smooth transition of data between networks and equipment for air traffic and space traffic monitoring. Spacecraft should use a ADS – Automatic Dependent Surveillance, when the target itself determines its position and send information about it to the ground systems (Novák, 2010). FL650 ~ 60000 feet is selected as the boundary where responsibility passes from the area of air traffic control to the area of space traffic control. This transition boundary is also chosen mainly because most of surveillance aviation systems are limited to this altitude (Tullmann et al., 2017).

2.1.2. <u>Space traffic control</u>

For needs of space flights, it would be necessary to create space flight control centers. Controllers would be responsible for safety and flight above the FL650. Cooperation with air traffic control will be also necessary because some segments (departure, arrival) of flight will take place in airspace. To establish rules and procedures for transferring flight from airspace to space and vice versa, the usual procedures of a flight between individual FIRs could be used. In this case, a point at which will be flight transferred is precisely defined. This should include the transmission of flight data between traffic control units via online interfaces – principle of OLDI. Some sources state that STCO should also be responsible for movements at the spaceport. However, this depends on used aircraft (spacecraft) concept.

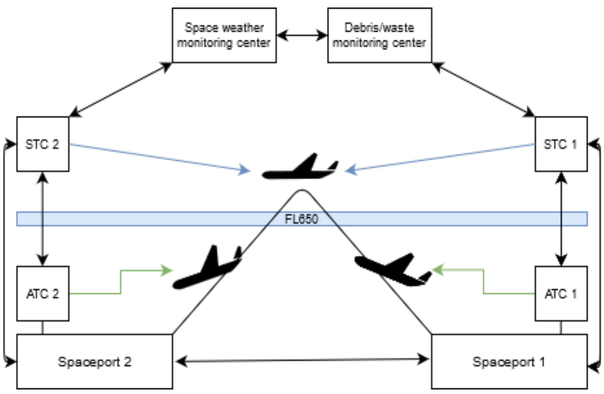

Figure 24: Diagram showing the connection of individual elements involved in space flights.

From text above and Figure 2, we can assume that air traffic controllers will continue to control of spacecraft during departure and arrival segment of flight in airspace. These steps will add new responsibilities, and therefore in case of future space operations, training should be added.

2.1.3. <u>Monitoring centers</u>

Besides of monitoring of the spacecraft and other space vehicles in orbit, it will be also necessary to monitor space waste or debris around Earth and monitor the state of space weather. According to NASA (2017), orbital debris is any man-made object in orbit around the Earth which no longer serves a useful function. Such debris includes nonfunctional spacecraft, abandoned launch vehicle stages, mission-related debris and fragmentation debris. According to ESA (2020) statistic, number of functioning satellites is about 3000 and number of tracked debris objects is about 27370. According to NASA (2021), the highest density of debris is between 800 and 850 kilometers. Referring to Tullmann (2017), the maximum altitude of a hypothetic flight could be 500 kilometers. Figure 3 from Lucken, Hubert and Giolito (2017) shows the density of space debris and waste at different altitudes.

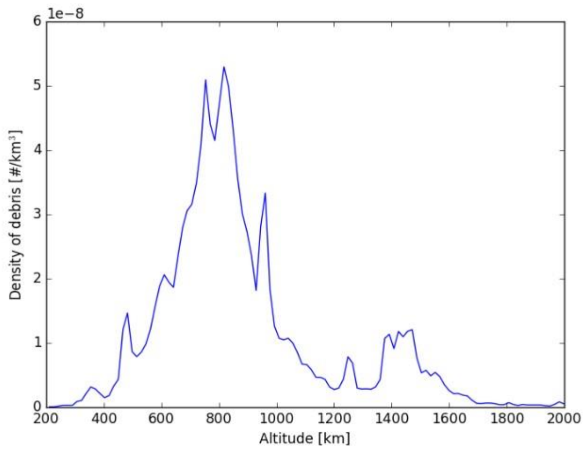

Figure 3: Density of debris at different altitudes. Source: Lucken, Hubert and Giolito (2017).

The attached graph in Figure 3 shows that the density of space debris up to 500 kilometers is not very high. However, there is still a risk of a possible collision. Based on the known trajectory between the destinations and based on the performance parameters of the spacecraft, it would be possible to calculate distances between the spacecraft and the space debris or satellite for each second of flight. The NORAD Two-Line Element database seems to be suitable for these needs. It contains trajectories of all monitored objects. Flight planning center in cooperation with debris monitoring center should verify risk of collision during whole flight. In case of possible conjunction with other objects, slot of departure time will be released to avoid a potentially dangerous situation. This means that the distance which poses a danger to the vehicle has to be introduced. In case of ongoing flight, updated informations (in form of bulletin) with possible conjunction and correction maneuvers should be presented to crew by space traffic controller (Figure 4).

State of Space weather and its forecasting is very important for operation. The National Oceanic and Atmospheric Administration's (NOAAA) Space Weather Forecast Center has sufficient monitoring and forecasting capacity. NOAAA can provide information about space weather conditions, where data from the last observation and thus predictive models are given. These warnings apply to geomagnetic storms, solar storms, and radio blackouts.

The state of space weather around the Earth is influenced mainly by the Sun. Mainly by the coronal mass ejection, solar flares, extreme ultraviolet radiation (EUV) and many others. Radiation caused by solar radiation storm from coronal mass ejection are dangerous because it has impact mainly on human health. EUV and solar flares mainly affect the ionosphere. This is mainly ionization, when the so-called radio blackout can occur, i.e., the loss and impossibility of a radio connection. The highly ionized atmosphere also causes an increase of drag as the ionosphere becomes denser. Therefore, orbiting devices must perform frequent correction maneuvers to return to their original orbits (NOAAA, 2021). NOAAA constantly monitors the state of the Sun and its accompanying phenomena. For space flight operations is NOAAA able to issue forecasts or warnings in advance.

In case of severe conditions, flight planning center in cooperation with NOAAA or equivalent space weather monitoring center should be able to issue warnings of these phenomena or suspend operations. Just because of the loss of communication, such a flight poses a serious safety problem. As some phenomena can last from hours to days, it is not considered logical to issue slot time. In the event that a sudden incident affects an ongoing flight, it will be necessary to issue safety procedures and guidelines for this purpose.

The above-mentioned centers already exist mainly for the satellite operations, they could potentially expand their capacities and capabilities for needs of space point-to-point flights and achieve better cost-effectiveness.

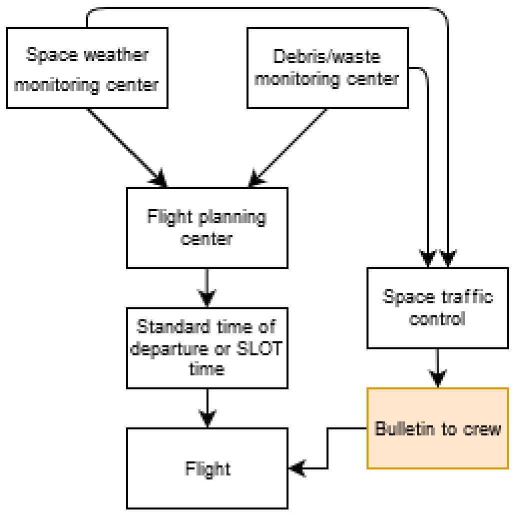

Figure 4: Flight planning scheme.

2.2. Spacecraft for suborbital flight

Today, experts are working with three main concepts of spacecraft for suborbital flight. These concepts are:

1. Vertical take-off and landing
2. Horizontal take-off and landing,
3. Hybrid take-off and landing.

2.2.1. Vertical take-off and landing

This concept works with conventional rockets launch from Earth. Main difference from standard rocket is, that this type is fully reusable, because first stages are driven back to Earth. This leads to economic efficiency, because costs for launch are smaller than in case of disposable rockets.

SpaceX's Starship rocket (Figure 4) represents the appropriate model of this concept. This ship is mainly designed for Mars's mission and satellites launching operations, but SpaceX takes into account a possibility of Earth-to-Earth traveling (Musk, 2017). Elon Musk, CEO of SpaceX, said that average price of ticket for suborbital intercontinental flight will be about 1200 USD/flight (Dinkin, 2017). Connection time between two destinations, depends on distance is estimated about 25 – 40 minutes. Given such a price, there could be considerable demand for such travel, as experience in space tourism shows that, due to the significant cost of orbiting the Earth, orbital space tourism will not be affordable for the general public in the coming decades (Yi-Wei Chang, 2020).

Figure 5: Big Falcon Rocket with Starship module. Source: Musk, 2017.

2.2.2. Horizontal take-off and landing

In the future, this type of spacecraft could use the experimental engine SABRE (Synergetic Air Breathing Rocket Engine), which in the initial flight phase works as conventional jet engine with additional combustion and after reaching a certain altitude, the principle of engine operation changes to rocket engine. This engine was originally designed for the British concept of the HOTOL (Horizontal take-off and landing) spacecraft from the 80s.

A newer concept that would use SABRE engine is also from Britain and is called Skylon Spaceplane (Figure 5). This spacecraft would be able to accelerate to Mach 5.5 when reaching an altitude of 28 kilometers. Above this altitude up to 90 kilometers, rocket engine would be able to accelerate Skylon to Mach 27.8 (Hempsell et al., 2014). Unfortunately, this concept is currently only on blueprints a there is only an engine, which is currently in the testing phase. From available data and operating manuals, we know that this type of spacecraft would need a special RWY only for Skylon, approximately 5.5 kilometers long (Hempsell et al., 2014).

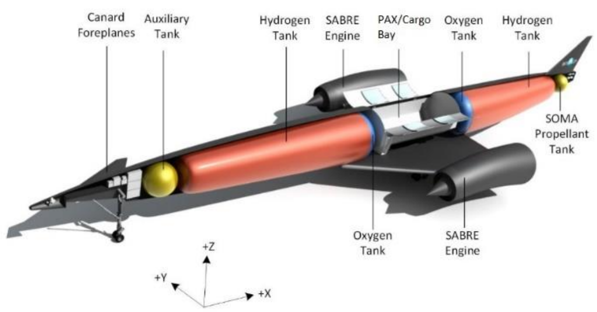

Figure 6: Model of Skylon Spaceplane with interior equipment. Source: Hempsell et al.,2014.

This concept is designed for the transport of passengers and cargo, where replaceable containers for cargo or passengers would be installed in the aircraft as required. In the case of PAX version, a container would be able to carry 24 passengers and 7800 kilograms of cargo. Container with satellite deploying mechanism (satellite up to 10 tons) is another option (Hempsell et al., 2014). Passenger container is designed with full life support systems, so no spacesuits would be needed.

In addition to this concept (Skylon), European Union has been working on the FAST20XX project, which has explored two new concepts of suborbital means of transport. The first of these is the Alpha, a small space vehicle with a hybrid launch principle. The second project is SpaceLiner, a two-stage rocket (Starship principle). However, this second concept was not considered feasible until the second half of the 21st century (Mason-Zwaan, Moro-Aguilar, 2013).

2.2.3. Hybrid take-off and landing

As a last option, we chose the already existing spacecraft of the American company Virgin Galactic called VSS Unity/Space Ship Two. This company does not currently use its spacecraft for suborbital point-to-point traveling but only for space tourism purposes. The company has also signaled its interest in leveraging its space technology to develop high-speed, point-to-point travel (Grush, 2020). We chose this company as an appropriate example, because it shows a feasible option to launch spacecraft into space, albeit on a small scale.

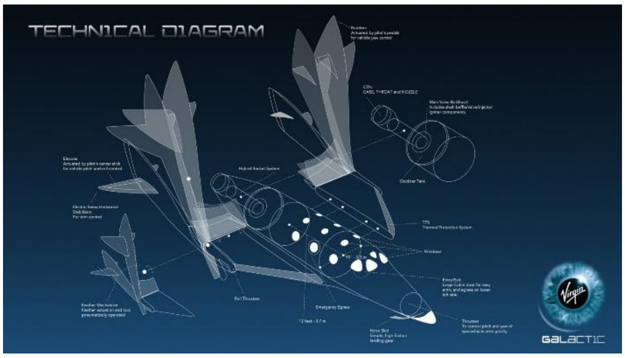

Figure 7: Technical diagram of VSS Unity Spacecraft. Source: https://www.virgingalactic.com/learn/

The whole mission is to bring the VSS Unity spacecraft to space by the mother aircraft (mobile launch pad) VSS Eve. It takes-off as a conventional aircraft and bring the VSS Unity to a height of 45000 – 50000 feet (13.7 – 15.2 kilometers), where it will come to disengage and ignite the rocket engine, which will get the spacecraft to the edge of space. So far, the height has reached 80 kilometers (Karman's border in the USA), but in the future Virgin Galactic wants to reach a limit of 110 kilometers. After reaching the highest point, the spacecraft will return to its home base in New Mexico using a gliding flight. The spacecraft is designed for 2 pilots and 6 passengers. (Sheetz, 2020).

According to available sources, the company has made a partnership with NASA to work together to develop a high-speed aircraft capable of intercontinental ballistic flight around the Earth. For this development, the company wants to draw on its experience in the design and operation of the aforementioned spacecraft (Etherington, 2020).

2.2.4. Maneuverability of vehicle

The maneuverability of an aircraft also needs to be addressed. For concepts with hybrid and horizontal take-off, movement in the atmosphere around the main axes will be provided via movable control surfaces. Rocket during launch uses thrust vectoring for basic maneuvering. In space, special system for maneuvering the vehicle will need. The aircraft could therefore use the reaction control system (RCS), which is also known from the operation of space shuttles and other space vehicles. This RCS or orbital maneuvering system provides the thrust for orbit insertion, orbit circularization, orbit transfer, deorbit, abort to orbit (NSTS News reference manual, 1988)[b].

2.3. Spaceports

New airports/spaceports will be needed to operate spacecraft and other space vessels and vehicles. Some research recommends/suggests that the construction of such spaceports be carried out as an extension of some of the world's hubs for air transport, in order to copy routes between those destinations (Tullmann, 2017). But experiences show that even the usual expansion of the airport seems to be very problematic. Such extension is only possible if a hybrid or horizontal spacecraft concept is used for the flights. In case of vehicles with vertical take-off, existing cosmodromes could be used, or new ones could be built in order to copy routes. In addition, the ground infrastructure should include fuel storage areas in accordance with applicable regulations, a fire extinguishing system suitable for the planned activities. In the first instance, such a place must contain hangars of the correct size with adequate dimensions to accommodate vehicles and to allow all necessary activities there before and after the flight or during the turnaround between flights (Santoro et al., 2018).

At least the basic infrastructure already exists in America for these flights and vehicles. For example, Spaceport America in New Mexico, which uses Virgin Galactic for its needs. Unfortunately, there is no similar spaceport in Europe and no spaceport has been built to launch rockets. For these purposes, ESA uses spaceport Kourou located in French Guaina (ESA, 2020).

Figure 8 shows, that spaceport object does not differ significantly from a regular airport. It is equipped with a passenger check-in terminal and apron area. The terminal is also use as a hangar for aircraft storage and aircraft maintenance. Spaceport is equipped by concrete RWY with dimensions 3658x61 meters, with 16/34 orientation (Airnav.com, 2020). Spaceport also has access to Special Airspace Restricted Areas – 5111A and 5111B, which do not have an upper limit on request. (FAA, 2020)

Based on official data, this spaceport is able to provide the following services:

1. Horizontal launch and landing,
2. Suborbital flight training and research,
3. Weightless flights,
4. Test-flight aviation,
5. Straight-line aerodynamics testing,
6. Unmanned flights (Spaceport America, 2020).

In addition to the RWY, Spaceport also has facilities and infrastructure for rocket launches. Company is also adding a new infrastructure for Vertical Launch. These improvements are expected to be finished by mid-2021 (Spaceport America, 2020).

Spaceport America clearly shows to us that several types of space vessels can be served in one special place. Therefore, this possibility should be considered in future planning and that instead of costly construction of individual space vessels launch facilities (rockets – cosmodromes, spacecraft – spaceports), combined solutions could be built.

Figure 8: Spaceport America, New Mexico from satellite image. Source: Google Maps

3. Results and discussion

At present, we can only rely on solutions proposals that deal with the topic, because point-to-point travel on suborbital path is unfortunately not used today, or not practice at all. The first physical facilities are under construction or are in operation mainly in the United States, where flights are performed only to a minimal extent.

The similarities with air transport and satellite operations may seem to be an advantage in connection with the creation of rules and standards for operation. This new concept could work with the know-how and best practices from these segments. It is necessary to mention that the existing monitoring (communication) networks could be used, especially in the initial stages, to avoid an excessive increase in the cost when building new networks. We assume that initial operation will be not so burdensome for the system.

The SpaceX with its Starship rocket, seeks to connect destinations on the planet through suborbital flights. The first tests of this rocket are currently underway. This rocket has many uses. From our point of view, it seems that the company focuses more on getting astronauts to Mars with the aforementioned rocket than on the possibility of traveling Earth-to-Earth. Getting people to Mars have more potential and greater prestige. Referring to information from official Elon Musk's Twitter account, prediction of the first test flight of the Starship into space could take place by 2022 – 2023.

Virgin Galactic is currently in the process of launching its first flight with passengers. However, form the already mentioned alliance with the American NASA, there is no exact date when the first flight of the newly developed supersonic aircraft should take place. Given the current situation of the sets, is assumed that the creation of an aircraft will be not a priority for those companies. But concept of mobile launch pad for possible suborbital traveling looks like the right, because by using a mobile launch pad (VSS Eve) spacecraft consumes less propellant than an equivalent ground-launched vessel and is more sustainable and cost-effective (Cordis EU research results, 2015).

Europe would also like to have a share on the suborbital travel market. Unfortunately, we can work only with rough designs of Skylon concept or others. For Skylon spacecraft, the SABER engine is going to the test phase, so we do not yet know the overall results. From the available sources we know that developed precooler for this engine was able to successfully cool the system under conditions of air flow at the speed of Mach 5. It is making a significant milestone in the development of this engine (Reaction Engines, 2019), not only for this spacecraft.

As far as the safety of these devices is concerned, in addition to active elements, it proposes to include passive elements in the form of ballistic parachute systems. These parachutes would be fired in an emergency and the device itself would then descend safely to Earth (Škultéty, Čerňan, Rostáš, 2019).

As the FUA concept is being moved, especially in European region, in order to increase the efficient use of airspace (Eurocontrol, 2020), author considers the concepts of spacecraft with horizontal and hybrid take-off to be the most optimal choice, because using a rocket, it is still necessary to take into account its limited manoeuvrability and thus the need of own segregated airspace. In other concepts, the is a possibility, when spacecraft is able to achieve established navigation accuracy (RNP), full integration into the air transport system without the need of segregated/reserved airspaces.

For many concepts, we do not know the exact date when they should start operation, yet. At best, we know only a very rough estimate. It can be assumed that the crisis in air transport caused by the global pandemic of COVID-19 will significantly delay the dates already issued or it will completely suspend the development of flying space vessels.

In the end we state that vehicles and infrastructure are constantly being developed and improved. Therefore, current devices may seem outdated in the near future and may be better and improved than the models shown in this paper.

4. Conclusion

Suborbital travel offers many opportunities for the development of transport on Earth. The biggest advantage is of course, the speed of vehicle, because higher speeds can be achieved at high altitudes. Mainly due to the fact that sonic boom at higher altitudes is not a problem, but mainly due to the different composition of the atmosphere. This paper describes the most important elements that will be needed to perform this type of flights. It deals with the problem of monitoring networks for transport, which includes the actual monitoring of spacecraft as well as other objects on orbits and space weather. CNS, airport design and possible variants for spacecraft are also described. This paper applies to generally known matters and knowledge gained in the development and operation of existing facilities and infrastructures that would be suitable for this type of traveling.

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