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A case study for spacegate point-to-point transportation: Evaluation of a reference end-to-end mission operations and assessment of the associated safety aspects / Santoro, Francesco; Bellomo, Alessandro; Del Bianco, Alberto; Vittori, Roberto; Viola, Nicole; De Vita, Francesco. - In: PROCEEDINGS OF THE INTERNATIONAL ASTRONAUTICAL CONGRESS. - ISSN 0074-1795. - 11(2014), pp. 8140-8152. ((Intervento presentato al convegno 65th International Astronautical Congress 2014: Our World Needs Space, IAC 2014 tenutosi a can nel 2014.

Availability:

This version is available at: 11583/2656243 since: 2016-11-17T12:13:44Z

Publisher:

International Astronautical Federation, IAF

Published

DOI:

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IAC-14.D6.2-D2.9.1

A CASE STUDY FOR SPACEGATE POINT-TO-POINT TRANSPORTATION: EVALUATION OF A REFERENCE END-TO-END MISSION OPERATIONS AND ASSESSMENT OF THE ASSOCIATED SAFETY ASPECTS

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The ALTEC-conducted Spacegate feasibility study addresses the opportunities offered by the sub-orbital flight with special emphasis to future generation transportation. Pursuing the same systemic methodology of the initial Spacegate definition activities, this paper focuses on some specific aspects of suborbital operations and outlines a top level end-to-end operating cycle for a reference suborbital mission spanning from pre-flight, to flight, re-entry and post landing operations and associated Ground Segment. Special focus is given to identification of suitable locations in Italy for suborbital operations, and to liftoff and re-entry phases; the results of specific simulations are also reported, showing some lift off options and the feasibility of the spiral shaped descent maneuver that improves the pilot controllability of the vehicle during the re-entry phase. Further, this paper outlines within the selected reference mission, the main safety aspects considered as driving factors in planning and implementing future generation transportation; areas such as launch/landing range and relevant risk management/mitigation policies, as well as selection of safety driving criteria in the definition of trajectories and space transition corridors, and capabilities to monitor the vehicle ascent and re-entry will be assessed. Safety regulations will also be evaluated to protect launch range, drive spaceport site selection and consequently the ability of the spaceport to accommodate large numbers of passengers and participants, as well as a number of simultaneous operations such as training, vehicle integration tasks, and passenger preparation for flight. For human flight in general, and in particular for commercial point to point activities at this early stage, it is vital to minimize risk since a fatal accident at the very beginning of flights will put the entire business in jeopardy. The regulatory challenges with regards to safety will also be outlined in this paper, related to executing Spacegate activities in Europe and collaborations with the involved Agencies in the USA and Europe (FAA, ENAC, ENAV, SESAR, EASA) will be explored; in particular, some initiatives have already been started, that include active ALTEC participation to the IAASS Space Safety Technical Committee (SSTC) that was created to contribute to the advancement of the Safety in the area of the "Commercial Suborbital Flight".

I. INTRODUCTION

This paper describes some of the main aspects involved in planning a point-to-point suborbital flight and the relevant operations, as well as the major driving safety guidelines. Some of the major aspects affecting the development of an overall mission

scenario will be considered, which can further be investigated in subsequent research work. The development of a reference suborbital mission flow, both for flight and ground operations, and the description of the interaction with Safety throughout the whole process, is the initial step toward the

definition of a proper activity plan and the associated ground support. In particular, Spaceports as takeoff, landing and ground processing /passengers facilities are not supposed to be built from scratch, but at least initially will be based on existing sites, perhaps with specific future upgrades. The Spacegate overall system approach is shown in Fig. I, where the major components are identified, namely Research and Analysis, Technology, Ground Segment, Regulatory and Certification. All the aspects identified in this paper are related to the components in Fig.1

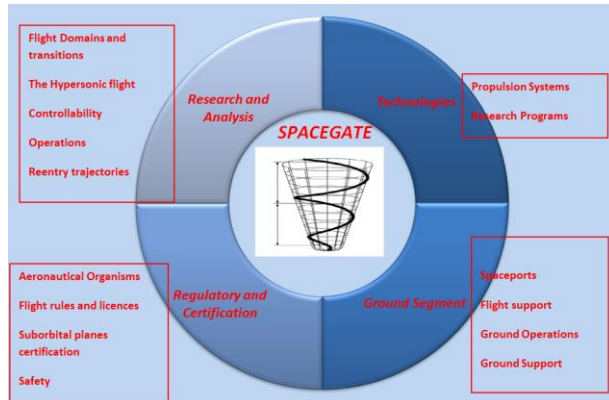


Fig.I: Spacegate Overall System Approach

II. SITES SELECTION

II.I Departure and landing Spaceports

As already pointed out in [1], the Spacegate concept is based upon the usage of existing ground infrastructures and facilities, which would be assessed for possible upgrades, if needed. A Spaceport is a launch/landing site where hypersonic vehicles can take-off, cross both the aeronautic and the high altitude domains, in order to reach the space domain, and re-enter in the atmosphere through sub-orbital or parabolic flights. In the Spacegate study, Spaceport does not mean building brand new infrastructures, but rather making the most of existing sites, possibly with selected upgrades to fulfill the operating requirements. For parabolic flights, the launch Spaceport is the same of the re-entry one; for sub-orbital flights, because of the horizontal component of the velocity vector, the re-entry Spaceport differs from the launch one. The site selection derives from evaluations performed as part of the Ground Segment activities shown in Fig. I. As an example of the evaluations performed therein, the Decimomannu military airport in Sardinia, whose location is shown in Fig.II, has specific favorable aspects, mostly related to surrounding landscape, vicinity of cities or populated areas (noise and debris impact), weather, airport dimensions, commercial and scheduled flights, available runways and dimensions, available Navigational Aid System (Nav aids), airspace type

and dimensions, prohibited, restricted and dangerous areas, military activities. The airport is included in the Cagliari Class C / D Airspace and, specifically, inside the CTR – Zone 1. There are some constraints in the usage of the Decimomannu airport, due to prohibited, restricted and dangerous areas, as listed herein: The Decimomannu Airport is close to the following classified areas:

- R 54 – Oristano
From SFC to FL600: Heavy military air activity and target towing training
HR: Mon-Fri, H24
- R 59 – Capo Frasca
From SFC to FL150: Air/Ground Firing exercise
HR: Mon-Fri, H24
- D40A – Decimomannu
From 1000' AMSL to UNL: Air to Air firing and Combat training
HR: Mon-Fri HJ+/-30'



Fig. II, Decimomannu Airport Location

This last area, specifically, covering the airspace from 1000' AMSL to UNL, could allow the mission profile of a typical Sub-orbital spaceflight, without interfere with Commercial or General Aviation flights or Airways.

Light: HIRL, REIL, PAPI, ABN, ALS RWY 17L
TACAN: CH 019X DEC
NDB: 331 DEC
Fuel: JP-8
Fire Fighting: Cat 8 ICAO

Another site that is a good candidate for suborbital operations in Italy is the Taranto Grottaglie Airport in Puglia. The following paragraphs will provide more detailed information on both airports

II.II Decimomannu Airport Characteristics

The main characteristics and the map of the Decimomannu Military Airport are summarized in Fig. III and Fig. IV respectively.

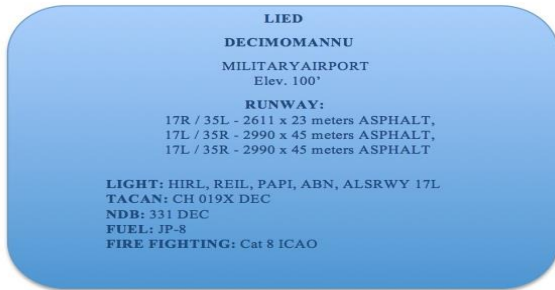


Fig. III, Decimomannu Airport Characteristics

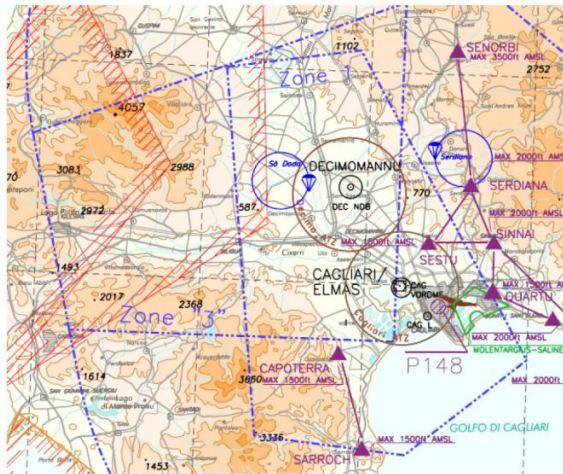


Fig.IV: Decimomannu Airport Map

II.III Taranto Grottaglie Airport Characteristics

The Taranto-Grottaglie "Marcello Arlotta" Airport (Italian: Aeroporto di Taranto-Grottaglie "Marcello Arlotta") (IATA: TAR, ICAO: LIBG), serves Taranto and Grottaglie, both located in the province of Taranto in Italy. The airport is located 1.5 km (0.8 NM) from the city of Monteiasi, 4 km (2.2 NM) from Grottaglie and 16 km (8.6 NM) from Taranto. It is named for Marcello Arlotta (1886-1918), an Italian aviator. The airport is used for general aviation, with no commercial airline service. Fig. V and Fig VI show the map location of the Taranto Grottaglie Airport

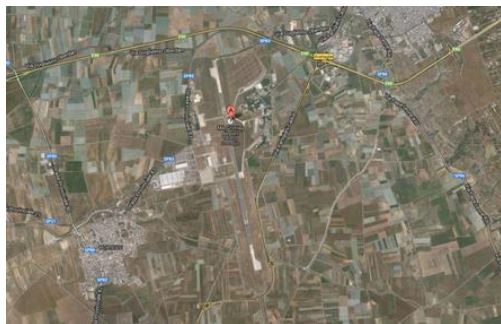


Fig.V: Taranto Grottaglie Airport Location

Fig.VII is a summary of the main characteristics of the Taranto Grottaglie airport. There are potentially other locations in Italy suitable for suborbital operations, in particular the Military Airport of Pratica di Mare (IATA: QLY, ICAO:LIRE)

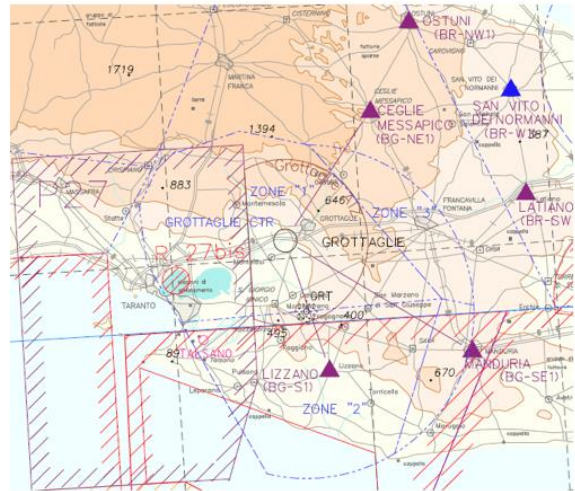


Fig.VI: Taranto Grottaglie Airport Map



Fig.VII : Taranto Grottaglie Airport Characteristics

III. LAUNCH OPTIONS

The Spacegate study considers the following two launch options:

- Horizontal Single-Stage-to-Orbit (SSTO) Launch: The majority of SSTO concepts will take off horizontally from a conventional runway like the Decimomannu runway and transition immediately to the vertical ascent. These operations will be entirely contained within reserved airspace.
- Horizontal Two-Stage-to-Orbit (TSTO) Launch: Some RLV concepts call for the vehicle to be taken to an airborne launch point by a ferry aircraft. Some of these first-stage aircraft are piloted, and some operate autonomously. The

piloted ferry aircraft may operate outside of reserved airspace while en route to and from the airborne launch point. Autonomous first-stage aircraft would be required to remain within reserved airspace.

Fig.VIII shows a pictorial view of a parabolic flight profile based on horizontal takeoff and landing

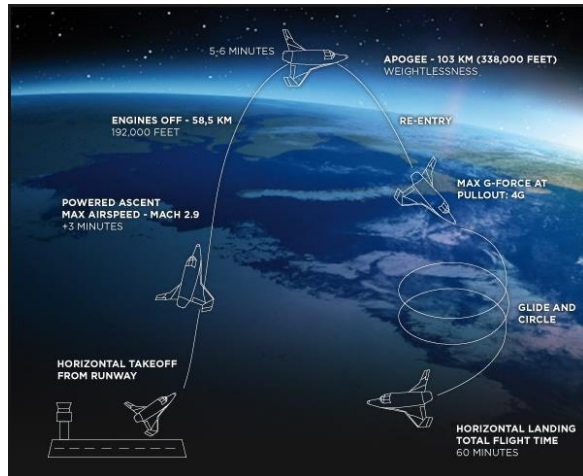


Fig. VIII: Pictorial view of a parabolic flight profile

IV. MISSION FLOW

A Suborbital Mission Operations flow can be described by the flow chart of Fig. IX, that shows the typical operations phases. Every phase will have to be further detailed depending upon the selected vehicle and the relevant mission configuration. It is initially assumed that the takeoff and reentry phase occur horizontally on an airport runway.

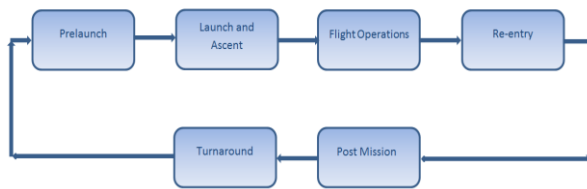


Fig.IX: Suborbital Mission Operations Flow

A specific Ground Segment will have to be defined to properly provide the functional capabilities to support the mission both on ground and on flight. This includes the ground facilities and tools that support the operations at the Spaceports, the Spacegate Control Center, the Ground Stations deployed as appropriate along the planned trajectory to track the vehicle and the associated communication network. For reference purposes only, Fig.X shows the Ground Segment of the ESA Intermediate Experiment Vehicle, IXV. A top level preliminary description of the main functions associated with the Spacegate

Control Center is provided in paragraph IX. The following paragraphs provide a more detailed description of the various mission phases.

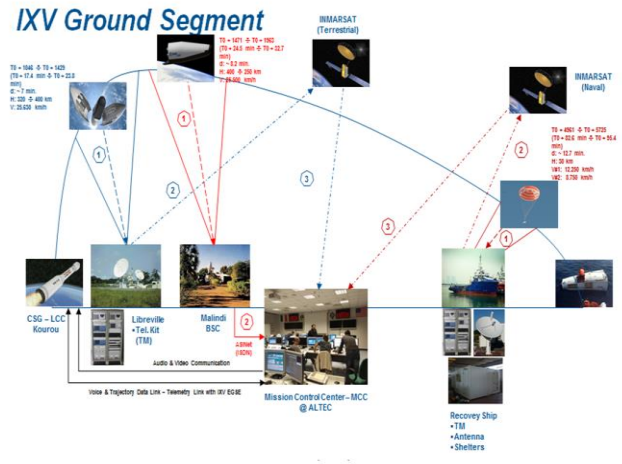


Fig.X: Ground Segment of the IXV Mission

V. PRE-LAUNCH

Pre-launch operations include all the activities that need to be accomplished to prepare the vehicle for flight. In general the vehicle will undergo specific preflight checkout to verify the correct behavior of all the subsystems and equipment. The latter activities depend upon the selected launch option and are supported by specific Ground Support Equipment. Subsequent prelaunch operations include vehicle fueling, on-loading food and other perishable items, and boarding crew and passengers. Fuel shall be supplied to the spacecraft via an automated umbilical and underground piping network from the fuel storage facility. Launch-support services facilities provide consumables for passenger/crewed flights and should be delivered to the flight vehicle at pre-launch and removed at landing/recovery. Fig. XI describes the functional decomposition of the Pre-launch activities block shown in Fig.IX. In future works, this decomposition shall further be developed to derive the relevant lower level system requirements.

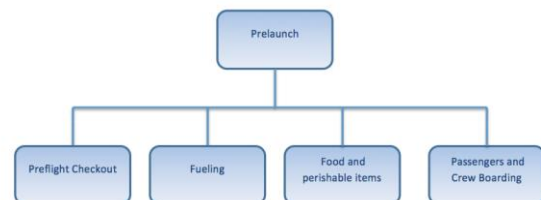


Fig. XI: Prelaunch activities Operations Flow

Flight-support services facilities include all the relevant buildings, operations and equipment necessary to maintain the spaceport and could be located either on-site or remote from the launch complex. The relevant operations encompass all the functions required to control the spaceport facility including facility management, flight control and planning, communications, security, and emergency services.

VI. LAUNCH

This paragraph shows some preliminary results of specific simulations of flight dynamics laws on the longitudinal plane [2] for a winged, Single-Stage-To-Orbit (SSTO) system, taking off from a runway.

The developed simulation tool is flexible enough to simulate the ascent for both SSTO and TSTO systems, providing as output useful vehicle data such as altitude, horizontal displacement, attitude, velocity, visible horizon and so on. The considered test case includes an SSTO vehicle with mass of 5000 kg[10], wing area of 6.65 m², and max thrust of 51.6 kN. The liftoff speed is 98 m/s to a parabolic flight with engine cutoff after 190 seconds. As shown in Fig. XII and Fig. XIII, the ascent profile is such as the vehicle reaches the altitude of about 100 km in less than five minutes, with an horizontal displacement of less than 100 Km. Considering the Decimomannu Military Airport as departure site, the visible horizon from the vehicle is shown in Fig. XIV. The attitude of the vehicle is shown in Fig. XV and the velocity profile in Fig. XVI. The used model is flexible enough that the same simulation can be run for a TSTO, setting up a two steps approach, a step for the first stage with an horizontal or vertical takeoff, and a step for the second one using as a starting point the moment it is released.

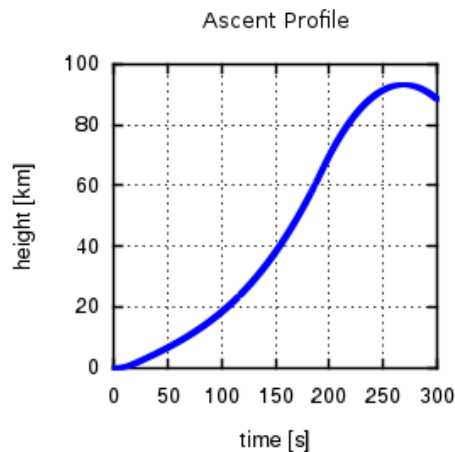


Fig. XII: SSTO Ascent Profile versus time

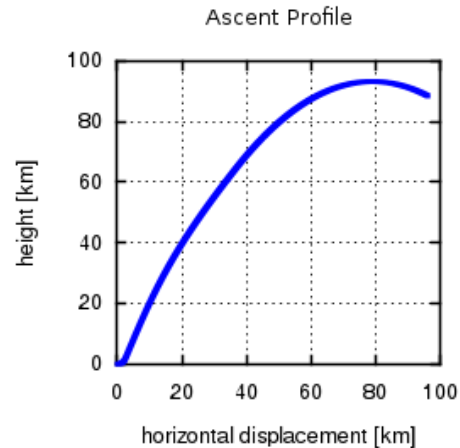


Fig. XIII: SSTO altitude profile versus displacement

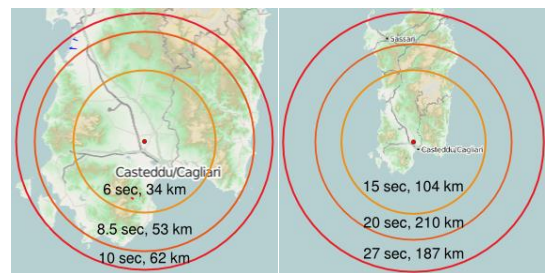


Fig. XIV: SSTO visible horizon at Decimomannu

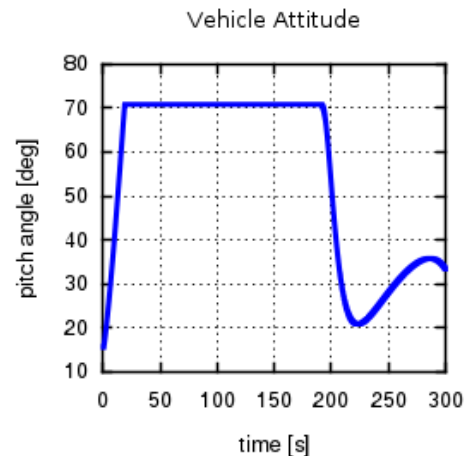


Fig. XV: Vehicle pitch angle versus time

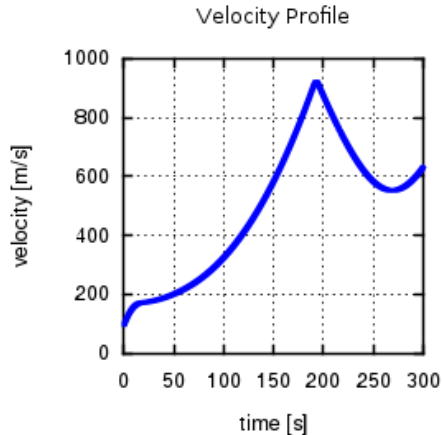


Fig. XVI: Vehicle velocity profile versus time

VII. REENTRY

The need for a safer access to space imposes the review of operational capabilities and hence of design approach for manned reentry vehicles of next generation. Up to now several hypersonic shapes have been investigated for use in recoverable space systems. Initial efforts focused on low Lift-to-Drag ratio (L/D), as Apollo spacecraft. Systems such as the Space Shuttle, although flying at medium L/D (<1.5) ratio, have the important features of being reusable. Furthermore, a high L/D ratio increases the dimension of the so-called re-entry window, namely the set of values of velocity, flight path angle and altitude compatible with the re-entry on a runaway. This implies a significant increase of the operational flexibility, also in the perspective of a quick return for reuse. Furthermore, enhancing a hypersonic vehicle L/D ratio, effectively increases the footprint (cross range area) in which the vehicle can safely maneuver and land, even in presence of unforeseen reentry anomalies or constraints at the primary landing site like weather. The need for a high degree of atmospheric control capability leads to consider a Shuttle-like configuration, i.e. a re-entry space glider. A possible shape of the vehicle is shown in Fig.XVII.

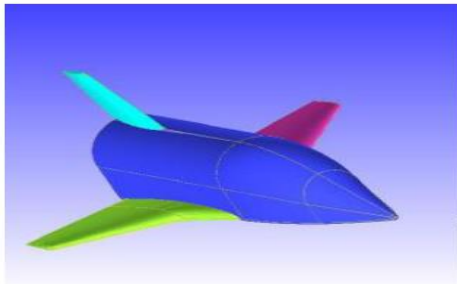


Fig. XVII: Possible Shape of the Re-entry Vehicle

Specific simulations were carried out to prove the feasibility of the Spacegate spiral re-entry maneuver as described in [1], as well as the gradual acquisition of the control by the pilot. For the present simulation, a lifting body with an aerodynamic efficiency approximately equal to 1 has been considered. The mass has been set to 7600 Kg, whereas the lifting surface has been set equal to 18 m². Both the lift and drag coefficients changes according to the angle of attack, through a first order expression, leading to a maximum value of 0,51.

In the perspective of a manned re-entry mission, the following constraints have been taken into account: Maximum load factor equal to 3g, maximum dynamic pressure of 30 kPa, maximum instantaneous heat flux (Sutton & Graves model) of 2.0 MW/m². For the purposes of the present study, an open loop guidance has been implemented, based on the angle of attack and bank angle variation for Shuttle-like, re-entry vehicles. The angle of attack is assumed constant and equal to 43° until the reaching of the condition suitable for the spiral re-entry. To prove the feasibility of the “SpaceGate” spiral manoeuver, specific simulations with a dedicated orbit propagator have been carried out. According to the described vehicle’s characteristics, the dynamic conditions necessary to start the spiral manoeuver occur at 44.3 km of altitude and a velocity relative to the flux equal to 4084 m/s. These conditions are obtained by imposing a maximum lateral acceleration equal to 1.7 g during the spiral trajectory. After a first roll-reversal, with an instantaneous curvature radius ranging between 500 and 1000 km, the “SpaceGate” spiral manoeuver is triggered. It should be noted that the spiral arch is not entirely executed. The high bank angle, held constant during the first part of the spiral, results in a decreased flight path angle as well as increased descending rate, and in turn, the exponential growth of the atmosphere density causes an abrupt reduction of the curvature radius. A more gradual shrinkage of the trajectory can be driven through an advanced guidance of the bank and incidence angles. The simulation output is shown in Fig.XVIII through Fig.XXI, that provide the main features of the re-entry trajectory. In particular, Fig. XVIII is relevant to the mechanical and thermal stress experienced by the vehicle during reentry, Fig. XIX and Fig. XX provide the velocity and altitude profile, and Fig.XXI shows the Ground Track displacement at reentry. Thermal fluxes, dynamic pressure and load factor appear below the specified thresholds.

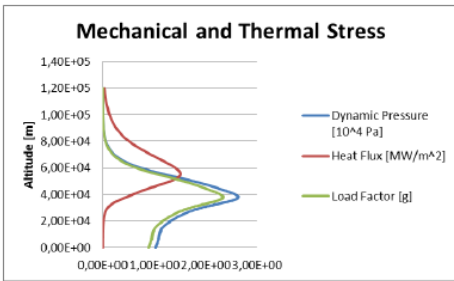


Fig. XVIII: Mechanical and thermal stress at reentry

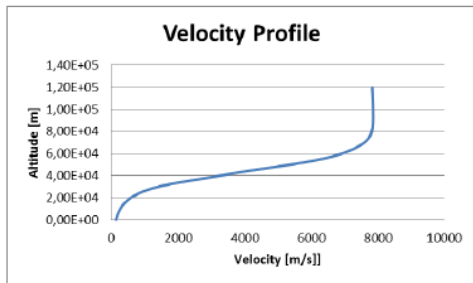


Fig. XIX: Velocity Profile versus altitude reentry

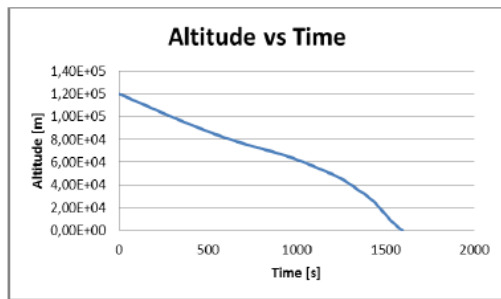


Fig. XX: Altitude versus time diagram

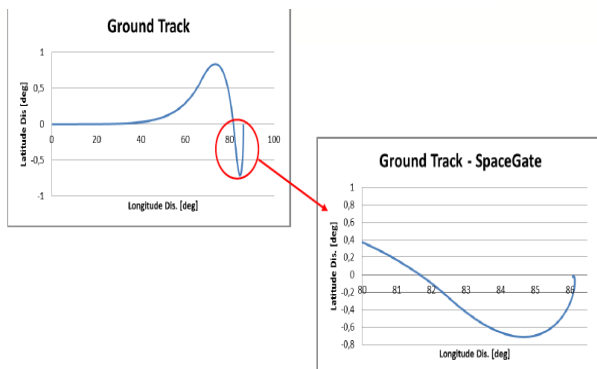


Fig. XXI: Ground track displacement at reentry

VIII. POST MISSION

Post Mission Operations start from the flight vehicle arriving at the landing facility and taxiing to the landing and recovery area, where post-flight safing procedures occur, and crew and passengers are off-loaded and recovered. The vehicle then should be moved to the vehicle processing and service bay, where the performance of the subsystems and equipment is verified and scheduled maintenance operations are performed. A Main Spacecraft Ground Operations facility is assumed to be the center of operations for pre-flight spacecraft preparation and post-flight spacecraft service. The facility should be designed to accomplish the fastest possible turnaround time from spacecraft recovery to next launch. Preventive maintenance and spacecraft systems checks should be performed in the Main Spacecraft Ground Operations Facility. For extensive check procedures, Spacecraft shall be towed off-line, to the maintenance area, where heavy maintenance, overhaul, and component replacement can be performed.

IX. SPACEGATE CONTROL CENTER

The proposed Spacegate Preliminary Architecture includes a Control Center function to support all the Prelaunch, Launch / Mission and Reentry operations. Continuous coordination with the Control Towers and ATC control shall be implemented during operations. The Center includes a Mission Control Center, handled by the Spaceflight control team, whose members represent each discipline, and report directly to the Mission Director. As an example, Fig. XXII shows the Mission Support Center located at the ALTEC premises in Torino, Italy. The Flight Control Team shall work together and shall have the proper skills to execute the flight timeline and address all contingency situations.



Fig. XXII: The Mission Support Center (MSC) at ALTEC

The following disciplines have preliminary been identified to be part of the Spacegate Control Center; further refinement analysis is required to better define the positions and possibly include additional disciplines:

Mission Director: Leader of the flight control team. Responsible for overall Vehicle mission for all decisions regarding safe, expedient flight conduct

Operations Director and Safety: Head of the ground segment operation team and responsible for the overall operations of the ground segment. Safety position is also included

Vehicle Operations Manager: Responsible for the monitoring of the vehicle parameters and the provision of the actual status of the vehicle during the flight phases. He is supported by the Flight Control Team.

Trajectory Officer / Flight Dynamics Officer: Plans maneuvers and monitors trajectory in conjunction with Guidance, Navigation and Control

Ground Controller: Directs maintenance and operation activities, affecting Mission Control hardware, software and support facilities, coordinates spaceflight tracking and data network and tracking satellite system.

Propulsion Officer: Monitors and evaluate the propulsion and maneuvering systems, during all phases of flight, and manages propellants and other consumables available for maneuvers

Guidance, Navigation, and Control: Monitors all Spacecraft guidance, navigation and control systems, notifies Mission Director and crew of possible abort situations, advises crew regarding guidance malfunctions. Ensures that the onboard navigation and onboard guidance computer software executes the proper tasks to accomplish mission objectives

Maintenance, Mechanical and Crew Systems Engineer: Monitors the Spacecraft structural and mechanical systems, and follows use of onboard crew hardware and in-flight equipment maintenance

Power Systems Engineer: Monitors cryogenic levels for fuel cells, electrical generation and distribution systems and vehicle lighting.

Data Processing System Engineer: Determines status of data processing system including the onboard general purpose computers, flight-critical and launch data lines, the displays, onboard mass memory and software

Flight Activities Officer: Plans and supports crew activities, checklists, procedures and schedules. Develops the attitude timeline for most efficient pointing of the Spacecraft mission objectives.

Environmental Systems Engineer: Monitors cabin environmental control system, cooling systems, and cabin pressure control systems

Instrumentation and Communications Systems Engineer: Plans and monitors in-flight communications and instrumentation systems configurations.

CAPCOM Vehicle Communicator: Primary communicator between flight control and crew.

X. SAFETY

X.I Spaceport Safety

One of the main driving Spaceport evaluation criteria is making sure that the risk to the public, to personnel at the take-off and landing area, and to national resources is minimized to the greatest degree possible. Launch/takeoff risk definition should be established based on a standard of a collective risk level of not more than 30 casualties in 1 million (30×10^{-6}) for the general public and not more than 300 casualties in 1 million (300×10^{-6}) for essential launch/takeoff area personnel.

The basic standard for the general public is not more than the risk voluntarily accepted in normal day-to-day activities.

Spaceport Safety department shall review, approve, monitor, and impose safety holds when necessary, on all prelaunch and launch operations to ensure that the hazards associated with propellants and other hazardous systems do not expose the general public to risks greater than those considered acceptable by national law and documents. The Spacegate concept is based on maximization of usage of existing sites, but the selected sites for suborbital operations shall undergo the process of Safety risk management as a one time, early system assessment activity, aimed at initial identification of hazards in all departments and operational activities of the spaceport, including those related to suborbital vehicle operators and supporting entities that operate at and directly around the spaceport; once hazards are identified, analysis and assessment of the risks posed by these hazards shall be conducted, as well as identification of controls to mitigate the risks to as low a level as is reasonably practicable; in this way, hazards are prevented from evolving in accidents or serious incidents. This process may eventually lead to some specific infrastructure improvements and implementation of changes. Safety risk management provides the initial frame of reference against which assurance of safety is conducted on a continuous basis. The identified hazards should cover both flight safety of crew and passengers, and safety of the people on the ground.

The following operational activities should be considered when developing the Safety risk management process:

- Spaceport operator core operational activities, i.e. the support to the takeoff operation and landing of suborbital vehicles.
- The provision of Air Traffic Management on the surface of the spaceport and in the vicinity of the spaceport (reflecting the range envelope of the suborbital vehicle) while airborne, especially when this service is provided by the spaceport operator.
- The maintenance of the spaceport.

- Support activities to the spaceport, e.g. servicing and ground-handling of the suborbital vehicle, transporting crew and passengers to the suborbital vehicle.
- The storage, handling and transportation of solid and liquid propellants. Risk controls should include safe distances between different explosive hazard facilities, and between an explosive hazard facility and public areas. Also, the public should not be exposed to hazards due to the initiation of explosives by lightning.

Special emphasis shall be given to the Spaceport Safety Critical Systems that shall include all airborne and ground subsystems of the Spaceport Safety System. The Spaceport Safety System consists of airborne and ground flight termination systems (FTSs), airborne and ground Range Tracking Systems (RTSs), and the Telemetry Data Transmitting System (TDTS). All Spaceport Safety critical systems shall be designed to ensure that no single point of failure, including software, will deny the capability to monitor and terminate or result in the inadvertent termination of a launch vehicle or payload, as applicable.

The Spaceport shall ensure that all personnel, located on site or on any supporting site, within the Spaceport area, are provided protection from the hazards associated with Spaceport operations.

There are no explicit regulations concerning Safety Management System for Spaceports however, for example, the FAA-AST have stipulated that Spaceports have to obtain an Environmental Assessment (EA). Within the EA there are limited requirements concerning health and safety and handling of rocket propellants; however this does not constitute a formal Safety Management System (SMS,) as required of existing airports, and hence it is important that the Spaceports should have a formal Safety Management System (SMS), tailored to the requirements of suborbital vehicles and their unique operations. A Safety Management System (SMS) should ensure that all departments of the spaceport are continually aware of the safety hazards present, are able to prioritize these hazards based on safety risk, act if the safety hazard is too high by mitigating the risk, and assure that the mitigation action works.

The Safety Management System (SMS) does not necessarily generate the need for an additional set, or duplication of documents. The SMS requirements should complement the procedures already documented, especially for aerodromes extending their operation to suborbital launches.

There are four components of an SMS:

- Safety Policy and Objectives

- Safety Risk Management
- Safety Assurance
- Safety Promotion

X.II Take-off and landing Safety

Take off trajectories shall be developed considering the location of potential abort landing sites, and avoiding hazardous terrain, such as mountain ranges that may complicate search and rescue operations in the event of emergency return-to-base. For example, the Decimomannu site appears to offer proper terrain and surround conditions favorable to suborbital operations. Specific screenshots of the Decimomannu runway are shown in Fig. XXIII and Fig. XXIV.



FigXXIII: Decimomannu runway (Google Earth)

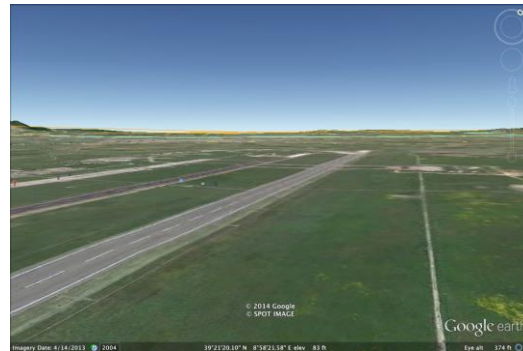


Fig.XXIV: Decimomannu runway and surroundings (Google Earth)

Proper alternate to takeoff and alternate to landing sites shall be selected to ensure safety in case of emergency, malfunctions or bad weather conditions. In the case of Decimomannu airport, the civil airport of Cagliari Elmas may be a proper alternate airport. For ferried launch vehicles or launch vehicles capable of flying under jet power, trajectories shall be planned such as the engine is ignited over sparsely or unpopulated areas and away from air traffic.

X.III Aircraft Safety

It is assumed that the aircraft used is already certified for the Suborbital Spaceflight, including the fulfillment of all Safety Requirements related to the Airframe, Propulsion and Systems.

X.IV Flight Crew Safety / Survival Systems

Suborbital vehicle design involves unique features and innovative fabrication processes coupled with the latest engineering analysis to produce vehicles flying beyond Mach 3 to reach 100 km and above. The vehicle ground and flight test numbers will be low and they will not be certified per their orbital (and aviation) counterparts. Therefore during the early development and commercial operating phase, the analysis confidence levels will be lower than certified vehicles. Additionally the designs are different using various launch methods, different propellants, engines etc. and so for commercial human suborbital spaceflight the protection of flight crew and spaceflight participants should be analysed effectively not only for normal flight conditions but also for abnormal and emergency conditions. In particular, deterioration of a contingency situation can continue until the point when it becomes necessary to escape or abandon the spacecraft to ensure the survival of the crew and participants on board. Contingencies scenarios shall be considered to address relevant flight personnel survival capabilities. These should include system failures and emergencies such as fire, collision, toxic atmosphere, decreasing atmospheric pressure and medical emergencies among others.

The Vehicle design and operations shall allow for safe abort, including as necessary flight personnel escape and rescue capabilities, for all flight phases starting with takeoff operations. Survival Systems, in this sense are related to the vehicle only, and provide escape, safe haven and emergency egress. Survival Equipment include both personnel life support and protective equipment (such as spacesuits, personal oxygen systems) and also equipment onboard to assist in emergencies, such as fire-fighting and medical capabilities.

The escape system, including any sensor, equipment and circuitry shall comply with the requirements of Design to Tolerate Failures and of Design for Minimum Risk. Possible survival and escape systems shall include:

- Vehicle Suborbital Parachute
- Occupant Parachutes
- Protection Space Suit
- Ejection seats
- Survival Pods
- Encapsulated Seat
- Specific Inflight Crew Escape System

Fig. XXV shows a typical concept of crew survival escape system

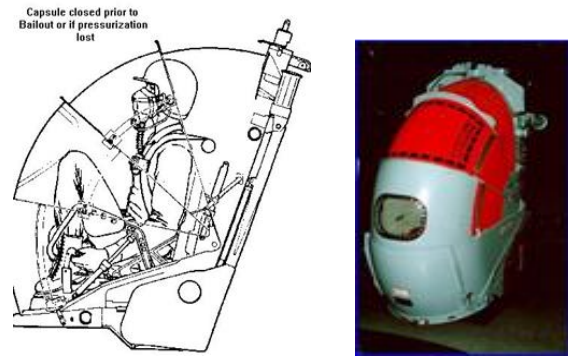


Fig. XXV: Concept of Crew Survival Escape System

XI. REGULATORY

XI.I General

Europe applies to suborbital aircrafts the ICAO definition found in Annex 8 of the Chicago Convention, “an aircraft is any machine that can derive support in the atmosphere from the reactions of the air other than the reactions of the air against the earth’s surface.” As a result, suborbital vehicles would fall under the legal regime pertaining to aircraft, necessitating certificates of airworthiness as per the rules set forth by the EASA and ICAO. Hence, there are two distinct differences between the US and European models. While the US regime is based upon licensing, in which the operator bears full responsibility for operations, the European centers rely upon certification, since the certifying authority bears some portion of responsibility; hence, Europe treats suborbital flight as predominantly a part of aviation, bringing it into the ICAO regime for international air law. The overall schematic of involved organizations is shown in Fig. XXVI

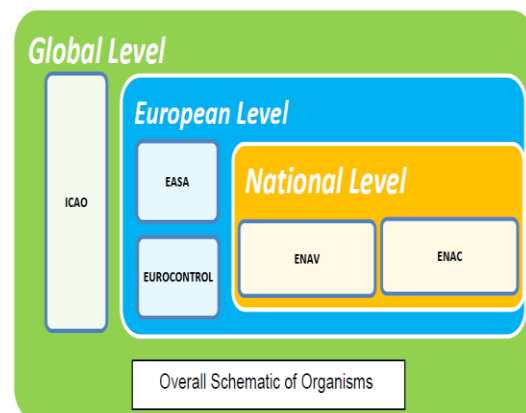


Fig. XXVI: Regulatory Organisms

In the USA, the XCOR Lynx vehicle [9] will operate as an FAA AST-licensed suborbital reusable launch vehicle. XCOR already has successfully passed the AST licensing process with an earlier vehicle concept, and is actively involved in the development of the statutory and regulatory framework within which Lynx will operate. Lynx will have aircraft-like operations up to four times per day from any licensed spaceport with a 2,400 meter (7,900 ft) runway, suitable abort options, fast turnaround (two hours), low maintenance intervals (designed for 40 flights before preventive maintenance action), and low cost operations. Lynx operates under visual flight rules (VFR). In Europe the EASA's jurisdiction ends when the activity is occurring in outer space. At that point, Member States' national responsibility takes over, in accordance with Article VI of the Outer Space Treaty requiring States to authorize and continually supervise the activities of their nationals in space. To perform an intercontinental point-to-point suborbital trajectory, a vehicle must be designed to reach the necessary speed and manage the thermal environment of transiting the atmosphere both during takeoff and landing. In order to carry passengers through international borders, the spacecraft should have undergone an internationally accepted certification process and comply with normal aviation legislation.

XI.II Airspace / Air Traffic Management

The European Regulation (EC) needs to harmonize the safety element as applied to aerodrome/spaceports and Air Traffic Management (ATM)/(ANS) and define the implementation rules, including the safety requirements. Currently, ATM/ANS for suborbital flight in the US is handled on an as needed basis but will have to integrate within the existing ATM/ANS system in use for aviation. Sub-orbital operations to and from the same spaceport are likely to be operated through a variety of spacecraft systems, operating in different ways, flying several profiles and requiring various airspace solutions to support such operations. Specific airspace solutions would need to be designed on a case-by-case basis, taking into account particular system requirements.

In same case a cylinder of Special Airspace, with a radius of 10–20 nautical miles, would be enough to allow a typical launch and recovery profile, avoiding the necessity for large volumes of airspace. The flight profile, proposed in this paper for example, will likely include a gradual circling descent – unlike the space shuttle, which flew a steep straight-in approach, operating at an 18°–20° angle on final approach.

Point to point intercontinental spaceflight, at suborbital level, is still theoretical. With no operating example the level of information, regarding airspace requirements, is minimal. If operating from an existing busy commercial aerodrome, the integration with general air traffic, without the need to employ Special Airspace, would be essential.

Suborbital flights operating from Point to Point will generate a need for en-route separation. However, beyond the departure and approach phases, separation with other en-route traffic would not be necessary, due to the altitude at which a spacecraft will operate.

There will be a requirement for the launch operator/spaceport operator to ensure that the required airspace/ATC procedures are in place. These arrangements should include the allocation of appropriate radio frequencies for communication with the ATC. The frequencies would be assigned by the relevant aviation authority, through international agreement, for operations extending into outer space. This system is already in place through ICAO, in a manner that will ensure compliance with the International Telecommunication Radio regulations.

XI.III Regulatory in Italy

In Italy specific very important steps are being carried out to bring up to speed the regulatory system, at least initially to allow starting of suborbital experimental activities. On March 12th 2014 at Washington DC, in the occasion of the Open Workshop 'The New Frontiers for Research & Aerospace Technologies', Hypersonic and re-entry vehicles, organized with the strong support of Colonel Roberto Vittori, FAA and ENAC (The Italian Authority of Civil Aviation) signed a Memorandum of Cooperation in the development of Commercial Space Transportation, and a follow-on working agenda was generated identifying specific areas of interest. One of these areas was the setup of a proper suborbital flights regulatory strategy, and additional aspects such as licensing versus aviation-like, specific ad-hoc approach and the relevant legal requirements, liability, insurance issues. A few days later, a second Memorandum of Cooperation was signed between ENAC and the Italian Air Force. An increased interest in Italy toward the suborbital activities was apparent during the International Symposium: 'Hypersonic: from 100,000 to 400,000 ft' held in Rome, Italy, on June 30th-July 1st 2014.

XII. CONCLUSIONS

Basing upon the Spacegate Operation Concept and the initial set of Top Level Operation Requirements derived during earlier studies, specific preliminary aspects relevant to the development of a suborbital end-to-end mission scenario have been

evaluated, and some important driving operating and safety aspects have been addressed. Specific ground sites in Italy are considered potentially suitable for suborbital operations because of favorable aspects, such as surrounding landscape, vicinity of cities or populated areas (noise and debris impact), weather, airport dimensions, commercial and scheduled flights, available runways and dimensions, available Nav aids, airspace, military activities. The execution of suborbital activities requires the development of a proper Ground Segment that has to include a Control Center with the associated specific functions. A SSTO take off concept with horizontal takeoff and an atmospheric reentry with horizontal landing, according to the typical Spacegate spiral shaped maneuver were evaluated through the development and execution of specific simulations; the simulations results show for the defined test case the vehicle ascent profile and attitude data during both takeoff and reentry, as well as the feasibility of the spiral reentry maneuver that should improve the pilot control capability. The various Safety aspects were analyzed, starting from the driving criteria to select a Spaceport and put in place a Safety Risk Management process, through the guidelines to planning the proper takeoff and landing trajectories. Special emphasis has been given to flight crew safety and survival systems that largely affect the design and operations of suborbital vehicles. The implementation of the suborbital flights in Italy will be based, at least initially, on the follow on of the Memorandum of Cooperation between FAA and ENAC and the subsequent one between ENAC and the Italian Air Force. The activities will somehow refer to the current FAA approach for regulatory and certification process.

ACRONYMS LIST

| | |
|----------|--|
| A | |
| ABN | Aerodrome beacon |
| ALS | Approach lighting system |
| ALTEC | Advanced Logistics Technology Engineering Center |
| AMSL | Above mean sea level |
| ANS | Air Navigation Services |
| ATM | Air Traffic Management |
| C | |
| COMSTAC | Commercial Space Transportation Advisory Committee |
| CRI | Certification Review Item |
| CTR | Control |

D

| | |
|----------|---|
| DARPA | Defense Advanced Research Projects Agency |
| E | |
| EA | Environmental Assessment |
| EASA | European Aviation Safety Agency |
| ELV | Expandable Launch Vehicle |
| ENAC | Ente Nazionale Aviazione Civile |
| ENAV | Ente Nazionale assistenza al Volo |
| ESA | European Space Agency |
| EVA | Extra-Vehicular Activity |

F

| | |
|---------|---|
| FAA | Federal Aviation Administration |
| FAA/AST | FAA Office of Commercial Space Transportation |

H

| | |
|------|---|
| HAF | High Altitude Flight |
| HIRL | High intensity runway edge lights |
| HJ | Sunrise to Sunset |
| HR | Hours |
| HTHL | Horizontal Take-off, Horizontal Landing Hazardous Materials |

I

| | |
|------|--|
| IATA | International Air Transport Association |
| ICAO | International Civil Aviation Organization |
| ISO | International Organization for Standardization |
| ISS | International Space Station |
| IT | Information Technology |

L

| | |
|-----|-----------------|
| LEO | Low Earth Orbit |
|-----|-----------------|

M

| | |
|---------|---|
| MoD | Ministry of Defence |
| NAS | National Air Space System |
| NASA | National Aeronautics and Space Administration |
| NASTAR | National Aerospace Training And Research Centre |
| NATO | North Atlantic Treaty Organization |
| NAVAIDS | Navigational Aid System |
| NLA | New, Large Aircraft |
| NM | Nautical Miles |

O

| | |
|-----|--------------------|
| OST | Outer Space Treaty |
|-----|--------------------|

P

| | |
|------|-----------------------------------|
| PAPI | Precision approach path indicator |
|------|-----------------------------------|

R

| | |
|------|--------------------|
| REDL | Runway edge lights |
|------|--------------------|

| | |
|----------|---------------------------------------|
| RLV | Reusable Launch Vehicle |
| RWY | Runway |
| S | |
| SFC | Surface |
| SSTO | Single Stage to Orbit |
| T | |
| TAR | Terminal area surveillance radar |
| TSTO | Two Stage to Orbit |
| U | |
| UN | United Nations |
| UNL | Unlimited |
| V | |
| VTHL | Vertical Take-off, Horizontal Landing |
| VTVL | Vertical Take-off, Vertical Landing |

BIBLIOGRAPHY

[1] IAC-13,B6,1.9x17812,The Italian Spacegate: Study and Innovative approaches to future generation transportation based on high altitude flight, F.Santoro, A. Bellomo, A.Bolle, R.Vittori

[2] Meccanica del Volo, Carlo Casarosa, Plus

[3] FAA Commercial Space Transportation Experimental Permit Program Report to COMSTAC

[4] Federal Aviation Administration-Launch and reentry Vehicles
(http://www.faa.gov/about/office_org/headquarters_offices/ast/licenses_permits/launch_reentry/)

[5] SESAR Joint Undertaking
(<http://www.sesarju.eu/>)

[6] Eurocontrol, The European Organization for the Safety of Air Navigation, SESAR and Research
(<http://www.eurocontrol.int/content/sesar-and-research>)

[7] Accommodating sub-orbital flights into the EASA regulatory system, Jean-Bruno Marciacq; Yves Morier, Filippo Tomasello, Zsuzsanna Erdelyi, Michael Gerhard

[8] EASA, European Aviation Safety Agency, Certification Specifications for Normal, Utility, Aerobatic, and Commuter Category Airplanes
([http://www.easa.eu.int/agency-measures/docs/certification-specifications/CS-23/CS-23%20Amendment%20%20\(corrigendum\).pdf](http://www.easa.eu.int/agency-measures/docs/certification-specifications/CS-23/CS-23%20Amendment%20%20(corrigendum).pdf))

[9] The advantages, potentials and safety of VTOL suborbital space tourism operations, Norul Ridzuan Zakaria, Nasri Nasrun, Jalaluddin Abu, Asmadi Jusoh, Liayana Azim, Prof. Md. Azlin Said, Md. Sayuti Ishak, Norul Rafidi Zakaria

[10] XCOR Aerospace, About Lynx,
<http://xcor.com/lynx/>

[11] IAASS – ISSB-S-1700, Rev. B/2010: Space Safety Standard – Commercial Human Rated System

[12] IAASS – Guideline for the Safe regulation, design and operation of Suborbital Vehicles – Dec 2013

[13] IAASS – Safety Design for Space Systems - Gary Musgrave Ph.D, Axel Larsen, Tommaso Sgobba

[14] EC N° 216/2008: Common rules in the field of civil aviation and establishing a European Aviation Safety Agency

[15] CAA-UK: CAP 1189 UK Government Review of commercial spaceplane certification and operations – July 2014

[16] FAA - Established Practices for Human Space Flight Occupant Safety (Draft) – Sep 2013