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THE ADVANTAGES, POTENTIALS AND SAFETY OF VTOL SUBORBITAL SPACE TOURISM OPERATIONS

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ABSTRACT

Suborbital space tourism offers short-time zero gravity and Earth view from space to its customers, and a package that can offer the longest duration of zero-gravity and the most exciting Earth view from space to its customer can be considered a better one than the others. To increase the duration of zero gravity time involves the design and engineering of the suborbital vehicles, but to improve the view of Earth from space aboard a suborbital vehicle, involves more than just the design and engineering of the vehicle, but more on the location of where the vehicle operates. So far, most of the proposed operations of suborbital space tourism vehicles involve a flight to above 80km and less than 120km and taking-off and landing at the same location. Therefore, the operational location of the suborbital vehicle clearly determines the view of earth from space that will be available to its passengers. The proposed operational locations or spaceports usually are existing airports such as the airport at Curacao Island in the Caribbean or spaceport specially built at locations with economic interests such as Spaceport America in New Mexico or an airport that is going to be built, such as SpaceportSEA in Selangor, Malaysia. Suborbital vehicles operating from these spaceports can only offer limited views of Earth from space which is only few thousand kilometers of land or sea around their spaceports, and a clear view of only few hundred kilometers of land or sea directly below them, even though the views can be enhanced by the application of optical devices. Therefore, the view of some exotic locations such as a colorful coral reef, and phenomena such as a smoking volcano on Earth which may be very exciting when viewed from space will not be available on these suborbital tourism packages. The only possible way for the passengers of a suborbital vehicle to view such exotic locations and phenomena is by flying above or near them, and since it will not be economic and will be more risky for a suborbital vehicle to fly above such objects after taking off from a spaceport far away from the object, and later returning to the spaceport, the way to go is to have the operation of the suborbital vehicle near the exotic locations. Unfortunately, some exotic locations such as a tropical archipelago in the middle of a clear blue ocean or a permanent icecap on a mountain range with variety of vegetation around it due to differences in height may not have suitable runway to function as spaceport, and for such reason, VTOL (vertical take-off and landing) capability for suborbital tourism vehicle may be worth considered. VTOL suborbital space tourism vehicle may not operate from a remote uneconomical location even though the location is near an exotic viewing target, but such vehicle may operate from a luxury super yacht that can sail to exotic locations around the world, and during the journey, the passengers can be trained and prepared for the flight of their life. Such is an advantage and potential of VTOL suborbital space tourism vehicle, but VTOL operation can be more complex than a conventional operation and therefore will increase the risk of operation, and for this reason the safety issue for such operation is very significant. This paper explores and discusses some advantages and potentials of VTOL suborbital space tourism operations and safety issues related to them. It also describes a couple of proposed concepts of VTOL suborbital tourism vehicles and potential exotic locations on Earth to be viewed from such vehicles.

Figure 1. A VTOL Spaceplane taking-off from an exotic spacepad (from Re-Entry animated movie).

1. INTRODUCTION

Space tourists have been visiting the International Space Station (ISS) since April 2001, using governments' space transportation infrastructures including spaceport, launch vehicles and also the ISS. This has been a very positive start for space tourism industry, even though those who can purchase such tourism service were only millionaires since the service has been offered at a very high price tag.

The real space tourism however will be more affordable when suborbital space tourism starts using commercial spaceports and commercial suborbital spaceplane and becomes available to greater market size. Suborbital tourism however will be very limited in their offering compared to the tourism package aboard the ISS.

Even though Virgin Galactic will be offering its passengers the experience of floating in zero gravity while viewing through portholes (windows) inside the cabin of its SpaceShipTwo within a significant period of time (1), generally what suborbital space tourism will be offering are zero-gravity and opportunity to view Earth from space in a very limited time. Therefore, there are and will be efforts to maximize the quality of zero gravity and Earth viewing offered by the manufacturers and operators of suborbital tourism vehicles.

The quality of zero gravity can only be increased by increasing its time that is the longer the time or period of being in zero gravity or weightlessness, the better its quality. This involves the design and engineering of the vehicles, where basically the zero gravity time can be increased by flying the vehicle at a greater momentum. However, to improve the view of Earth from space aboard the suborbital vehicles, it involves more than just the design and engineering of the vehicles, but more on the location where the vehicles are operated.

So far, most of the proposed operations of suborbital space tourism vehicles involve a flight to above 80km and less than 120km and taking-off and landing at the same location, which is the spaceport. Therefore, the location of the spaceport clearly determines the view of earth from space that will be available to the passengers of the suborbital vehicles.

The proposed operational locations or spaceports usually are existing airports such as the airport at Curacao Island in the Caribbean or spaceport specially built at locations with economic interests such as Spaceport America in New Mexico or an airport that is going to be built, such as SpaceportSEA in Selangor, Malaysia. The major factor for the location of the spaceport is clearly the economy. These spaceports may or may not be able to provide the high quality view of Earth from space, depending on its geographical location.

Figure 2. An illustration of the spaceflight terminal at SpaceportSEA by Architect Noor Azizee Abd Aziz.

Suborbital vehicles operating from these spaceports can only offer limited views of Earth from space which is only few thousand kilometers of land or sea around their spaceport, and a clear view of only few hundred kilometers of land or sea directly below them, even though the views can be enhanced by the application of advanced modern optical devices. Therefore, the view of some exotic locations such as a colorful coral reef, and phenomena such as a smoking volcano or a volcano approaching eruption which may be very exciting when viewed from space will not be available on these suborbital tourism flights.

The only possible way for the passengers of a suborbital vehicle to view such exotic locations and phenomena is by flying above or near them. Even though there is at least a paper proposing suborbital spaceplanes flying higher and long distance between continents that may fly above such exotic locations (2), such flights will be more expensive, and for suborbital spaceplanes that take-off and landing at the same spaceport, it will not be economic and will be more risky for them to fly above such locations after taking off from a spaceport far away from the locations, and later returning to the spaceport again.

Therefore, a possible economic and low risk method to enable such flight above the exotic locations is to have the operation of suborbital vehicles near the locations. Unfortunately, some exotic locations such as a tropical archipelago in the middle of a clear blue ocean or a permanent icecap on a mountain range with variety of vegetation around it due to differences in height may not have suitable runway to function as spaceport, and for such reason, VTOL (vertical take-off and landing) capability for suborbital tourism vehicles may be a practical and economical consideration.

However, the economy and market trend will determine the operational locations of the VTOL suborbital space

vehicles, which most probably will not be a remote uneconomical location even though the location is near an exotic viewing target, but such operations may be from a luxury super yacht that can sail to exotic locations around the world, and the journey which will last weeks if not months, will provide ample time for the passengers to be trained and prepared for the flight of their life.

Only VTOL suborbital vehicles will have such advantage and potential, but since their operation can be more complex than a conventional operation, the operational risk may be increased, and for this reason the safety issue for such operation will be very significant and need attention.

2. FUTURE CONCEPTS OF VTOL SUBORBITAL TOURISM OPERATIONS

2.1. Operation from Seaborne Spacepad

This concept was first described by Space Tourism Society Malaysia Chapter (STS-MC) in a brochure, published and distributed on August 2010, whereby 2 types of VTOL suborbital vehicle carrier ships were proposed. The first type was a luxury super yacht carrying only VTOL suborbital spaceplane, and the second type was a carrier catamaran carrying both VTOL and short horizontal take-off and landing suborbital spaceplane (3).

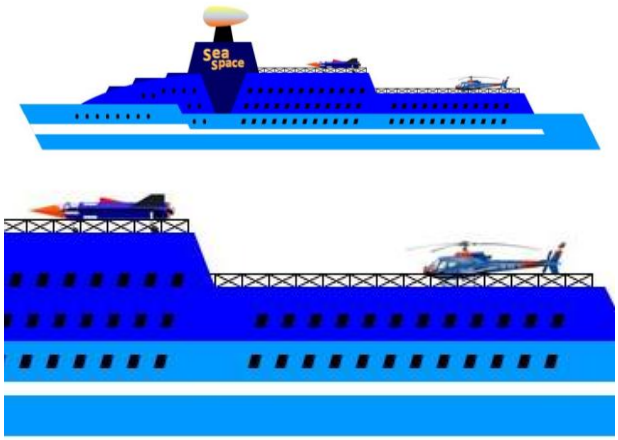

Figure 3. An illustration of A VTOL spaceplane and a helicopter aboard a large luxury super yacht.

Since there are luxury super yachts equipped with helipad, the concept of having a spacepad for the operation of suborbital vehicles from the yachts is more practical and comprehensible. The spacepad can be the helipad specially designed for the take-off and landing of a suborbital vehicle instead of a helicopter or another pad for the landing of suborbital vehicle besides the helipad. Therefore a luxury super yacht may have a spacepad instead of a helipad, and a larger yacht may have both a helipad and a spacepad.

Part of the passengers of the yacht will be the space tourists who will embark the suborbital vehicle at a specific location. The yacht will cruise to an exotic location where the view of the location from space will be breathtaking enough such as a colorful coral reef or a smoking volcano about to erupt. When it reaches an area near the location, the yacht will stop and its passengers who had purchased the tourism package which include the suborbital flight will take turn flying aboard the suborbital vehicle, while the passengers who had not purchased such package will become the excited viewers.

Operations from seaborne spacepad in the middle of an ocean far away from populated lands also enable the usage of expandable small fuel tanks and solid rocket boosters, which may contribute to the economy, simplicity and safety of the VTOL suborbital vehicles.

2.2. Operation from Spacepad Tower

This concept was first described by STS-MC in a paper, published and distributed on October 2010, whereby the operation of VTOL suborbital spaceplane from spacepad at the top of high-rise building was discussed (4). In the paper, there is an illustration of a building that is a spaceport complex where there are facilities for the maintenance of the spaceplane and the accommodation, preparation and training of the space tourists. Such building is called, spacepad tower.

Figure 4. A spacepad tower may be similar to Burj-Al-Arab Hotel, a very exclusive building within or near a city with 2 VTOL pads, one for helicopter, and another one for VTOL suborbital spaceplane.

Spacepad towers can be built at or near touristic cities, and may have 2 VTOL pads for the operation of a helicopter and a VTOL suborbital spaceplane respectively. The operation of city spacepad tower will enable suborbital tourism activity within a city with high rise buildings and skyscrapers.

2.3. Operation from Exotic Spacepad

Exotic spacepad is a concept of operating VTOL suborbital vehicle from a spacepad built at exotic locations such as a small tropical island in the middle of the ocean or a site on a mountain range.

For a small tropical island to be an operational spacepad, it needs a transportation system that will be able to bring the space tourists to the island. An interesting transporter to be considered is seaplane or helicopter, where this aircraft will fly from a cruise ship of nearby hotel carrying 4 to 6 passengers at a time to the island for them to fly to space and view the surrounding oceanic phenomenon. This type of operation however will be very prone to weather condition.

The spacepad can be built on a private or government-owned small island, and since it is a small island, its security can be well planned and established by having the ocean as its natural obstacle to intrusion, and further enhanced by electric fencing, closed circuit video cameras and guards. Therefore, the spacepad can be very safe from intruders.

A site on a mountain range can be an exotic spacepad too, and can be built and operated at a lower cost compared to that on an island in the middle of the ocean, because conventional transportation such as cars and buses can reach the spacepad if there is an available road or train if there is an available rail track nearby or a cable car system can be built to connect the spacepad to an existing nearby public station.

2.4. VTOL Suborbital Spaceplane Concepts by Space Tourism Society Malaysia Chapter

STS-MC has proposed several concepts of VTOL suborbital spaceplanes for future suborbital tourism. 2 of them are called, “Langkasa 2” and “SOLVES”.

Langkasa 2 is a conceptual design of VTOL small suborbital spaceplane (S3) carrying 2 passengers in piloted mode or 3 passengers in autopilot mode to slightly above 100km above sea level. Its single turbofan and rocket engines are positioned in tandem in a configuration known as centerline hybrid thrust (CLHT) for maximum aerodynamics and stability during VTOL (4). Its long wheel base and wing design further enhance this stability.

The VTOL capability of Langkasa 2 is provided by the synchronization of the thrusts from its lift fan and a pair of vectoring nozzles from its turbofan. The lift fan is powered by the same turbofan via a gearbox and a rotating shaft. The gearbox can engage (for VTOL) and disengage (for forward jet-powered flight) the lift fan to/ from the turbofan and also control the speed of the lift fan. The spaceplane takes-off and lands using its turbofan and climbs to space using its rocket propulsion.

Several designs of Langkasa 2 have been produced over the years, since the first one was presented at the 4th IAASS conference (5).

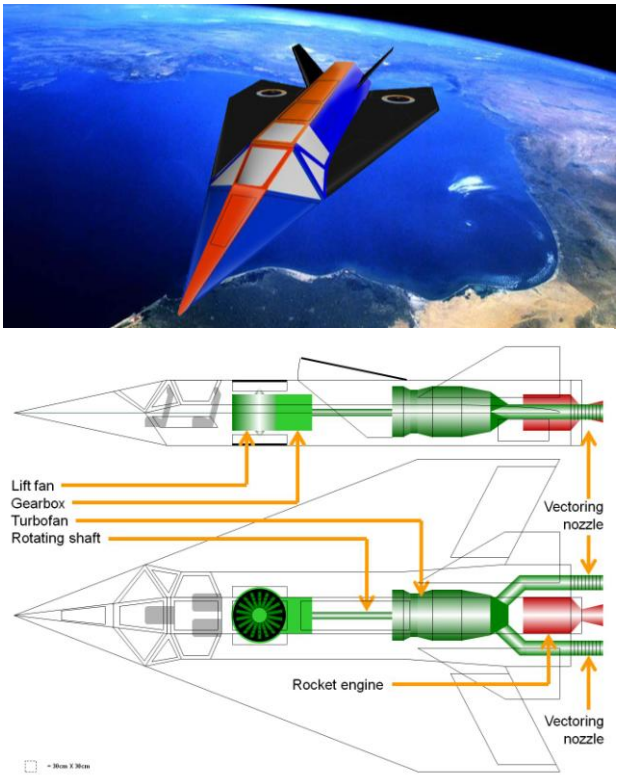

Figure 5. Langkasa 2 (6)

Due to its small size, Langkasa 2 will be able to carry only very limited amount of rocket propellant to perform only a single climb to reach above 100km from sea level with the help of momentum.

A method under study to enable the spaceplane to perform double climb is in-flight refueling, where the spaceplane will be refueled with rocket propellant by an airborne tanker. This method will enable the spaceplane to perform double climb while remain small and light, and increase the quality of its service by providing double trip to space consecutively to its passengers.

Langkasa 2 will be able to perform in-flight refueling effectively because being a fixed-wing vehicle with horizontal thrust, it can safely approach an airborne tanker horizontally from the rear of the tanker using its turbofan as in conventional in-flight refueling.

Figure 6. Conventional in-flight refueling (from www.aviationexplorer.com).

However, for normal operation, there will be no in-flight refueling as the spaceplane climbs only once to space, and an airborne tanker will not be available under normal circumstances.

Langkasa 2 will fly back to the spacepad using its turbofan and land vertically and safely with empty rocket propellant tanks.

Due to vast experience in in-flight refueling, particularly in the air forces, its techniques and technology have been perfected. An airborne tanker may be able to perform up to 20 refueling of small suborbital spaceplanes with empty rocket propellant tanks, and if operated from a base which is not a spacepad or spaceport, then spacepads and spaceports can be built free of rocket propellant storage, which will only increase the safety of the spacepads and spaceports.

SOLVES (Suborbital Low-Cost & Low Risk Vehicle to the Edge of Space (50 Miles)) is a conceptual design of low-cost and low-risk VTOL suborbital vehicle carrying 4 passengers with its propulsion system designed to reach slightly above 50miles or 80km above sea level (7).

The 2 most significant components of SOLVES for vertical landing are VPR (vertically passive rotating) wings and an electrical propulsion with a vectoring nozzle, which ensure the vehicle to land safely and precisely at its landing point.

The VPR wings will be closed and flushed against the fuselage during ascend, but will be opened and extended during descend. The wings will be loosened up and naturally rotate with their axes of rotation perpendicular to the fuselage due to the lift force available particularly at lower altitude as the SOLVES descends and the air is thickened. The naturally and passively rotating wing will control the speed at which the vehicle is descending, so that the vehicle will not crash due to gravity.

While descending, SOLVES will rotate with the centerline of its fuselage as its axis of rotation, so that its passengers will be able to have 360^{O} of horizontal views besides the downwards view. The rotation will be initiated with small thrusters fired tactically along the horizontal plane to provide rotational momentum. The rotation will stop progressively with the application of the same thrusters but fired at the opposite directions at 20km from sea level, and the electrical propulsion at the bottom of the passenger cabin will be ignited.

The battery powered electrical propulsion is to steer SOLVES using a vectoring nozzle until it lands safety and precisely at the landing point. The extra power of the battery is generated by the VPR wings. The electrical propulsion minimizes mass and space and also is free from environmental and noise pollution.

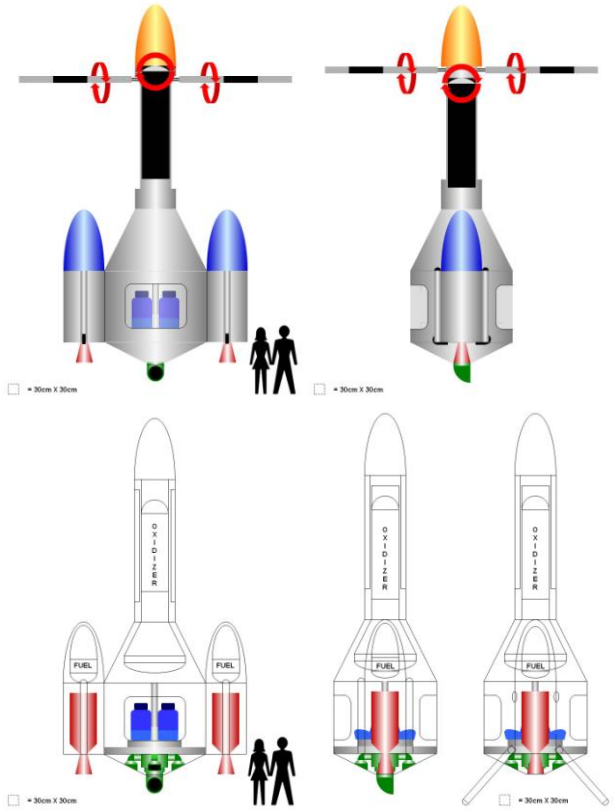

Figure 7. SOLVES (6)

During descend, the fuel and oxidizer tanks are already empty, enhancing the safety and stability of SOLVES as its point of gravity has moved lower to the center of the passenger cabin at the bottom of the vehicle. Being at the bottom, the passengers can enter and exit the cabin conveniently, safely and rapidly.

2.5. Potential Preferred Views from Space

The potential preferred views from space for suborbital tourists will mostly consist of beautiful natural large enough objects and phenomena seen from space, and they will be bright and colorful.

A very bright and colorful phenomenon to view from space will be the aurora which will look spectacular when it curves reflecting the Earth curvature. This spectacular view will only be available to the space tourists aboard suborbital vehicles operated near the poles, such as from a luxury super yacht sailing near the Arctic or Antarctic.

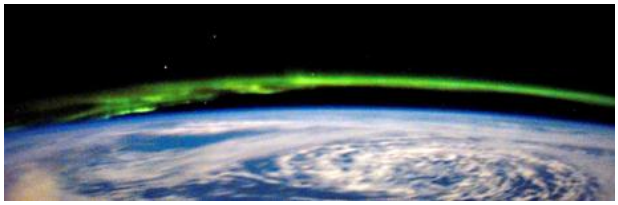

Figure 8. Aurora viewed from space (from www.nationalgeographic.com).

Other very potential choice will be large permanent icecaps at mountaintops, because they are large enough and will look very bright from space. The Alps, for example will look very attractive because it has a large permanent icecap surrounded by green vegetation and blue lakes. A package to view the Alps from space from aboard a VTOL suborbital spaceplane operating from a luxury super yacht in the Mediterranean will be very exciting.

Figure 9. The Alps from space (from esamultimedia.esa.int).

Another very interesting icecap with colorful surrounding is the icecap above the Andes between Argentina and Chile, because the weather on the Argentinean (eastern) side is much dryer and very much different from that on the Chilean (western) side, which is wetter, due to the Andes functioning as a natural separator between the two, resulting in a very contrasting types and colors of landscape and vegetation on both sides. Therefore this icecap is located between colorful and different landscapes and vegetations. A trip to view this colorful natural beauty from space by a VTOL suborbital spaceplane operated from a luxury super yacht in the south-eastern Pacific will be an adventurous one.

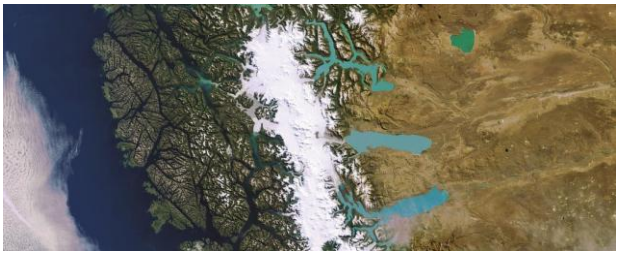

Figure 10. The Andes between Argentina and Chile from space (from esamultimedia.esa.int).

Another very interesting colorful and large and bright enough natural beauty to be viewed from space will be the coral reefs, which will also be suitable to be viewed from aboard VTOL suborbital spaceplane operating from luxury super yacht. Viewing vulnerable natural beauties from space such as the coral reefs will be able to create great awareness of the natural environment that need preservation and protection.

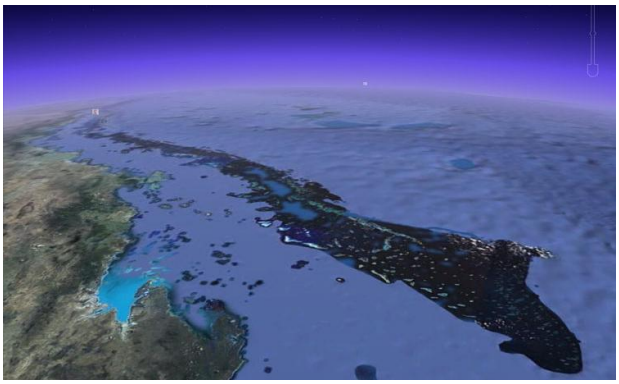

Figure11. The Great Barrier Reef seen from the edge of space (from www.extremescience.com).

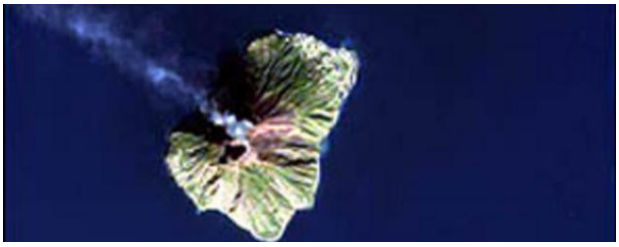

Figure 12: A smoking volcano on an island in Italy (from esamultimedia.esa.int)

A smoking volcano or a volcano approaching eruption will also be a terrific view from space and may also become a preferred view for the suborbital space tourists. Such volcanoes can also be approached by luxury super yachts with spacepad.

Even though the above potential preferred views from space are proposed to be viewed from VTOL suborbital spaceplanes operating from luxury super yachts, such spaceplanes can also be operational from spacepads or spaceports on nearby lands. The advantage of the luxury super yachts with spacepad or seaborne spacepads compared to the spacepads or spaceports on land is that the earlier are more flexible and can actually travel to the preferred destinations and offer variable suborbital tourism experiences, while the later can only offer flight over fixed destinations.

A strange and mysterious natural landscape, such as Tarim Basin in Taklamakan Desert, East Turkestan can be a hot spot too. This large, strange and very dry basin, which is also very far from oceans, is surrounded by permanent snowcapped highlands which block the basin from any kind of precipitation, resulting in highly contrasted color geography from its surroundings. Such exotic views may be the target of VTOL suborbital spaceplanes operating from exotic landed spacepads.

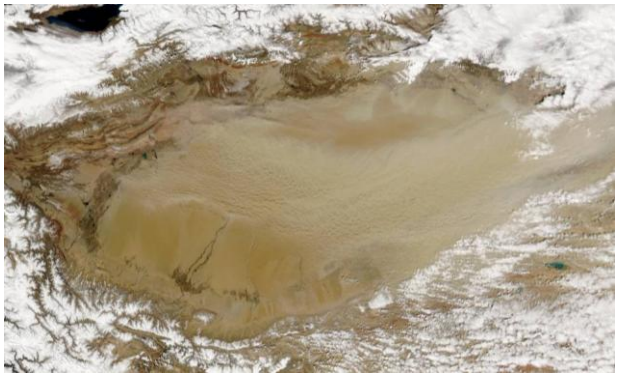

Figure 13. Tarim Basin, Taklamakan Desert, East Turkestan (from earthobservatory.nasa.gov)

Therefore, there can be various interesting potential preferred views from space for the suborbital tourists, depending on the operational flexibility of the VTOL suborbital spaceplanes. New interesting places on Earth that had never been heard or seen before may become well known due to growth of this new VTOL suborbital tourism.

3. ADVANTAGES, POTENTIALS AND SAF/ETY OF VTOL SUBORBITAL TOURISM OPERATIONS

Considering that VTOL suborbital vehicles will be able to operate at locations that lack runways, the vehicles have significant advantages over the vehicles without VTOL capability, because not only there will be more flexibility of operational location to the VTOL vehicles, but also less investment is needed to build runways.

The business of VTOL suborbital tourism will grow with time as suborbital tourism matures, because after the successful initial current early stage of suborbital tourism which focuses on economy, simplicity and safety, the future more matured industry will start giving attention to creativity and innovation.

Since viewing Earth will be the most enjoyable activity aboard a spaceflight (8), and VTOL suborbital vehicles will be able to provide more choices of such view, the vehicles absolutely will have great and promising potentials.

VTOL suborbital spaceplane is VTOL suborbital vehicle with fixed wing and horizontal thrusts, similar to fixed wing aircrafts but with VTOL and spaceflight capability. The wing is very important because it physically interacts with air and significantly contributes to the safety of the vehicle during landing at spacepad.

From experience of Sea Harrier VTOL operation and an AV-8B study (9), fixed-wing VTOL aircraft were able to land safely and precisely at its landing point. The wing, assisted by the horizontal thrust enables the aircrafts to be effectively maneuvered to their landing pad. Fixed-wing aircrafts operating on aircraft carriers since World War 2 have proved that wing and horizontal thrusts are very effective for the aircrafts to maneuver to land on the carriers.

Such capability of landing safely and precisely at landing point which is due to the availability of wing is very significant for the operation of VTOL suborbital tourism spaceplane, particularly if the spaceplane operates from a seaborne spacepad. For a moving seaborne spacepad, the safest way to land a suborbital vehicle is by approaching the pad from the rear, and this is only possible with fixed wing VTOL suborbital vehicle with horizontal thrusts or VTOL suborbital spaceplane.

VTOL suborbital vehicles without wing may be able to land safely, but may not be able to land precisely at landing points due to their lack of wing and horizontal thrusts.

Another safety advantage available on fixed-wing VTOL aircrafts compared to VTOL aircrafts without wing is that if the VTOL propulsion of the fixed wing aircrafts is not working, the aircrafts still have wing that will be

useful for safe landing, while the VTOL aircraft without wing will not have such opportunity. VTOL suborbital spaceplanes with jet propulsion will be able to use this advantage effectively in such emergency situation.

To further enhance the safety of VTOL suborbital spaceplanes operating on seaborne spacepad, the spaceplane should be designed to be able to survive emergency landing on sea by having mechanisms such as floatable fuselage. Having the air-intake above the fuselage as in Langkasa 2 conceptual design will also help in this effort, as it will be able to avoid sea water from flooding into the propulsion system. The air intake of Langkasa 2 can also be closed.

Having VTOL system on a suborbital vehicle also increases the flexibility made available to the pilot, and this itself will increase safety of the flight.

4. CONCLUSIONS

Basically there are only two types of experiences offered by suborbital space tourism, which are the experience of zero gravity and the experience of viewing Earth from space, and both can be enhanced with the improvement in the engineering and technology of suborbital tourism vehicles and innovation in the operation respectively.

Increasing the quality of zero gravity can only be done by increasing the period or time of exposure of the space tourists to zero gravity environment, which is possible by increasing the momentum of the vehicles, but to increase the quality of the view of Earth from space requires innovation in the operation of the vehicles, which is possible by flying the vehicle above exotic locations on Earth.

Since most of these exotic locations are natural geographical features which are far away from runways that are traditionally located nearer to cities and densely populated area, VTOL capability that does not requires runways is needed for the suborbital vehicles to be able to operate near those locations.

Suborbital space tourism will continue its existence in the era of orbital tourism as a lower cost alternative of space tourism. Unlike during the current early stage of suborbital tourism, where suborbital vehicles are designed and developed with priority given to the economy, simplicity and safety of their operation, the later more matured stage of suborbital tourism will witness more attention is given to new and innovative operation of suborbital vehicles, including VTOL suborbital operations enabling viewing of exotic objects and phenomena on Earth from space.

With the maturity of VTOL suborbital vehicles operations, there will be more creative and innovative services available to space tourists. Among them will be suborbital tourism operated from seaborne spacepads, tower spacepads and exotic spacepads.

These innovative VTOL suborbital operations will create a new era of suborbital tourism, where the service providers will be competing in offering interesting packages to their customers. However, this situation will only arise when the suborbital tourism industry becomes matured and this explains the futuristic advantage and potential of VTOL suborbital tourism operations and the effort that will be invested in ensuring the safety of such operations.

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