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From aviation tourism to suborbital space tourism: A study on passenger screening and business opportunities

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ABSTRACT

Due to the significant amount of cost for privately paid passenger to travel the Earth orbit and beyond, orbital space tourism (OST) is not affordable for the general public in the coming decades. Therefore, the second best could be the suborbital space tourism (SST). According to the following facts, SST could be right at the corner: in October 2017, the Saudi Arabia intended to invest 1 billion USD into Virgin Galactic; on December 11, 2019, Blue Origin's New Shepard had a wholly successful 12th flight test mission (NS-12); and then on February 13, 2020, Virgin Galactic's spaceplane SpaceShipTwo, named VSS Unity, has been successfully relocated to its commercial headquarters at Spaceport America. Referring to the possible or potential effects of reusable suborbital launch vehicle (RSLV) trajectory dynamics on the neuro-vestibular system of passenger, this paper studied and discussed the pre-flight passenger screening contents and the related business opportunities for SST. Requirements for the third class medical certificate of the Federal Aviation Administration (FAA) of the USA have been proposed as a major reference. Since the SST is a new emerging market, contents for pre-flight screening of tourist need be rigorous, but could be adjustable based on accumulated flight experience in the future. The related business opportunities, either academic or commercial, in pre-flight training, pre-flight adaption, post-flight adaption, and data analysis, are expected to form a new industry chain gradually from 2020s to 2030s or 2040s.

1. Introduction

By definition, space tourism is the travel to space of passenger for recreational purposes [1]. Its first appearance can be traced back to the 1960s [2]. On February 27, 2017, the private company SpaceX announced that it had been approached to fly two private citizens on a trip around the Moon in late 2018, but it had then postponed the mission to the middle of 2019 [3], and then further postponed to no earlier than 2023. However, both passengers had paid a significant deposit to do the Moon tourism flight. Also, the total development cost would be as high as 2 billion to 10 billion USD [4]. Actually, from 2001 to 2009, 7 millionaires travelled to the Russian segment of the International Space Station (ISS) 8 times, but the cost for each orbital space tourism (OST) trip is tens of million USD [5,6]. In other words, even after six decades of space technology development with major support by the governmental sectors, travelling to Earth orbit and beyond is still only for a handful of millionaires [6]. For the general public, suborbital space tourism (SST) might be possible and could be affordable for those people who are rich enough and highly interested in it with the willingness to pay [7].

For the most recent development in SST, the Public Investment Fund (PIF) of Saudi Arabia and the Virgin Group signed a non-binding memorandum of understanding for a partnership on October 26, 2017, under which PIF intends to invest approximately 1 billion USD into Virgin Galactic [8]. Also, on December 18, 2017, Virgin Galactic and Agenzia Spaziale Italiana (Italian Space Agency, ASI) announced that they had signed a letter of intent under which ASI would secure a full suborbital flight on Virgin Galactic's SpaceShipTwo (SS2) for scientific research in 2019 at Spaceport America in New Mexico [9]. And on July 6, 2018, Aerospace Logistics Technology Engineering Company (ALTEC), Sitael, Virgin Galactic and The Spaceship Company signed a framework agreement that intends to bring Virgin Galactic's commercial spaceflights to Italy [10].

Blue Origin's New Shepard System had a completely successful 12th flight test mission (NS-12) on December 11, 2019. The reusability of its rocket, as well as safety and reliability of the vehicle has been repeatedly verified [11]. Several scientific payloads have been carried onboard to the von Kármán line: one came from the University of Florida in Gainesville, Florida; another one procured by NASA was developed by researchers at the Kennedy Space Centre in Florida; and several student art

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Nomenclature

ALTEC	Aerospace Logistics Technology Engineering Company
APL	Applied Physics Laboratory (Johns Hopkins University)
ASI	Agenzia Spaziale Italiana (Italian Space Agency)
CERN	Conseil Européen pour la Recherche Nucléaire
ConDENSS	condensed Droplet experiment for NASA in suborbital spaceflight
CRExIM	Cell Research Experiment in Microgravity
DLR	Deutsches Zentrum für Luft-und Raumfahrt (German Space Agency)
EADS	European Aeronautic Defence and Space
ETC	Environmental Tectonics Corporation
FAA	Federal Aviation Administration
FAA/AST	Federal Aviation Administration's Office of Commercial Space Transportation
FOP	Flight Opportunities Program
GCTC	Yuri Gagarin Cosmonaut Training Center
HTHL	horizontal-takeoff-horizontal-landing
ISS	International Space Station
JRS	Japanese Rocket Society
LEO	low Earth orbit
NAL	National Aerospace Laboratory (Japan)
NASTAR	National AeroSpace Training and Research
NS-10	10th mission of New Shepard System
NS-11	11th mission of New Shepard System
NS-12	12th mission of New Shepard System
OSCAR	Orbital Syngas Commodity Augmentation Reactor
OST	orbital space tourism
P2P	point-to-point
PIF	Public Investment Fund
RSLV	reusable suborbital launch vehicle
S3	Swiss Space Systems
SC1-x	Space Communicator Xperimental
SFEM-2	suborbital flight experiment monitor-2
SNC	Sierra Nevada Corporation
SOP	standard of operation
SS2	SpaceShipTwo
SST	suborbital space tourism
SSTO	single-stage-to-orbit
TBD	to be determined
USA	United States of America
USD	United States dollar
UTMB	University of Texas Medical Branch
VTOL	vertical-takeoff-and-landing
VTVL	vertical-takeoff-vertical-landing
WK2	WhiteKnightTwo
ZARM	Das Zentrum für angewandte Raumfahrttechnologie und Mikrogravitation
ZGGE	Zero-Gravity Glow Experiment

experiments along with thousands of postcards from students around the world were also on the vehicle [12].

Virgin Galactic's spaceplane SpaceShipTwo (SS2), named VSS Unity, was successfully relocated to its commercial headquarters at Spaceport America on February 13, 2020 [13]. The relocation and starting of test flight meant that VSS Unity could further advance to commercial service from its mother port [13,14]. Also, Virgin Galactic is trying to sell suborbital spaceflight tickets again [15]. All of this evidence shows that realization of SST could be happening sooner than before. In the area of tourism, more than 600 passengers were already made registration [16]; and in the area of science, Blue Origin's scientific payload customers already reached 100 [17]. Therefore, there are many commercial opportunities in the areas of tourism and science.

Both SS2 and New Shepard are reusable suborbital launch vehicles (RSLVs). The SS2 belongs to the horizontal-takeoff-horizontal-landing (HTHL) type and the New Shepard is the vertical-takeoff-vertical-landing (VTVL) type. Since both of them use a rocket engine for propulsion, the high level vibration and noise flight environments, and the flight phases in the sequence of high-*g* acceleration, weightlessness, and high-*g* deceleration, are typical and very different from that of conventional airplane flight. In particular, the three flight phases occur within 11–12 min [18], meaning the potential severe effects on passengers' neurovestibular and sensorimotor systems [19]. The trajectory dynamics and characteristics, as well as the effects on the passengers and pilot, have been discussed in Refs. [19–21], where Reference [21] emphasized that the symptoms after short-duration suborbital spaceflight need researchers to pay special attention.

The purposes of this paper were to study the screening and examination suborbital space tourists, and to analyse the new business opportunities. Compared with aviation flight, the most significant challenge to SST tourists is the high-*g* acceleration, weightlessness and high-*g* deceleration. And compared with long-time orbital spaceflight, the most significant challenge is that these three flight phases occur one by one within about 11–12 min with each phase lasting for just a few minutes. Therefore, sensorimotor disruption in eye movement, postural stability and motor coordination are very likely to happen in the SST traveller. Even more, the SST pilot would experience such cycles frequently during day-to-day commercial operations. A phenomenon of long term resonance might happen. The matter of pre-flight screening and examination for SST tourists needs to be settled. Also, post-flight adaptation needs be considered [21].

The requirements of pre-flight screening, examination and adaptation, as well as post-flight adaptation will generate large new markets [22]. Besides, many new business opportunities could be developed under this emerging industry. When SST becomes routine in the future, many of the research institutes, private companies, universities, general commercial public, and even elementary and high schools might be able to afford it.

After this Introduction Section, the background of orbital and suborbital space tourisms are briefly presented in Section 2, the characteristics of RSLV trajectories are briefly described in Section 3. Then the proposed tourist's screening and examination are presented in Section 4, and the potential business opportunities are presented in Section 5. The discussion and limitations, and conclusions are given in Sections 6 and 7, respectively.

2. Background of orbital and suborbital space tourism

This section presents the background of SST and OST, providing a brief overview. The study and survey in the OST market can be traced back to as early as the 1980s, while in SST the market survey was basically started in the early 2000s [23,24]. In Refs. [25,26], the Futron Corporation made two extensive surveys in 2002 on OST and SST and then in 2006 on SST, respectively. Major findings include: the passengers interested in and willing to pay for SST flights are demographically distinct from those interested in and willing to pay for OST flights, the most attractive feature is to view the Earth from space, lower prices mean more demand, and the forecasts for 2021 in passenger number is about 13,000 with potential revenue at about 676 million USD per year. In the early 2010s, the Federal Aviation Administration's Office of Commercial Space Transportation (FAA/AST) issued two reports on commercial suborbital industry [27] and suborbital reusable vehicles [28] in 2011 and 2012, respectively. It was concluded in Ref. [27] that customer demand was building for commercial space tourism. And in

Ref. [28], it showed that demand for commercial suborbital flights was sustained and could be sufficient to support multiple providers. However, the most recent analysis and evaluation in Ref. [29] indicates that even if there were still significant uncertainties in commercial SST market, it could probably be made attractive by proper management of development. In summary, commercial SST obtained positive support from all of the above studies. Although there is still no SST tourism, it might be expected within a short time. On the other hand, there are already 7 OST millionaire tourists and this number might increase to 10 and even more within a few years.

2.1. Background of orbital space tourism

From the 1980s to the early 2010s, many international conferences in space tourism have been held, and surveys have been conducted in some of the countries with major space industry. The results are summarized as follows:

- In the UK: An opinion poll carried out in the UK in early 1980s showed that more than 50% of those under 45 and 65% of those under 25 would like a holiday in space [23].
- In Germany: Subsequent market studies conducted by Deutsches Zentrum für Luft-und Raumfahrt (DLR, German Space Agency) reported initial research indications that 4.3% of the German population was willing to spend roughly an annual salary (around several 10,000 USD in mid-1990s) for a holiday-trip into space [24].
- In England: Survey results in Southern England held in mid-2011 showed that 55% (38% male & 17% female) were very possible and possible in participating the space tourism, 36% (10.5% male & 25.5% female) were not so possible and impossible, and 9% (4.7% male & 4.3% female) were neutral [30]. Extended stay in the space hotels would become a reality in the far future. Preliminary analyses showed that excluding transportation, accommodation in the Space Hotel Berlin would cost about 100,000 USD per night [24].
- In Japan: Since 1993, the Japanese Rocket Society (JRS) had carried out its Space Tourism Study Program with many papers and reports published. In 1993, the survey of 3030 Japanese people revealed that more than 70% under 60 years old and more than 80% under 40 years old would like to visit space. Besides, 70% would be willing to pay up to three month salary for the trip. The study was done under the auspices of the Japanese National Aerospace Laboratory (NAL) and was considered convincing [31].
- In USA: Every year, tens of millions people visit the Smithsonian Air and Space Museum in Washington DC, as well as similar museums in many other countries. Various other space camps and conventions also represent the large and continuing space tourism market taking place on the Earth's surface. Earlier in the 1980s, an independent market study made in the USA on true travel to space found that over 40 million people would like to take a trip on a space shuttle, and some 55 million would like to take a cruise ship-like space trip. In total, they would be willing to pay some 900 billion USD to do so, or about 40 billion USD per year [32]. On September 16, 2014, NASA announced a critical component of Launch America, the country's highly anticipated next chapter in human spaceflight. Boeing and SpaceX share the 6.8 billion USD "space taxi" contract [33].

Then, NASA announced a plan to open the ISS for commercial business on June 7, 2019 [34]. The major purpose is to accelerate and promote a new commercial economy in low Earth orbit (LEO) for the innovations and ingenuity of USA industry. The plan attempts to establish a new economy through the mechanism of enabling use of the ISS for commercial activities, creating opportunity for private astronauts to the ISS, etc. [34].

- In Russia: Roscosmos, the Russian state space agency, is the only institute that has realized OST activities so far. Through the arrangement of an American space tourism company, Space Adventures, 7 tourists have travelled 8 times to the Russian segment of the ISS from 2001 to 2009. The first tourist was an American businessman Dennis Tito who has been reported to pay 20 million USD for the trip, and to undergo a 900 h pre-flight training in Yuri Gagarin Cosmonaut Training Center (GCTC) [5]. Russian's major purpose was to obtain budget compensation from tourists for the maintenance costs of its space station Mir [35]. Therefore, Tito's original plan was to visit Mir. After Russia decided to de-orbit Mir, he switched to visit the Russian segment of the ISS by taking a Soyuz spacecraft under successful management between Russian MirCorp and Space Adventures. When two tourists completed their visits to the ISS, Russian's space tourism was temporarily put on hold from 2003 to early 2005 due to the disaster of Space Shuttle Columbia. All Soyuz flights were reserved to support astronaut transportation between the Earth and the ISS. When the Space Shuttle returned to normal flight in July 2005, the Russian OST was resumed. Another 5 tourists successfully visited the ISS 6 times [35]. Then, since the retirement processes of Space Shuttle were started in March and completed in July 2011, all Soyuz flights needed to support astronaut transportation again. Also, the number of resident staff onboard the ISS was expanded, resulting in both the Soyuz systems and the ISS having no spare seats for tourists. Russian's OST was put on hold for the second time. In March 2015, Russia officially announced resumption of space tourism in 2018 [36]. On February 19, 2019, Roscosmos and Space Adventures signed a contract for sending two passengers on board a Soyuz spacecraft to the Russian segment of ISS in late 2021 [37]. For a general member of the public to become an OST tourist, the candidate must be trained one half year in the Russian Federal State Organization's GCTC.
- OST Developments in the Private Sector: The Phoenix concept of vertical-takeoff-and-landing (VTOL) single-stage-to-orbit (SSTO) was conceived in 1972 as a means to provide inexpensive access to space. In the 1980s, the concept was improved for use by non-astronaut passengers [38]. In September 1985, Society Expeditions signed a contract with Pacific American Launch Systems, a private company to develop the RSLV Phoenix for commercial operation in 1992. The proposed service was a 12 h flight in polar orbit using Phoenix which can carry 20 passengers with 50,000 USD ticket price. Based on the operations of one flight weekly, it represented a demand of about 1000 passengers per year. As of June 1986, some 250 people had placed deposits of 5000 USD each with Society Expeditions to book seats for 1992, meaning that the demand did exist at the level estimated by Society Expeditions [38].

Besides market surveys, the ticket price model for OST has been studied. Table 1 shows the estimated number of passengers per year versus the price at different phases in 1985 [23]. According to USD inflation rate, 1 million in 1985 is about 2.44 million in 2020. It seems that the 1985 estimation shown in Table 1 was very insufficient and was at least one order of magnitude lower than the current price. The current high price probably could explain why only 7 tourists completed 8 OST trips so far. Other factors such as individual health conditions, passing the screening, long hours training, personal availability, availability of vehicles, technological challenges, price affordability, willingness to

Table 1
Estimation of passenger number per year vs. price in 1985 [23,39].

Phase	Price (1985 USD)	Passengers/year
1) Pioneer	1) 1,000,000	50
	2) 500,000	100
2) Exclusive	1) 100,000	500-1000
	2) 50,000	5000
	3) 25,000	30,000–40,000
3) Mature	10,000	100,000–1,000,000

pay, overcoming psychological barriers are major concerns, too. But the extremely high price could be the first threshold and barrier. It might happen that wealthy enough (but not millionaire) passengers are interested, but are hesitant to take further action.

2.2. Background of suborbital space tourism

If the prosperity of aviation transportation and tourism in 1930s originated from the Orteig Prize awarded to Charles Lindberg for his unprecedented solo nonstop transatlantic flight in 1927 [40], then it would be reasonable to consider that the commercial SST was originated from the Ansari X Prize awarded to SS1 in 2004 [41]. The Ansari X Prize was an award for the first nongovernmental company successfully launching a manned reusable spacecraft into space two times within two weeks. Three basic requirements were [41]:

- The team must be private;
- To build a manned reusable spacecraft for three people, one pilot and two passengers; and
- To launch the spacecraft to reach an altitude of 100 km (62.14 miles known as the von Kármán line) and back twice within two weeks.

It was won on October 4, 2004, the 47th anniversary of the launch of Sputnik 1, by the Scaled Composites Company's Tier One Project, 8 years and 5 months after it was founded. Scaled Composites invested more than 100 million USD on the project to win the 10 million prize [41].

The flight of SS1 demonstrated that a small nongovernmental company could accomplish a major human suborbital spaceflight program. Also, it stimulated many developments of RSLVs, at least 2 in Europe and 5 in the USA. In Europe, European Aeronautic Defence and Space (EADS) with headquarters in Toulouse, France revealed in 2007 an HTHL spaceplane capable of carrying four passengers to reach a 100 km altitude [42]. After a quarter-scaled demonstrator performed a non-powered return phase flight test in Singapore in May 2014, no more news was released. The Swiss Space Systems (S3) Company in Switzerland planned to develop a suborbital shuttle named SOAR for small satellite launch, as well as for point-to-point (P2P) intercontinental passenger flights [43], but it was declared bankrupt in December 2016 [43].

Originally there were five major RSLV developers in the USA. The development work of Armadillo Aerospace teamed with Space Adventures was suspended on August 1, 2013 [44]. The developer XCOR of Lynx Marks I, II and III filed for bankruptcy on November 8, 2017 [45]. As such, there are three competing in the market currently.

- Sierra Nevada Corporation (SNC): The Dream Chaser developed by SNC was originally designed for crew and cargo transportations to suborbital and orbital altitudes. Currently, SNC is more focused on a cargo version for the ISS supply purpose, with crew transportation to ISS as the future version [46].
- Virgin Galactic: A design dedicated for commercial SST and science purposes, Virgin Galactic's SS2/WK2 is a spaceship/mother-ship combination which was almost fully flight tested in Spaceport Mojave. The SS2 is air-launched from WK2 at about 15 km altitude, and a rocket motor provides thrust for its spaceflight. It can carry two pilots and six passengers to suborbital altitude. SS2 completed the first test flight from its mother port the Spaceport America on May 1, 2020 [47]. Besides, Virgin Galactic already initiated the Astronaut Readiness Program on November 15, 2019, for its commercial astronaut customers to make pre-flight preparation [16].
- Blue Origin: The New Shepard System developed by Blue Origin is a kind of VTVL RSLV. Its 15 m^3 (530 ft^3) crew capsule can carry 6 passengers. Both its launch rocket and crew capsule are fully reusable to reduce SST ticket price. Conducted on December 11, 2019, the 12th flight test mission of the New Shepard System was a complete success. Also, the number of Blue Origin's scientific payload customers reached 100 [17].

For the 7 private companies mentioned above, the most ambitious two companies competing in the commercial SST and scientific experiment payloads markets are Virgin Galactic and Blue Origin. Both RSLVs of Virgin Galactic's HTHL type and Blue Origin's VTVL type are high technology and high cost systems, due to their high safety and high reliability requirements for human SST spaceflight. In Table 2, prices of five kinds of real or simulated commercial space travel are listed [48], where parabolic arc and balloon flights were added for reference and comparison [49]. Although the ticket price of Blue Origin (hundreds of thousands of dollars) is still to be determined [50], either real or simulated commercial space travel prices are considered to be very high, meaning that SST might attract only wealthy and highly interested passengers at this pioneer phase. It might take decades to go from pioneer to exclusive to a mature phase. Even at a mature phase after decades, the ticket price might be much higher than that shown in Table 1.

3. Characteristics of RSLV trajectories

In the designs of XCOR's Lynx, EADS′ space plane, SNC's Dream Chaser, Virgin Galactic's SS2 and Blue Origin's New Shepard System, they all need a rocket engine for spaceflight. Besides, EADS's space plane is equipped with turbofan engines for take-off and landing, and SS2 needs WK2 to carry it to 15.5 km altitude for air-launch. The typical flight profiles of SS2 and New Shepard System are presented in the following two subsections to show the three major flight phases of high-*g* acceleration, weightlessness and high-*g* deceleration.

3.1. Typical flight profile of HTHL SS2

Fig. 1 shows typical flight profile of spaceplane SS2, it is carried under the mother airplane WK2 to about 15.5 km altitude in the take-off flight phase to point 1, and is released with some drop to point 2 for air launch. A rocket engine equipped inside its belly is ignited to provide high thrust between points 2 and 3. This is the high-*g* acceleration flight phase with high levels of vibration and noise. The rocket engine burns out at point 3, but high thrust of the rocket engine already provides SS2 with high residual upward speed. After point 3, SS2 continues to go up to the highest point 4 with the high residual speed. From point 3 to 4 to a certain altitude before point 5, SS2 is in free fall. Only the Earth gravity force and aerodynamic force remain while the latter is negligibly small at such high altitude with very low atmospheric density. Therefore, SS2 and passengers onboard experience the free falling “weightlessness” flight phase. Then SS2 starts to touch the denser atmosphere gradually with very high reentry speed before point 5. The aerodynamic force becomes more and more pronounced gradually to decelerate SS2 until a certain altitude between points 5 and 6. This is the high-*g* deceleration flight phase. In order to reduce the effects of both aerodynamic deceleration and heating, SS2 uses the so-called feather configuration to increase drag and uses spiral down flight from point 5 to 6. Finally it resumes the un-feathered configuration at point 6 and glides from there to a horizontal landing [51].

Table 2
Five kinds of real or simulated commercial space travel and prices.

Developer/Operator	OST or SST or neither	Price (USD)
SpaceX	OST	>20 million
Blue Origin	SST	(TBD)
Virgin Galactic	SST	250,000
Zero Gravity Corporation	Neither, parabolic arc flight	5400+tax
World View Enterprises	Neither, balloon, 30 km altitude	75,000

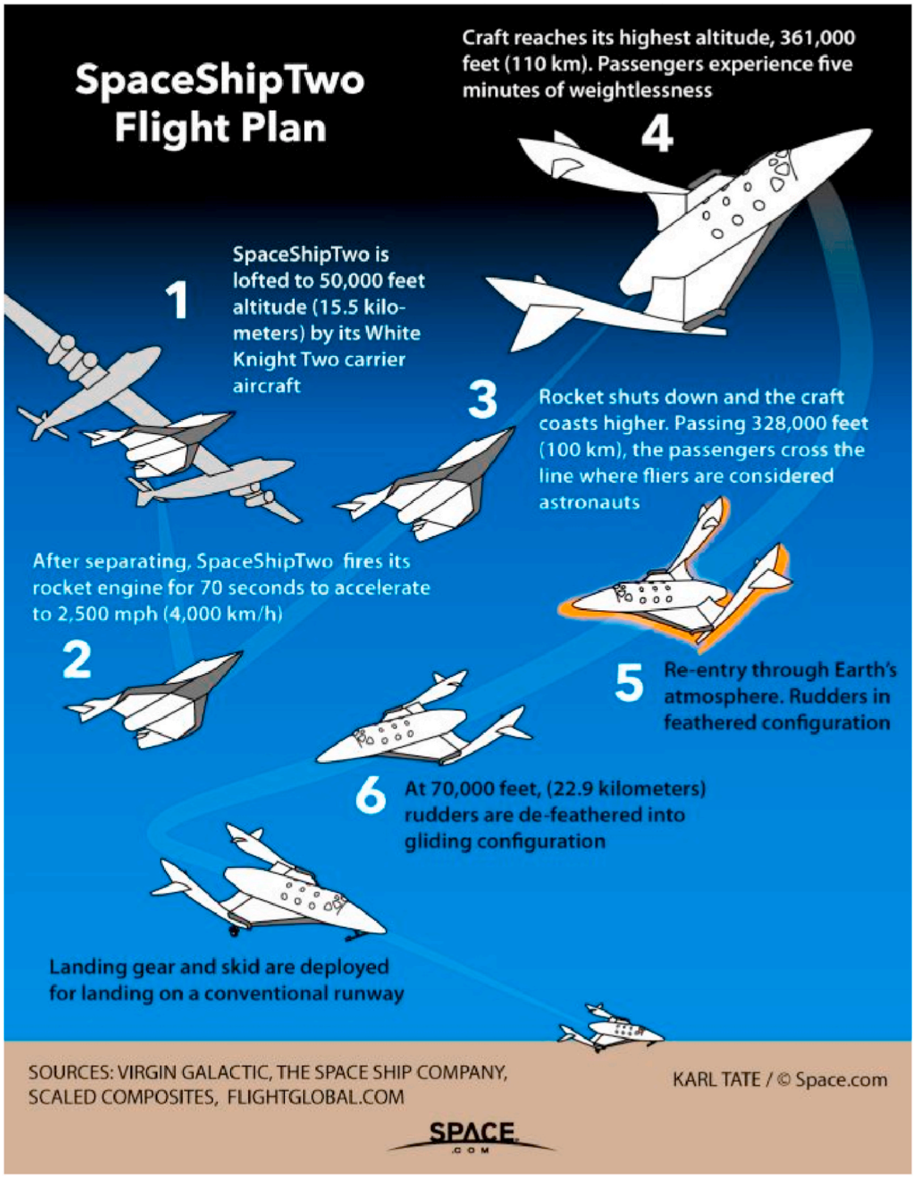

Fig. 1. Flight plan of SS2 (figure credit: Karl Tate [51]).

3.2. *Trajectory dynamics of VTVL New Shepard*

The flight plan of the VTVL New Shepard System is shown in Fig. 2 [18]. The total flight time is about 11 min, consisting of about 2 min thrusting, 4 min coasting and 5 min descending phases, respectively. After burnout of the propulsion module, the crew capsule is separated to continue its SST flight. It then reenters the denser atmosphere and is brought to the ground by using 3 parachutes. On the other hand, the used rocket engine lands vertically using its own landing thrust and is recovered for reuse. The New Shepard System has a crew capsule of 15 m^3 to accommodate 6 passengers and a propulsion module to provide 490 kN maximum thrust with 110 s burning time. The total height and mass are about 19 m and 29,500 kg, respectively. Therefore, the initial g-value is 490,000/29,500/9.81 = 1.69 and is about 6 times that of a typical-wide body airplane. And the final g-value with maximum thrust could be as high as 490,000/11,000/9.81 = 4.54 or about 16 times that of a typical wide-body airplane. The burnout and highest altitudes are about 38 km and 110 km, respectively. The vertical velocity component at the burnout point is about 1189 m/s, and the flight time from there to the highest point is about 121.2 s. The coasting phase starts at the point where the crew capsule is separated. After the highest point it starts to reenter. The high-g deceleration flight phase is encountered upon reaching the denser atmosphere at lower altitude. Finally the parachutes are deployed for vertical landing [18,52].

4. Contents of SST tourist screening and examination items

In Reference [53], a four-step guideline has been proposed for a decision on the fitness and preparation of SST passengers. It suggests using the medical screening and examination criteria of professional pilots as the first step. A questionnaire with medical interview and go-no-go criteria could provide a preliminary estimation. The second step is physical examination which emphasizes the adjustment of the applicant to the SST environment. The third step is an intensive training program for the passenger to adapt to the SST challenge. Then the fourth step is a re-evaluation should there be a delay for any reason between the medical examination and actual travel. However, it might happen that only a very limited number of passengers could pass the evaluation under such rigorous criteria.

Before May 1, 2017, the FAA of the USA required private,

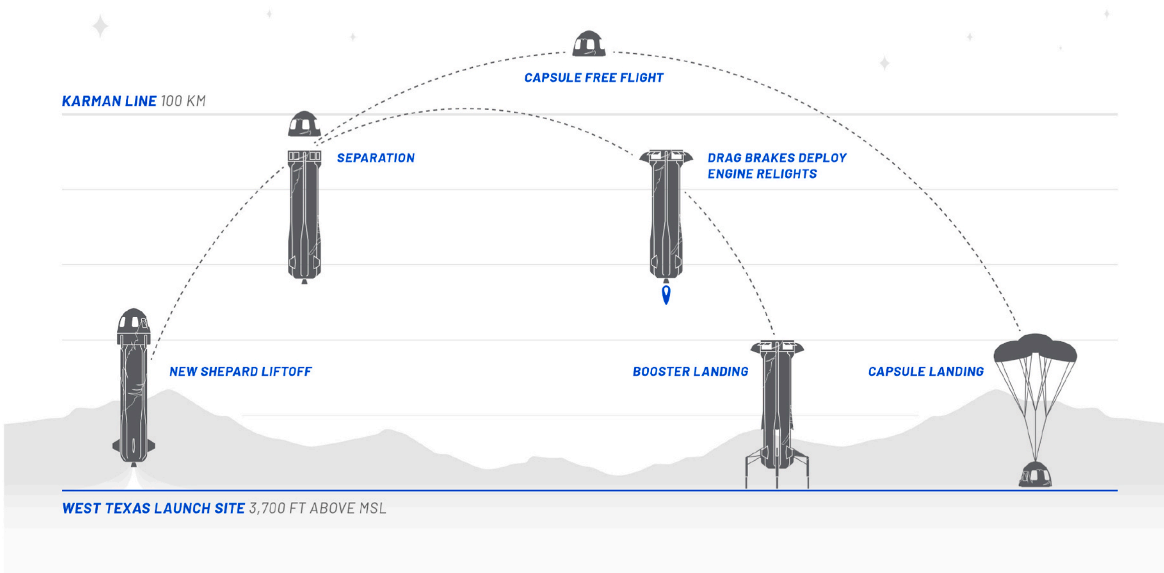

Fig. 2. Flight plan of New Shepard System (figure credit: Blue Origin [18]). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

recreational, and student pilots, as well as flight instructors, to meet the requirements of having a valid third class medical certificate. They needed to apply online and to have a physical examination by an FAA-designated aviation medical examiner. A medical certificate is valid for two and five years for pilots age 40 or over and for pilots age below 40, respectively. On January 9, 2017, the FAA issued a "Final Rule" which became effective on May 1, 2017, that allows general aviation pilots to fly without holding an FAA medical certificate if they meet certain requirements outlined in the congressional legislation [54]. One of the requirements is that they need to complete a medical education course, undergo a medical examination within the past 48 months, and comply with aircraft and operating restrictions, e.g., cannot operate an aircraft with more than six people onboard and the aircraft must not weigh more than 6000 pounds (2722 kg). Also, the airspeed of the aircraft can not exceed 250 knots or 288 miles per hour (464 km/h) [55]. It is considered in this paper that this "Final rule" could be proposed as a compromise and used as the guidelines for SST tourist examination and screening criteria.

The following medical education course and comprehensive medical examination checklist have been modified to fit the SST characteristics and passenger requirements. In the following sub-paragraphs 4.1 to 4.5, some contents were directly or partially cited from Refs. [54,55] for completeness and the convenience for readers.

4.1. Medical education course

For the commercial SST passenger, a face-to-face medical education course is considered to be a requirement. The course should teach passengers how to conduct medical self-assessments, to identify warning signs of potential serious medical conditions, to identify risk mitigation strategies for medical conditions upon occurring, etc. [54,55]. A test is recommended with a successful certificate issued to passengers who participate.

4.2. Section for the passenger to complete

The passenger needs to complete the items with a signature to affirm that the answers provided are all true and complete, that the prohibition from SST travel exists under any medically disqualifying condition, and that the passenger is aware of the regulations and applicable laws that permit SST travel [54,55].

4.3. Instructions for the passenger

It requires the checklist to contain a section with instructions for the passenger to provide the completed checklist to the physician performing a comprehensive medical examination.

4.4. Instructions for the physician

It requires the checklist to include a section for the physician to complete, that instructs the physician to perform a clinical examination of the passenger including: head (face, neck, scalp, nose, mouth, throat, ears and hearing, eyes and vision, pupils, ocular motility), lungs, chest, heart and vascular system, abdomen, viscera, anus, skin (body marks, scars, tattoos), genitourinary system, upper and lower extremities, spine, musculoskeletal, lymphatics, neurologic, psychiatric, blood pressure, general systemic, etc. [55]. The physician is requested to sign the checklist after completion of the examination, to provide the date of examination, personal contact information, and medical license number [55].

4.5. Special rules for cardiovascular and mental health conditions

A special medical examination is required when a passenger has any of the following: (1) A mental health disorder, (2) A neurological disorder, and (3) A cardiovascular condition [55].

The above listed items, after proper review and modification, could be applicable to SST passengers. For an SST pilot, more rigorous criteria such as those applicable to commercial transport pilots presented in Refs. [53] could be properly modified and adopted.

5. Potential business opportunities in SST

Along with starting commercial operations of SST in the private companies, development of potential research and business opportunities could be expected in the future. Since launches for SST will take place from spaceports over the whole world, a standard of operation (SOP) for medical examination and training program as well as acceptance criteria for passengers from the general public must be developed [53]. Establishment of passenger medical test and training centers will be mandatory and very helpful for the prosperous development of the SST industry.

5.1. Business opportunities in RSLV development

The development of RSLV is a potential business opportunity. But both the barrier and threshold of entry are very high. Technology and investment are more difficult to reach. Companies seeking to enter the new RSLV industry need to pay particular attention to how difficult these barriers and technologies are to overcome and how much time and capital will be required. In general, these barriers and technologies include: economies of scale, capital requirement, intellectual property, government policy, and competition strategy [56].

5.2. Business opportunities in spacelines for SST and P2P transportation

Although this is also a business opportunity of high barriers and technologies, at least it is not as high as the RSLV development. As of the current development status, Virgin Galactic and Blue Origin could be the first two commercial suborbital spacelines in the world. Once they start commercial SST and scientific research operations, the spacelines are formed. When the business becomes popular with passenger increases to a large number, current airline companies could be expanded and promoted from pure aviation transportation and tourism to include commercial SST business, or new spacelines could be established. Instead of developing RSLV, they just buy or rent the RSLVs for commercial SST business operations. In the longer future, service in long distance P2P transportation within much a shorter time could become possible [57].

5.3. Business opportunities in spaceport

Baikonur could be considered as the first commercial spaceport in the world. The first privately paid millionaire tourist Dennis Anthony Tito travelled from there to the Russian segment of the ISS in 2001 using Roscosmos' Soyuz rocket and spacecraft systems [58]. The first spaceport exclusively dedicated to SST purposes is the Spaceport America as shown in Fig. 3. Located in the Jornada del Muerto desert basin in New Mexico, USA, the Spaceport America calls itself "where we offer the world an invitation to space". Officially declared open on October 18, 2011, construction of the very first temporary launch facility began on April 4, 2006 [59]. Compared with Spaceport America, the Mojave Air and Space Port located in Mojave, California is the first facility to be certified and licensed as a spaceport by the FAA of the USA for horizontal launches of reusable spacecraft on June 17, 2004 [60]. Spaceport America is the mother port of SS2 and WK2. Virgin Galactic will start commercial SST operations here. Some other nations are interested in becoming the first country to operate commercial SST from within their own borders.

In Europe, Spaceport Sweden located in Kiruna, 145 km above the Arctic Circle, could be considered as a very ambitious one so far. For tourists, the iron mine town is already a world famous destination because of its ice hotel, midnight sun in summer and northern lights in winter. By taking advantage of a large wild area and minimal air traffic, the Spaceport Sweden Company tried to build the first commercial spaceport of Europe in Kiruna. It attempted to make Kiruna the first SST station of Virgin Galactic outside the USA. Currently, aerial tours of the northern lights via airplane are offered. More activities under consideration or planning include free-fall wind tunnel experience, high-altitude balloon launch with a retrievable camera, flight in an experimental aircraft and even astronaut training. The Esrange Space Centre of Swedish Space Corporation is on the east side of Kiruna [61].

Besides the above examples, many spaceports are either under planning or in conceptualization phases around the world.

5.4. Business opportunities in passenger screening and training

Exemplified by the spaceplanes SS2 and New Shepard System, the whole flight profile includes high-*g* acceleration (about 3g), weightlessness and high-*g* deceleration (about −4.5g) phases within about 11–12 min [18]. The SST tourists have a very different feeling and experience then the current commercial traffic flight during a rather short time. Therefore, the physiological and neuro-vestibular education, training and screening are essential for SST passengers. They are going to be anxious and feel motion sickness. Their bodies are under enormous stress. There will be problems for those people who have heart risk, back trouble, diabetes, joint issues, etc. On the other hand, they will also suffer space motion sickness during the so-called microgravity or weightlessness while participating in SST for the first time. It is due to sensory conflicts on not knowing what is up or down or left or right. In fact, there is no up or down or left or right in space. It feels like vertigo coming on. At the same time, vomiting could happen rather suddenly when the rocket thrust stops [62].

The National AeroSpace Training and Research (NASTAR) Centre of Environmental Tectonics Corporation (ETC) has teamed up with the FAA as well as University of Texas Medical Branch (UTMB) to study the effects of simulated space travel on people with common ailments, such as high blood pressure, heart disease, diabetes, lung disease, asthma or a history of back or neck problems. Spacelines must teach future passengers to deal with the disorienting sensations of zero gravity as well as emergency procedures. Besides, they also need to learn survival skills in space such as using oxygen canisters [62,63].

Fig. 3. SS2 carried by WK2 was relocated from Mojave Air and Space Port to Spaceport America (figure credit: Virgin Galactic [14]).

Table 3
Commercial, science, research, technology and education payloads onboard New Shepard missions #7 to #12.

Mission	Date & Altitude	Payloads, Applications and Sponsors
#7 (M7)	December 12, 2017 (about 100 km)	Total 12 payloads, including: (1) Zero-Gravity Glow Experiment (ZGGE): Purdue University & Cumberland Elementary School with Arete STEM; (2) Arduino Nano microcontroller and art project: DCS Montessori Middle School with DreamUp; (3) Cell Research Experiment in Microgravity (CRExIM): Embry-Riddle University-Daytona Beach, University of Texas Health Science Centre at San Antonio & Medical University of South Carolina with Arete STEM; (4) Expression of genes in tumor growth: Embry-Riddle University-Daytona Beach, Grand Canyon University & Thermo Fisher Scientific with Arete STEM; (5) JANUS research platform: Applied Physics Laboratory (APL), Johns Hopkins University; (6) Evolved medical microgravity suction device: Orbital Medicine with Purdue University, funded by NASA Flight Opportunities Program (FOP) [68]; Etc.
#8 (M8)	April 29, 2018 (107 km)	Total 30 payloads, including: (1) suborbital flight experiment monitor-2 (SFEM-2): NASA Johnson Space Centre; (2) Schmitt Space Communicator Xperimental (SC1-x): Solstar (Santa Fe, New Mexico); (3) Daphnia: University of Bayreuth with Das Zentrum für angewandte Raumfahrttechnologie und Mikrogravitation (ZARM), funded by DLR; (4) EQUIPAGE: Otto von Guericke University with ZARM, funded by DLR; (5) EUPHORIE: University of Duisburg-Essen with ZARM, funded by DLR [69]; Etc.
#9 (M9)	July 18, 2018 (120 km)	Total 12 payloads, including: (1) Same as (2), M8; (2) GAGa (Granular Anisotropic Gases): Otto-von-Guericke University with OLYMPIASPACE, funded by DLR; (3) Same as (1), M8; (4) condensed Droplet experiment for NASA in suborbital spaceflight (ConDENSS): Purdue University, funded through NASA FOP; (5) APL Electromagnetic Field Experiment: APL, Johns Hopkins University, funded through NASA FOP; (6) Vibration isolation platform data logger: Controlled Dynamics, funded through NASA FOP; (7) mu Space-1: mu Space Corporation (Bangkok, Thailand); (8) "Fly My Stuff" program: A suite of payloads from Blue Origin employees; Etc [70].
#10 (NS-10)	January 22, 2019 (107 km)	This test flight mission was dedicated to NASA FOP. Total 8 NASA-supported experiment payloads aimed at advancing in-space technologies crucial for future exploration [71].
#11 (NS-11)	May 2, 2019 (105 km)	Total 38 payloads, including: (1) Orbital Medicine: Dr. Marsh Cuttino, funded by NASA FOP; (2) Temperature fluctuations test in microgravity: New Century Technology High School, by a group of students from Huntsville, Alabama. (3) MIT Media Lab Space Exploration Initiative: Built by the MIT Media Laboratory with artists, engineers, scientists, and designers [72].
#12 (NS-12)	11 Dec '19 (about 100 km)	3 payloads, including: (1) Imaging and analyzing genes changes of Arabidopsis thaliana plants: University of Florida in Gainesville; (2) Orbital Syngas Commodity Augmentation Reactor (OSCAR): Kennedy Space Centre (Florida), NASA; (3) Thousands of postcards: From students around the world sponsored by several student art experiments as part of collaboration with the rock band OK Go [73].

Major preparation and training for SST passengers include medical examination, weightlessness and high-*g* trainings. Better simulation guarantees better quality and feeling in actual flight. Usually three days are required for the training. NASTAR has designed a two-day basic training course through tailoring and rearrangement. Its purposes are to relieve the expected huge amount of SST passengers and to provide the passengers necessary experiences. There are two prerequisites for passengers to take part in the training. First is the FAA class 3 certificate or its equivalence. Second is that the passenger is in good health and able to join in all activities [62]. Major contents are classroom courses, training and simulation. In day one, it uses an altitude chamber to give the altitude physiology training. Then in day two, there are centrifuge and space flight simulation trainings. Trainees would learn about potential impacts of space flight on the human body, spirit and emotion. They would be trained to use a spacesuit, life support equipment and the space systems.

The SST tourists would be from a general population of various cultural background, age, gender, and health conditions. They all need to withstand physical loads of spaceflight such as acceleration force, deceleration force, microgravity, vibration, noise and radiation. In particular, the three flight phases come one by one within a short duration for just about 11–12 min. When the SST market becomes popular and prosperous in the future, many centers for screening, examination and training like NASTAR must be established.

5.5. *Business opportunities in travel agency*

So far, Space Adventures founded in 1998 is the sole private spaceflight company in the world, and the only company currently providing OST opportunities for private astronauts to fly to and live in space. From 2001 to 2009, it arranged eight spaceflights for seven privately paid passengers to the ISS using flight-proven Russian space vehicles. Currently, it has an agreement with SpaceX to fly two private citizens and one professional cosmonaut on a free-return trajectory around the far-side of the Moon in the early 2020's [64,65].

In SST, both Virgin Galactic and Blue Origin are selling tickets by themselves [66,67]. In other words, besides developing the RSLVs, they are also doing the travel agency business at this early beginning phase. However, when SST becomes popular and the business is prosperous in the future, the model of current aviation tourism would be used. Most of the business would be shared by the current travel agencies. New travel agencies might be formed to provide more services such as passenger screening, evaluation, training, etc.

As mentioned above, Virgin Galactic and ASI announced on December 18, 2017 that they had signed a Letter of Intent to secure a full suborbital flight on Virgin Galactic's SS2 for scientific research in 2019 at Spaceport America in New Mexico [9]. Obviously this launch has been postponed, but it meant an initiative in any case. Then, as the Italian aviation authority has designated the Taranto-Grottaglie Airport as the future home for HTHL spaceflight in Italy, ALTEC, Sitael, Virgin Galactic and The Spaceship Company signed a framework agreement on July 6, 2018 that intends to bring Virgin Galactic's commercial spaceflights to Italy [10].

On December 12, 2017, Blue Origin sent the first batch of commercial payloads to suborbit at the 7th test flight mission (M7) of New Shepard. The batch consisted of 12 commercial, research and education payloads with full FAA license [68]. Table 3 presents the commercial, science, research, technology and education payloads onboard New Shepard test flight missions from numbers 7 to 12. Blue Origin announced the total number of these payloads has already reached 100. All payloads came from NASA, DLR, universities, private companies, and even students of high and elementary schools, exemplifying that many business opportunities in this area might be developed.

As early as June 2013, NASA had already announced that past prohibitions about flying people on commercial suborbital vehicles would be lifted. Then on December 19, 2017, it announced that as commercial suborbital vehicles capable of carrying both payloads and people prepare to enter service, NASA would be willing to consider allowing agency researchers or payload specialist funded by its FOP to fly on those vehicles. Blue Origin's New Shepard vehicle is already carrying research payloads, including those for FOP, but without people on board. However, the vehicle will be able to support missions carrying payloads and people in the future. Virgin Galactic's SS2 vehicle will also fly research payloads accompanied by a payload specialist [74].

5.6. Business opportunities in art, styling and design

Furthermore, the SST business opportunities can even be extended to the aspects of art, styling and design [75]. The author of References [76, 77] tried to set forth the idea that "the universe works to connect experts between and across different disciplines" [76], and the Uncertain Garden idea designed for renovating a space at IdeaSquare in Conseil Européen pour la Recherche Nucléaire (CERN) [77]. Many kinds of peripheral commercial merchandise could be designed and manufactured to form a very special and unique market. Actually, the Blue Origin shop is open already.

5.7. Other business opportunities

There are still many other business opportunities such as software development and improvement [78]. Many kinds of software are required to analyse all kinds of flight data from RSLV to passengers. Well designed and developed software could analyse the 'big data' efficiently to improve hardware performance and SST service quality in many aspects. Most importantly, health conditions of both RSLVs and passengers could be more effectively monitored to enhance flight safety. In legal and regulations areas, there are new businesses to study and settle all issues related to SST.

6. Discussion and limitations

Starting in the late 1920s, it took several decades for aviation transportation and tourism to reach prosperity and maturity stretching across the piston engine and jet engine eras [79]. The progress from aviation tourism to SST, and in particular for SST to be prosperous and mature, several decades up to the 2030s and the 2040s could be needed, too. From the time Virgin Galactic announced offering trips to suborbital space in 2004 [80] and unveiling SS2 in 2009 [81], 16 and 11 years have passed, respectively. Many countries might be interested in operation of the SST business, but have very limited and insufficient infrastructures, except the USA. Besides RSLV, the required infrastructures include market surveys, feasibility and viability evaluations, policy and regulations, spaceport, spacelines, passenger screening and examination systems, passenger training facilities, safety measures and insurance, etc.

Since there are still no SST flight data about passengers up to now, FAA's Final rule [55] was proposed to be the necessary criterion in this paper for passengers from the general public. Compared with NASTAR's curriculum [62], FAA's Final rule might be more proper than that proposed in Ref. [55], and could be helpful in the development of SST industry. These criteria are considered to be lower and less rigorous than the professional commercial pilot criteria proposed in Refs. [53]. An argument might be raised that risk might occur for those passengers in between. Usually necessary conditions do not mean sufficient conditions, and the criteria proposed in this paper are not considered to be sufficient conditions. Nevertheless, it is hoped that these proposed criteria could provide a useful reference. For business opportunities in the applications of RSLV, two major aspects are in SST and experiments for scientific payloads. Although the weightlessness flight phase is just about 5 min, there are the advantages of short turn-around time, easy approach for instruments and experimenters, reasonable prices, more flexibility in interfaces, more flexibility for different industrial and academic levels, etc.

However, many challenges still lie ahead to go from aviation tourism to SST. This paper has just given preliminary studies with a compromise screening package proposed and business opportunities presented. There are limitations in this study and more research must be completed in the future. According to Ref. [82,83], about 95% of passengers who have taken the NASTAR training course have shown no problems. Therefore, it would be a reasonable assumption that all professional pilots could pass the Final rule proposed in this paper. Then, another question is how much danger might be caused by lowering the screening criteria? Therefore, the following topics should be further studied in the future:

- How many people who are able and willing to pay tens of thousands USD for SST ticket price could and could not pass the professional pilot medical screening?
- If the development of the SST market is not as expected or very limited in the future [84,85], what would happen or what could be the next new emerging merchandise in SST?
- How to evaluate the danger which could be put on passengers by lowering the medical requirements from professional pilot tests?
- To establish a complete standard operation procedure for passengers from pre-flight to post-flight adaptions.
- To study and review worldwide readiness in the related issues: market demand, national policy, infrastructures, legal and regulations, insurance, etc.
- How to efficiently open the SST market if everything goes on smoothly in the future?

No matter that there are still many concerns in the emerging commercial RSLV and SST industry, particularly in the terms of feasibility and viability, highly interested passengers who could afford and have the willingness to pay about 25 thousand USD, still could have high hopes for SST. It is expected that this industry could go from pioneer to exclusive to mature phase within two to three decades, i.e., from 2020s to 2030s or 2040s.

7. Conclusions

Like aviation tourism, SST should open to the general public without constraints on age, gender, education level, wealth, and so on. However, there is a big gap for general passengers to go from aviation tourism to SST. Major challenges are the three very different flight phases which do not occur in aviation flight, the high-g acceleration (more than $+3\,g$), the weightlessness (zero g) and the high-g deceleration (more than $-4.5\,g$). Even more, these three phases of flight come one-by-one within 11–12 min consecutively with each phase lasting a few minutes. As a consequence, pre-flight screening, examination, education, training and adaptation, as well as post-flight adaptation for passengers would be mandatory. In this study, the FAA's new policy "Alternative pilot physical examination and education requirements - Final rule, 14 CFR

Parts 61, 68, and 91" that became effective on May 1, 2017 was followed and tailored to fit the characteristics of SST. Then, the business opportunities accompanying the new emerging SST industry were discussed. Discussions presented were business opportunities from the aspects of RSLV development, spacelines, spaceport, passenger screening and training, travel agency, scientific research, software development, and legal and regulations study. For more in-depth insight into the new SST industry, qualitative and quantitative analyses would be helpful and necessary in the future.

Declaration of competing interest

Author declares that there is no conflict of interest in this paper.

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References

[1] F.G. von der Dunk, Space tourism, private spaceflight and the law: key aspects, Space Pol. 27 (2011) 146–152, https://doi.org/10.1016/j.spacepol.2011.04.015.
[2] T.F. Rogers, "Space tourism – its importance, its history, and a recent extraordinary development,", May 2000, pp. 20–25, 13th Humans In Space (HIS) Symposium, Fira, Santorini, Greece,.
[3] BBC, "Elon Musk unveils first tourist for SpaceX 'Moon loop',", Science & Environment (2018).
[4] L. Grush, The easiest way for Elon Musk to raise money for SpaceX might be tourism, Verge (2018).
[5] BBC News, " Profile, Tito the Spaceman," *Sci/Tech*, BBC Homepage, UK, 2001. http://news.bbc.co.uk/2/hi/science/nature/1297924.stm. (Accessed 2 May 2020).
[6] M. Sheetz, "A Trip to the International Space Station Will Cost Tourists $52 Million," *Investing in Space*, CNBC, 2019.
[7] M. Wall, "How SpaceShipOne and X Prize Launched Commercial Spaceflight 10 Years Ago," *Spaceflight*, Space.com, 2014.
[8] J. Foust, Virgin Signs Agreement with Saudi Arabia for Billion-Dollar Investment, " *spacenews.com*, 2017.
[9] Virgin Galactic, "Italian Space Agency (ASI) signs letter of intent for Virgin Galactic research flight, Virgin Galactic News (2017).
[10] Virgin Galactic, "ALTEC, SITAEL, Virgin Galactic & the Spaceship Company sign framework to bring commercial spaceflights to Italy, " Virgin Galactic News (2018).
[11] Blue Origin, New Shepard mission NS-12 updates, " Blue Origin News (2019).
[12] T. Gray, "Blue Origin's New Shepard Conducts 12th Test Launch, " *SPACEFLIGHT.com*, 2019.
[13] M. Wall, "Virgin Galactic's VSS Unity space plane arrives at New Mexico spaceport,", Spaceflight, Space.com (2020).
[14] Virgin Galactic, Virgin Galactic Welcomes SpaceShipTwo Unity to Spaceport America, " *Virgin Galactic News*, New Mexico, 2020.
[15] M. Wall, "Virgin Galactic gearing up to start selling suborbital spaceflight tickets again,", Spaceflight, Space.com (2020).
[16] Virgin Galactic, Virgin Galactic kicks off astronaut readiness program, " Virgin Galactic News (2019).
[17] Blue Origin, New Shepard mission NS-12 updates, " Blue Origin News (2019).
[18] Blue Origin, "Your 11-minute Flight to Space: New Shepard Mission Profile," *Blue Origin* news.
[19] F. Karmali, M. Shelhamer, Neurovestibular considerations for suborbital space flight: a framework for future investigation, J. Vestib. Res. 20 (Nos. 1–2) (2010) 31–43.
[20] M.F. Reschke, E.F. Good, G.R. Clément, Neuro-vestibular symptoms in astronauts immediately after space shuttle and International Space Station missions, Journal of the American Academy of Otolaryngology – Head and Neck Surgery Foundation 1 (4) (2017), 1–8.
[21] M.F. Reschke, G. Clément, Verbal reports of neurovestibular symptoms in astronauts after short-duration space flight, Acta Astronaut. 152 (November) (2018) 229–234.
[22] S. Benjamin, Exploration to exploitation: an industry analysis of suborbital space tourism, *New Space:* The Journal of Space Entrepreneurship and Innovation, 6 (No. 1) (March 2018) 87–98.
[23] P.Q. Collins, D.M. Ashford, Potential economic implications of the development of space tourism, Acta Astronaut. 17 (No. 4) (April 1988) 421–431.
[24] M. Reichert, The Future of Space Tourism, " paper IAA-99-IAA.1.3.07, 50th IAC, Amsterdam, The Netherlands, October 1999, pp. 4–8.
[25] Futron Corporation, Space Tourism Market Study: Orbital Space Travel & Destinations with Suborbital Space Travel, " Futron Corporation, Bethesda, Maryland, USA, 2002 (viewed on 19 June 2020), https://www.spaceportassociates.com/pdf/tourism.pdf.
[26] Futron Corporation, Suborbital Space Tourism Demand Revisited, 2006 (viewed on 19 June 2020), https://www.rymdturism.se/images/pdf/Futron-Suborbital-Space-Tourism-Demand-Revisited-Aug-2006.pdf.
[27] FAA/AST, The U.S. Commercial Suborbital Industry: A Space Renaissance in the Making, " FAA/AST, Washington, DC, USA, 2011.
[28] The Tauri Group, "Suborbital Reusable Vehicles: A 10-year Forecast for Market Demand," the Tauri Group, FAA/AST and Space Florida, Washington, DC, USA, 2012.
[29] M. Guerster, E. Crawley, R. de Neufville, Commercial viability evaluation of the suborbital space tourism industry, New Space 7 (No. 2) (June 2019) 79–92, https://doi.org/10.1089/space.2018.0038.
[30] M.V. Reddy, M. Nica, K. Wilkes, Space tourism: research recommendations for the future of the industry and perspectives of potential participants, Tourism Manag. 33 (No. 5) (2012) 1093–1102.
[31] P. Collins, R. Stockmans, M. Maita, Demand for Space Tourism in America and Japan, and its Implications for Future Space Activities, " 6th ISCOPS, Marina Del Rey, California, USA, 1995, p. 8, 6.
[32] Office of Technology Assessment, Civilian space stations and the U.S. future, in: Space, Congress of the United States, OTA-STI-241, Washington D.C., 1984, p. 118.
[33] A. Walker, "Boeing and SpaceX will share NASA's $6.8 billion space taxi program, Gizmodo.com (2014).
[34] NASA, NASA opens international space station to new commercial opportunities, private astronauts,", NASA Release 19-044 (2019).
[35] Wikipedia, "Space tourism," Wikipedia, https://en.wikipedia.org/wiki/Space_tourism#cite_note-42 (viewed on 2 May 2020).
[36] Phys.org, Russia to resume space tourism in 2018, Phys.org (2015).
[37] Space Adventures, Roscosmos and Space Adventures sign contract for orbital space tourist flight: two spaceflight participants to launch to the ISS in 2021, " Space Adventures news (2019).
[38] G.C. Hudson, "History of the Phoenix VTOL SSTO and recent developments in single-stage launch systems," paper AAS 91-643, Proceedings of 4th AAS/JRS/CSA Symposium, ISCOPS, 17-20 November 1991, Kyoto, Japan, AAS Vol. 77, pp. 329-351.
[39] Y.-W. Chang, J.-S. Chern, A study and discussion on the cost issue of suborbital and orbital space tourism, J. Tourism Hospit. 7 (Issue 1) (January 2018), https://doi.org/10.4172/2167-0269.1000334.
[41] V. Goel, "Case study: Orteig Prize – incentive prize competition, Goel Insights: Innovation, Strategy, Technology, Health (2011), Version 1.0.
[40] M. Wall, "How SpaceShipOne and X prize launched commercial spaceflight 10 years ago,", Spaceflight, Space.com (2014).
[42] E. Howell, Spaceplane: suborbital vehicle for space tourism & science, " Space.com (2016).
[43] J. Turl, Swiss Space Systems declared bankrupt, Baytoday.ca (2016).
[44] J. Foust, Armadillo Aerospace suspends vehicle development work, Space News (2013).
[45] J. Foust, XCOR Aerospace files for bankruptcy, Space News (2017).
[46] N.T. Redd, "Sierra Nevada's Dream Chaser space plane could launch astronauts one day, Space.com (2019).
[47] Virgin Galactic, "Virgin Galactic's SpaceShipTwo completes first flight from Spaceport America, Virgin Galactic news (2020).
[48] J. Chang, "Space Tourism: how much should you save for a space trip?" Reviews for Business, FinancesOnline, https://financesonline.com/space-tourism-how-much-should-you-save-for-a-space-trip/(viewed on 6 May 2020).
[49] Zero Gravity Corporation, "ZERO-G Experience® pricing," Zero Gravity Corporation website, https://www.gozerog.com/index.cfm (viewed on 6 May 2020).
[50] A. Boyle, "Blue Origin's CEO Says First Space Trips on New Shepard Will Cost 'hundreds of Thousands of Dollars', " Space, GreekWire, 2019.
[51] K. Tate, How Virgin Galactic's SpaceShipTwo Passenger Space Plane Works (Infographic), " *space.com*, 2012.
[52] Y.-W. Chnag, "From Aviation Tourism to Suborbital Space Tourism: a Study and Discussion on Tourist Screening Criteria and Business Opportunities, paper IAC-18-D2.9-D6.2.2, 69th International Astronautical Congress (IAC), Bremen, Germany, 2018.
[53] G. Kluge, C. Stern, M. Trammer, I. Chaudhuri, P. Tuschy, R. Gerzer, "Commercial suborbital space tourism – proposal on passenger's medical selection, Acta Astronaut. 92 (No. 2) (2013) 187–192.
[54] FAA, FAA issues general aviation medical rule, " FAA News & Updates (2017).
[55] FAA, Alternative pilot physical examination and education requirements - final rule, 14 CFR Parts (2017), 61, 68, and 91 (Docket No.: FAA-2016-9157; Amdt. Nos. 61-140, 68-1, and 91-347), RIN 2120–AK96, FAA, Department of Transportation (DOT), USA, 9 January.
[56] S. Benjamin, Exploration to exploitation: an industry analysis of suborbital space tourism, *New Space*: The Journal of Space Entrepreneurship and Innovation 6 (No. 1) (2018) 87–98.
[57] S. Dinkin, Could suborbital point-to-point really be worth $20 billion a year in 2030? The Space Review, Spacenews (2019).
[58] C. Morgan, "Shuttle – Mir: the United States and Russia Share History's Highest Stage," *the NASA History Series*, NASA SP-2001-4225, National Aeronautics and Space Administration, Lyndon B. Johnson Space Centre, Houston, Texas 77058, USA, 2001.
[59] Spaceport America, "Welcome to spaceport America," Spaceport America, http://spaceport america.com/(viewed on 7 May 2020).

[60] Y.-W. Chang, J.-S. Chern, "A Study on Potential Spaceports for Suborbital Space Tourism in Taiwan," Paper IAC-19-D6.3.10, 70th International Astronautical Congress, Washington, D.C., USA, 21 – 25 October 2019; also, Acta Astronautica (under review).
[61] D. Messier, Spaceport Sweden wins Kiruna lapland award, Parabolic Arc (6 February 2015).
[62] NASTAR, "Suborbital space training – suborbital space flight participant," NASTAR, https://www.nastarcenter.com/aerospace-training/space/passengers/suborbital-space-training (viewed on 7 May 2020).
[63] C.S.T. Coe, Federal Aviation Administration Centre of Excellence for Commercial Space Transportation Year 8 Annual Report Executive Summary, " Centre of Excellence for Commercial Space Transportation (COE CST), FAA, USA, 2018.
[64] Space Adventures, Circumlunar mission, Space Adventures News (2018).
[65] Space Adventures, Space Adventures Announces Agreement with SpaceX to Launch Private Citizens on the Crew Dragon Spacecraft, " *Space Adventures Press Releases*, 2020.
[66] M. Wall, Virgin Galactic Gearing up to Start Selling Suborbital Spaceflight Tickets Again, " *SPACE.com*, 2020.
[67] J. Foust, Blue Origin still holding off on New Shepard ticket sales, Space News (2019).
[68] Blue Origin, "First Commercial Payloads Onboard New Shepard, " *Blue Origin News*, 2017.
[69] C. Bergin, Blue Origin Conducts New Shepard Test Flights with Commercial Payloads, " N*ASASpaceFlight.com*, 2018.
[70] Blue Origin, Payload Manifest on Mission 9, " *Blue Origin News*, 2018.
[71] A. Boyle, Blue Origin sends NASA-backed payloads to space and back on suborbital rocket ship, GeekWire (2019).
[72] L. Grush, Blue Origin successfully launches and lands its New Shepard rocket during 11th test flight, Verge (2019).
[73] T. Gray, "Blue Origin's New Shepard conducts 12th test launch, NASASpaceFlight.com, (2019).
[74] J. Foust, NASA willing to consider flying researchers on commercial suborbital vehicles, Space News (2017).
[75] R. Miller, The Art of Space: the History of Space Art, from the Earliest Visions to the Graphics of the Modern Era, Zenith Press, The Quarto Group, Inc., London, 2014.
[76] Y. Tanaka, "The art of mediation through 'the universe' – a dialogue between an engineer and a designer at CERN, Acta Astronaut. 161 (2019) 502–508.
[77] Y. Tanaka, Uncertain garden – space design for fertilizing uncertainty at IdeaSquare, CERN, Acta Astronaut 172 (2020) 1–6.
[78] B. Lamm, For your next business opportunity, look to the stars, Space News (2020).
[79] Avjobs, "History of aviation – first flights," Aviation Job Search, https://www.avjobs.com/history/index.asp (viewed on 8 May 2020).
[80] Cnn, Now Virgin to Offer Trips to Space, " *CNN.com*, 2004.
[81] J. Amos, Richard Branson Unveils Virgin Galactic Spaceplane, " *BBC News*, 2009.
[82] K. Gray, Learning to Fly: Future Space Tourists Train like Fighter Pilots, " *ZDNet*, 2013.
[83] L. Hall, "Got a ticket to space? You'll have to train first,, Air and Space Magazine (2017).
[84] D. Kasaboski, Supply, Not the Sky, Is the Limit for Space Tourism, 2020.
[85] J. Stromberg, "Why Space Tourism Is Going to Be Utterly Disappointing?" Vox.Com, 2015.