International Association for the Advancement of Space Safety

Guidelines for the **safe** regulation, design and operation of **Suborbital Vehicles**

IAASS Suborbital Safety Technical Committee Manual

Dec 2013

FOREWORD

By Isabelle Rongier – President of the IAASS SS TC

The International Association for the Advancement of Space Safety (IAASS) has provided valuable advice, guidance and training for a global and thriving space community for a number of years. The Suborbital Safety Technical Committee (SS TC) is our newest committee having been formed in 2011. The purpose of forming this committee was to support the new regulators and designers within the suborbital domain. The SS TC's members include suborbital vehicle designers as well as systems safety specialists, space lawyers and hence the committee is well placed to understand the emerging issues.

As we have seen over the formative stages of the suborbital player's developments, accidents have occurred and sadly scientists have died. Breaking new ground and developing novel technologies is clearly not without risk but how far should we let this industry grow before implementing well-founded and rationalized guidelines? The IAASS strongly believes guidelines are needed now, before the first commercial flights have commenced (in regards the forerunners such as Virgin Galactic and XCOR) and especially for those vehicle designs under development.

The guidelines will evolve over time and also be updated with lessons learned and new regulations. I commend these guidelines for the suborbital community and look forward to strengthening relationships for an open and learning culture as the nascent industry develops.

AMENDMENTS

Issue No.	Date	Amendment Details/Rationale
1	Dec 2013	Initial Issue post 6th IAASS Conference

GLOSSARY

Acronyms

AC	Advisory Circular
ALOS	Acceptable Level of Safety
AMC	Acceptable Means of Compliance
ARA	Authority Requirements for Aircrew
ARO	Authority Requirements for Air Operations
ATM/ANS	Air Traffic Management/Air Navigation Services
CAMI	Civil Aerospace Medical institute
CFIT	Controlled Flight Into Terrain
COEST	Centre of Excellence for Commercial Space Transportation
CRM	Crew Resource Management
DOT	Department of Transport
EA	Environmental Assessment
EASA	European Aviation Safety Agency
EC	European Commission
E_C	Expected Casualty
ECG	Electrocardiogram
ECLSS	Environmental Control and Life Support System
ECSS	European Cooperation for Space Standardization
ESA	European Space Agency
ESARR	EIROCONTROL Safety Regulatory Requirement
FAA-AST	Federal Aviation Administration Office of Commercial Transportation
GM	Guidance Material
GP	General Practitioner
IAASS	International Association for the Advancement of Space Safety
ICAO	International Civil Aviation Organization
IR	Implementing Rules
LOC-I	Loss of Control - Air
LOC-G	Loss of Control - Ground
MAC	Mid Air Collision
NASA	National Aeronautics and Space Administration
OPS	Air Operations
OR	Operator Requirements
ORA	Organization Requirements for Air Crew
ORO	Organization Requirements for Air Operations
PTF	Permit to Fly
RCofA	Restricted Certificate of Airworthiness
RTC	Restricted Type Certificate
RLV	Reusable Launch Vehicle
SFP	Spaceflight Participant
SMM	Safety Management Manual
SMS	Safety Management System
SO	Suborbital level (in relation to software)
SoA	Suborbital Aircraft
SPI	Safety Performance Indicator
SS	Suborbital Safety
SSE	Safety Significant Event
SW	Software
TC	Technical Committee
VT/VL	Vertical Take-off/Vertical Landing

Definitions

1st Party: Individuals paid for (employees) and directly involved in operating/ controlling/ supporting the suborbital vehicle

2nd Party: Individuals participating in the flight who are not 1st parties or 3rd parties

3rd Party: The uninvolved public

Component: executable piece of software located in a subsystem or system

Accident: For the purpose of this document, an accident is an unplanned event or series of events that results in death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment. A 'mishap' is also used by the FAA-AST in this context i.e. an unsuccessful mission due to an accident or incident.

Hazard: A physical situation, *condition*, or state of a system, often following from some initiating event, that *unless mitigated* may lead to an accident.

Failure: The inability of a system, subsystem, component, or part to perform its required function within specified limits, under specified conditions for a specified duration.

Fault: an abnormal condition or defect at the component, equipment, or sub-system level which may lead to a failure

Mission: a suborbital mission is from engine start (includes engine start of mother-ship) to the end of the landing phase (and taxying if appropriate) i.e. the mission stops when the vehicle is then towed or handled by ground personnel.

Safety-critical software: software product (which may consist of more software components) supporting a safety critical function that if incorrectly or inadvertently executed can contribute to the occurrence of a hazardous system state.

Safety Management: The systematic management of the risks associated with operations, related ground operations and engineering or maintenance activities to achieve high levels of safety performance

Spaceflight Participant: People who have paid for a suborbital flight or people who are participating in scientific research/experiments; they are 2nd parties per the above classifications

Suborbital Flight: There are various types of vehicles under development, ranging from vertical launch/vertical landing, air launch to horizontal take-off and landing. These vehicles are intended for suborbital flight, meaning a flight up to an altitude at which the vehicle does not reach its corresponding orbital velocity.

In general terms this is a flight up to the ‘edge of space’ i.e. not leaving the Earth’s Atmosphere. This is nominally the Von Karman Line (100km as recognized by the Fédération Aéronautique Internationale), however the IAASS recognize that some vehicles will reach a higher altitude for specific suborbital profiles yet not attain the required orbital escape velocity and therefore no specific delimitation line is set.

Suborbital Vehicle: Any vehicle conducting suborbital flights per the definition above; this includes Reusable Launch Vehicles (RLV) and Suborbital Aircraft (SoA)

Subsystem: Part or element of a system

System: A set of interdependent elements constituted to achieve a given objective by performing a specified function [based on IEC 50:1992 as quoted by ECSS]

1. INTRODUCTION

By Dr Andy Quinn – Chair of the IAASS SS TC

The suborbital industry is showing real progress in terms of development and there are many companies competing in the race to achieve suborbital commercial operations. These companies have experienced many challenges in their endeavors to win this new "space race", ranging from difficulties in obtaining investment, technical difficulties and also with regulatory issues. To date, we can only judge the progress of some of the leading suborbital companies by the successful milestones achieved or the accidents encountered.

The progress of Virgin Galactic has been well documented as they continue with their test schedule culminating in air-launched rocket (short) powered flights. However the design development at Scaled Composites has not been without incident; an explosion occurred during 'simple' cold-flow rocket tests in 2007, killing 3 scientists. Other accidents have occurred at Armadillo Aerospace & Blue Origin: they both use a vertical take-off/vertical landing (VT/VL) approach and the Blue Origin test vehicle Sheppard suffered an 'instability' resulting in thrust termination and destruction of the vehicle; the same occurred to Armadillo's 'STIG' vehicle. Herein lays the fundamental concern of the IAASS Suborbital Safety Technical Committee – growth without guidance.

In Europe, EADS-Astrium is developing a suborbital aircraft (SoA) under a possible EASA certification approach. Other space-plane models include the Rocketplane XP (from the United States). These rocket-powered suborbital vehicles have aerospace engines for normal take-off and (capabilities of) powered landing. Additionally XCOR's Lynx suborbital vehicle is rocket-powered from the runway with a single pilot and one passenger. Development of these aircraft-style space-planes, as well new VT/VL vehicles, requires novel approaches in determining safety criteria and requires rationalization/harmonization of the licensing and certification approaches to cater for worldwide operations.

New Commercial Spaceports

Along with novel suborbital vehicles, new commercial spaceports are being developed; either by extending existing airports with extra facilities and certifications, or by developing totally new infrastructures similar to an airport, with runways and terminals to support passengers and other commercial payloads including scientific experiments. The two major spaceport developments are Spaceport America and Mohave Air/Space Port in the USA. Other developing spaceports outside the USA include Caribbean Spaceport on Curacao Island, Spaceport Malaysia, Spaceport Sweden plus a proposal for the United Arab Emirates. The emergence of these new commercial spaceports at multiple locations around the world creates the need for global air and space traffic management approaches as well as spaceport safety guidelines.

Main Issues to Resolve

There is currently only one framework that covers suborbital flights – the US Licensing approach (which may adopt a certification framework later). In Europe there is a possible Certification (phased) approach for suborbital (and orbital) vehicles. This could present

difficulties for US-based vehicles with a launch license to integrate into a European framework. Also there is no set safety target or defined safety requirements for existing US-based suborbital vehicle designers in relation to Acceptable Levels of Safety for those on board. The IAASS SS TC would argue that the two forerunners (Virgin Galactic and XCOR) need guidance as much as those currently developing vehicles or those at the concept stage, despite lack of actual suborbital historical data. Indeed we believe that enough expertise and know-how exists to develop initial and rationalized safety targets and vehicle requirements that will not stifle the industry.

Suborbital Technical Committee: Purpose and Goals

I proposed the formation of a Suborbital Safety Technical Committee at the 4th IAASS Conference (Huntsville, Oct 2010) and in May 2011 the committee was formalized. The purpose was to contribute to the advancement of the field by addressing the technical and regulatory challenges of the emerging industry. The committee required experts from the field with a passion to influence decision makers for safer suborbital operations. The committee is formed by representatives from Government, Industry and Academia around the world; namely the FAA (CAMI), the EASA, Rocketplane XP, EADS-Astrium, Swiss Space Systems (S3), Space Tourism Society, Orbspace, McGill University, International Institute of Air & Space Law, Saturn SMS Ltd, NLR-ATSI, Space Horizon, GMV, techcos GmbH, Stardust Consulting, NewSpace Consultant Corporation, AltecSpace, Knights Arrow and Embry-Riddle Aeronautical University. Appendix 1 details the SS TC members and in particular acknowledges those who contributed to this Manual.

The goal of the committee is to contribute to the development of suborbital industry guidelines and best-practices towards a global harmonization on the various challenges facing the industry today. The technical issues that are and will be addressed cover definition and harmonization of safety criteria and regulatory approaches, as well as providing guidance on system safety engineering practices from design to operations. Crew and passenger (or *spaceflight participant*) safety considerations as well as spaceport planning and operations are also within the scope of the terms of reference of this technical committee. In January 2013 the SS TC workshop ratified 5 sets of guidelines and these are now compiled within this Guidance Manual. The workshop was held at the GMV facilities in Madrid – Muchas Gracias.

The aim of this Manual is to evolve as the industry evolves by providing rationalized guidelines from International industry players. It is intended that the SS TC will continue to produce guidance material for those topics considered to be a priority i.e. because there is currently no guidance or the existing guidance is not suitable for International operations. The new guidance material will be integrated into the Manual's relevant Chapters and the Manual will be published at each IAASS Conference going forward; this can also include updates to existing guidance material based on occurrences or new information being available; the current guidance in development has a placeholder in each Chapter for.

Finally a reminder on why this Manual exists: '**Safety is Not an Option**'[1]

[1] 'Safety is Not an Option' was the theme of the 6th IASS Conference in Montreal, May 2013

2. GUIDANCE ON REGULATORY FRAMEWORKS

2.1. CONSIDERATIONS FOR HARMONIZED REGULATORY FRAMEWORKS

GENERAL

The Technical Committee's objective in drafting these guidelines is to describe the frameworks now in place to regulate suborbital vehicles and flights, to briefly identify the gaps between these, and to offer a practical and rationalized solution. We recognize that air law controls air space and space law controls space. We seek a harmonized approach to address the situation where a State goes above its sovereign air space with its own vehicle to suborbital space for a brief period of time, 3 – 5 minutes, with no other State's involvement.

The two most developed systems in place are found in the US and in Europe. Europe's system may change. This document addresses the regulations in place as of 21 December 2012. In the US, the 1984 Commercial Space Launch Act established the Department of Transportation (DOT) as the regulatory agency over space launches, with the mandate to promote economic growth and entrepreneurial activity, to encourage the private sector to provide launch and reentry vehicles and related services, to simplify and expedite issuance of commercial licenses, and to facilitate and encourage the use of government developed space technology. [2] This mandate includes suborbital transportation.

The DOT delegates this authority to its agency, the Federal Aviation Administration (FAA). The FAA, through the Office of Commercial Space Transportation (AST), is responsible for licensing launch and reentry activities and launch sites (spaceports),[3] authority which was extended to include reentry of reusable launch vehicles in the Commercial Space Act of 1998.[4] The primary objective in licensing is to protect public safety as well as to promote US interests, while remaining in compliance with the US international obligations, including those arising under the Outer Space Treaty.

As yet, the European Union has not taken an official position on suborbital flights. However, the regime proposed by the European Aviation Safety Agency (EASA) takes a completely different approach than the US on the issue of regulating suborbital flight. In the US, suborbital vehicles are licensed[5] as spacecraft and launches are treated as space activities. While both are regulated within the FAA, this is accomplished in a completely separate branch, the Office of Commercial Space Transportation or AST. Licenses must be issued for launch vehicles, launch and reentry events, and launch sites.

Europe has been applying to suborbital craft 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*

[2] 51 U.S.C. 50901

[3] The FAA's authority, carried out by the AST derives from the CSLA of 1984. 51 USC 50901 *et seq*. Launch is defined in 14 CFR 401.5 and for an RLV ends after reaching apogee if the flight includes a reentry or after the vehicle lands on or impacts Earth and after the completion of activities necessary to effect the safe return of the vehicle on the ground.

[4] H.R. 1702/P.L. 105-303.

[5] License; meaning that the operator meets the FAA-AST launch licensing requirements – this does not include a license (or approval or certification) for the safe assurance of the vehicle. In terms of safety it only requires the operator to meet the 'expected casualty (Ec) target of 30x10-6 per mission.

reactions of the air other than the reactions of the air against the earth's surface." [6] 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. Distilled to the most salient characteristics, they are, first, that the US regime is based upon licensing, in which the operator bears full responsibility for operations while the European centers upon certification, wherein the certifying authority bears some portion of responsibility,[7] and second, that Europe treats suborbital flight as predominantly a part of aviation, bringing it into the ICAO regime for international air law.[8]

It is important to remember that this difference in classification of suborbital vehicles does not alter some basic realities. First, regardless of how classified while in airspace and despite the fact that there is no absolute as to where that begins and outer space begins, once a vehicle gets to a certain point, sovereignty ends and space law precepts control. Orbit is not always necessary.[9] 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.[10] That obligation cannot be delegated to the EASA, regardless of how the vehicles are classified and certified.[11] Other jurisdictions with domestic space law do not address suborbital transportation.

In the US, 14 CFR 400 *et seq*. contains the regulations pertaining to suborbital commercial space transportation. In Europe, the Basic Regulation found in EC 216/2008 and amended in 1108/2009 governs.[12] As the TC is proposing a procedure encompassing a formal agreement or handshake between the relative parties subsequent to approval for three prongs of safety assessment, this section will describe where and what regulations now exist regarding those prongs, which are: 1) suborbital vehicle safety approval; 2) suborbital operator approval; and 3) suborbital flight/launch approval notification. In addition, this section also includes guidelines pertaining to spaceports and ATM/ANS. Flight Crew Licensing can be found in the IAASS Suborbital Safety TC Operations Group guidelines.

Safe vehicle:

In Europe, there are several choices of certificates available for certification: 1) Type Certificate (TC); 2) Restricted Type Certificate (RTC); the TC and RTC is normally for vehicles produced in

[6] This leaves out hovercraft as well as rockets.
[7] Marciacq et al., *supra* note 6 at 4.
[8] Even ICAO does not rule out the possibility that suborbital flights could be subject to international air law at such time that they traverse foreign airspace, concluding that the relevant Annexes to the Chicago Convention "would in principle be amenable to their regulation." Concept of Suborbital Flights: Information from the International Civil Aviation Organization (ICAO) (19 March 2010) UN COPUOS Legal Subcommittee A/AC.105/C.2/2010/CRP.9.
[9] Art. 2(1) of the Convention on Registration of Objects Launched into Outer Space, 1975 (1023 UNTS 15). A very persuasive argument could be made for the idea that 100/110 km above sea level is recognized as the delimitation in customary international law.
[10] The fact that Member States bear responsibility for the space activities of their nationals does not preclude Member States' jurisdiction within their national airspace. These are two separate issues.
[11] The European position with regard to registration of suborbital vehicles appears to be that it is unnecessary as they are launched into outer space, but not into orbit, the parameter set forth in Article II of the Registration Convention in order to keep track of objects remaining in outer space, particularly in a certain orbital position. Jean-Bruno Marciacq, *supra* note 9 et. al. at 14.
[12] EC Regulation No. 216/2008 was amended in 1108/2009, which covers aerodromes. Together they are often referred to as the Basic Regulation. *See also* Commission Regulation (EU) No 290/2012 if 30 March 2012 regarding technical requirements and administrative procedures related to civil aviation aircrew and Commission Regulation (EU) No 965/2012 which deals with technical requirements and administrative procedures pertaining to air operations.

large numbers; 3) Restricted Certificate of Airworthiness (RCofA); the RCofA is a possibility where only a very limited series of vehicles are produced (based on Specific Airworthiness Specifications) and 4) Permit to Fly (PtF)[13]; the PtF is a type of airworthiness certificate for test flights pending the delivery of a TC/RTC or RCofA – the PtF cannot be used for commercial flights. Safety is a factor in the design of the vehicle to be certified and this is against specific codes of airworthiness.

In the US, the suborbital vehicle is licensed rather than certified. Licensing and re-entry of reusable launch vehicles is as per 14 CFR 431.1 to 431.93. Safety is also a factor but not against specific requirements (per certification) – there is a target of $30x10^{-6}$ per mission for Expected Casualty (Ec) which concerns death/injury to 3rd parties (the non-involved public). Licenses are either mission-specific [14] or for an operator,[15] as described in the next sub-section. Experimental permits for reusable suborbital rockets are granted under 14 CFR 437.1 to 437.95.

In order for these two frameworks to be applicable to an international harmonized approach, evidence is required demonstrating that the vehicle is safe (to a set of internationally recognized guidelines to internationally recognized acceptable levels of safety); ergo the vehicle will require a 'Safety Approval'.

Operator approval

Article 8 of the European Basic Regulation sets forth the requirements for operators.[16] In addition, Commission Regulation (EU) No 290/2012 of 30 March 2012 lays down technical requirements and administrative procedures related to civil aviation aircrew (ARA) while Commission Regulation (EU) No 965/2012 performs the same functions relative to air operations (ARO). These two regulations are reflected in Decisions 2012/006/Directorate R (ARA) and 2013/018/R (ARO). Explanatory Notes for both decisions are available. These decisions obligated the EASA to issue Acceptable Means of Compliance and Guidance Material for the application of the Basic Regulation and its Implementing Rules.

After demonstration of capability and means of discharging responsibilities associated with the privileges afforded to commercial operators, a certificate is issued to the operator. The certificate specifies the privileges and scope of operations.[17] Non-commercial operators shall declare their capabilities and means of discharging their responsibilities unless the implementing rules determine another procedure.[18]

As noted, in the US, 14 CFR 431.3(b) authorizes a licensee to launch and re-enter or land any of a designated family of RLVs that fall within approved parameters, including launch sites and trajectories, transporting specified classes of payloads to any re-entry site or pre-designated location (by licensee). This type of license is valid for a two-year renewable term.

Again, in order for these two frameworks to be applicable to an international harmonized approach, evidence is required demonstrating that the operator obtains an approval to operate (to a set of

[13] EC Regulation No. 216/2008 Article 5.
[14] 14 CFR 431.3(a).
[15] 14 CFR 431.3(b).
[16] These must comply with the essential requirements found in Annex IV.
[17] EC Regulation No 216/2008 Article 8 2.
[18] EC Regulation No 216/2008 Article 8 3.

internationally recognized operator requirements [such as flight crew licensing, operator licensing, and an operator Safety Management System (SMS)]); ergo the operators will require a 'Suborbital Operating Approval'.

Spaceport considerations

In Europe, spaceports will be subject to the same process as aerodromes, as they are considered commercial operations of suborbital vehicles.[19] Regulation (EC) No 216/2008 as amended by Regulation (EC) No 1108/2009 includes aerodromes in the European aviation safety regulatory system and assigns the EASA to develop Implementing Rules (IRs) to ensure safety. The IRs are based upon the SARPs found in Annex 14, Volume 1, Aerodromes.[20]

The rules are structured in three parts. The first, Part-AR, contains requirements for the competent authority in three sections: General Requirements, Management and Oversight, and Certification and Enforcement.[21] The next two parts are to be fulfilled by the aerodrome/spaceport operator. The second, Part-OR, is in five sections: General Requirements, Certification – Declaration, Operator Responsibilities, Management, and Manuals. The last, Part-OPS, contains three sections and includes Aerodrome Data, Aerodrome Operational Services, and Equipment and Installations and Aerodrome Maintenance. Cognizant of the challenges of the transition period, EASA has developed procedures to convert existing certificates and licenses into the new aerodrome certificate based upon the Basic Regulation and attendant IRs. Flexibility is built into the system, as the EASA is able to accept deviations that predate the Certificate Specifications.[22]

Hence, spaceports in Europe will be certified when compliant with their certification basis (which includes incorporating a formal SMS), just as aerodromes are, founded upon specifications slated to be available in 2013.[23] These specifications provide for a predetermined level of safety which does not yet exist.

The FAA AST grants spaceport licenses as per 14 CFR 420 *et. seq.* and re-entry sites as per 14 CFR 433.3. As with launch licenses safety is a key factor and is mainly covered in the Launch Safety requirements and within the Environmental Assessments – there is no definitive SMS for spaceports.

As before, for these two frameworks to be applicable to an international harmonized approach, evidence is required demonstrating that the Spaceport obtains an approval to operate which includes implementing a formal SMS that recognizes the delta between aerodrome and spaceport operations/safety management. The Spaceport SMS guidelines are detailed within the IAASS Suborbital Safety TC Operations Group guidelines.

[19] As noted, in Europe these are certified as aircraft.
[20] NPA 2011-20(A) at 2. "ICAO Annex 14, Volume 1, Aerodromes (Fifth edition, July 2009), has been used as the baseline, but not exclusively for all future European rules." *Ibid.*at 6.
[21] EASA NPA 2011-20(A) *Authority, Organization and Operations Requirements for Aerodromes* at 2.
[22] NPA 2011-20(A) at 3.
[23] Jean-Bruno Marciacq et. al. at 16.

ATM/ANS considerations

In Europe, the Basic Regulation (EC)[24] addresses the need to harmonize the safety element as applied to aerodrome/spaceports and ATM/ANS and tasks the implementing rules under development with the requirement that they be in the context of a comprehensive review of the safety requirements in the single European sky legislation.[25] The Spaceport SMS guidelines (including some references to ATM/ANS safety considerations) are detailed within Chapter 4.1.

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.

GUIDELINES
(a) Suborbital Vehicle Safety Approval:

(i) The suborbital vehicle designer/operator is to obtain an approval that the vehicle is safely designed and operated as defined by:

(1) Safety Criteria. Meeting the safety target of $1x10^{-4}$ per mission for catastrophic loss (per IAASS Suborbital Guidelines (see Chapter 3.1)

(2) Safety Requirements. Meeting agreed technical safety requirements (to be developed by the IAASS or appropriate International body).

(b) **Suborbital Operator Approval**:

(i) The suborbital vehicle operator is to obtain an approval that they meet the following requirements:

(1) Sufficient personnel with the required experience for the type of operations requested;

(2) 'Safe' aircraft, suitable for the type of operations requested (per (a) above);

(3) Acceptable systems for the training of crew and the operation of the aircraft (Operations Manual);

(4) A quality system to ensure that all applicable regulations are followed;

(5) The appointment of key accountable staff, who are responsible for specific safety critical functions such as training, maintenance and operations;

(6) Operators are to exhibit sufficient financial responsibility and/or liability insurance to adequately cover exposure for injury or death to second or third parties, in accord with both applicable domestic law and international law;

(7) Proof that the operator has sufficient finances to fund the operation;

[24] The amendments found in Regulation (EC) No 1108/2009 include aerodromes (spaceports).
[25] Regulation (EC) NO. 1108/2009 (18) referring to Regulations (EC) No 551/2004 and (EC) No 552/2004.

(8) The operator has sufficient ground infrastructure, or arrangements for the supply of sufficient infrastructure, to support its operations into the ports requested;

(9) The approval is held by a legal person who resides in the country or region of application;

(10) A safety management system (SMS), according to the Authority or ICAO requirements – shall be employed by the operator and approved by the relevant authority.

(c) **Suborbital Flight/Launch Approval**:

The suborbital flight/launch must be approved by the relevant authority by the relevant jurisdiction where the mission will be completed:

(i) Authorities;

(1) The relevant authority must provide an approval

2.2. FRAMEWORK FOR SUBORBITAL NON-WINGED VEHICLES

In development

2.3. FRAMEWORK FOR PAYLOADS RELEASED FROM SUBORBITAL VEHICLES

In development

3. GUIDANCE ON TECHNICAL CONSIDERATIONS

3.1. SAFETY CRITERIA

GENERAL

There is currently no regulatory requirement for an explicit quantitative safety target that form part of explicit safety criteria for suborbital flights. The IAASS believes that it is important to set guidelines now even before the first flights and that these guidelines must be based on global opinion from within the safety and airworthiness/spaceworthiness field of expertise.

These IAASS proposed guidelines are not biased towards the FAA-AST requirements or any European-based requirements; instead the aim is to provide rationalized guidelines based on existing information and knowledge gained from recognized papers and conferences and industry knowledge.

This topic only concerns safety criteria and does not propose requirements for hazard identification and analysis; these will form part of different Suborbital Safety Technical Group task.

There are no explicit regulations concerning suborbital safety criteria however the FAA-AST have provided exemplar (or guidance) hazard analyses tables within Advisory Circular (AC) 437.55-1, dated April 20, 2007. These are based on MIL-STD 882 and other industry guidelines however it is considered that suborbital flights require more rationalized criteria. Within Europe various papers relating to suborbital frameworks and safety have been provided at previous IAASS conferences to inform the community of different approaches (to that of the FAA-AST) i.e. *Towards Regulating Sub-Orbital Flights An Updated EASA Approach*[26]

GUIDELINES

The Guidelines are based on a Safety Target approach which is a top-down strategy focusing on safety critical aspects. A catastrophic **Safety Target of $1x10^{-4}$ per mission** (whereby a suborbital mission is considered an arbitrary 1 hour flight in total) is considered the **Acceptable Level of Safety** (ALoS) for suborbital flights. As there is **no historical data and only/limited evidence** to derive a safety target value (or indeed a safety objective value) then this has been derived from the following:

(a) The European Space Agency (ESA) standards[27] have provided a Mission Safety Risk (crew safety risk) as;

(i) *The probability of a catastrophic event during the entire mission shall not exceed $1x10^{-4}$*

(b) The IAASS Space Safety Standard sets the orbital safety target as $1x10^{-3}$ per mission and therefore derives a suborbital safety target as one order of magnitude more safe, therefore sets this as $1x10^{-4}$ per mission

[26] Marciacq et.al, as presented to the 4th IAASS Huntsville, USA - Towards Regulating Sub-Orbital Flights An Updated EASA Approach

[27] ESSB-ST-Q-003-Issue 1, September 2012; System Safety Engineering; Safety Technical Requirements for Human Rated Space Systems, section 5.2.1

(c) This suborbital Safety Target value is pragmatically 'estimated' in the middle between orbital spaceflight and civilian aviation; whereby suborbital is arguably 100 times safer than Space Shuttle and 100 times less safe than commercial aviation with its extensive historical record (implicit safety target is a catastrophic loss of 1 in 1 million flying hours)

(d) Recognizing that novel systems (such as the rocket propulsion system) and the integration of spaceflight unique systems may be a driving factor in the system safety analysis and due to immaturity will be difficult to achieve safety objectives with high reliability rates; therefore within a safety target approach this will allow for the analysts to include vehicle developer/operator based mitigation such as abort procedures, systems redundancy and limitations on operating area, etc.

Probability Classification:

(e) The following table (Table 1) provides guidance on the application of the probability values. This is applicable to the safety target approach in that design engineers need to demonstrate each failure condition probability and that cumulatively the catastrophic failure conditions do not exceed the ALoS of $1x10^{-4}$ per mission (flight);

Likelihood	Quantitative Description	Qualitative Description (specific item i.e. system/sub-system) – up to hazard level	Qualitative Description (spacecraft fleet or inherent risk to people) – accident level
Frequent	$X > 10^{-2}$	Likely to occur several times in the life of the item; probability greater than 10^{-2}	Continuously experienced
Probable	$10^{-2} > X > 10^{-3}$	Likely to occur one or more in the life of the item; probability less than 10^{2} and greater than 10^{-3}	Will occur frequently
Occasional	$10^{-3} > X > 10^{-4}$	Likely to occur sometime in the life of the item; probability less than 10^{-3} and greater than 10^{-4}	Will occur sometime
Remote	$10^{-4} > X > 10^{-5}$	Remote Likelihood of occurring in the life of the item; probability less than 10^{4} and greater than 10^{-5}	May occur sometimes
Extremely Remote	$10^{-5} > X > 10^{-6}$	Unlikely to occur in the life of the item; probability less than 10^{-5} and greater than 10^{-6}	Unlikely, but can reasonably be expected to occur
Extremely Improbable	$X < 10^{-6}$	So unlikely, it can be assumed occurrence may not be experienced in the life of the item; probability less than 10^{-6}	May not occur at all

Table 1: Probability Classifications

Severity Classification

(f) The following table (Table 2) provides guidance on the application of the severity classification. The severity classification table includes all severity considerations and is applicable to:

(i) Effect to People;

(A) 1st Parties (individuals paid for and directly involved in operating/controlling/the suborbital vehicle); also includes support personnel (such as maintainers) for inclusion in separate risk assessments for ground operations (see Spaceport Safety 4.1)

(B) 2nd Parties (individuals participating in the flight who are not 1st parties or 3rd parties)

(C) 3rd Parties (the uninvolved public)

(ii) Effect to the Asset (the vehicle) including human rated vehicles and unmanned vehicles

(iii) Effect to the Environment

Description & Category	Actual or Potential Occurrence	Effect To People			Effect to Asset		Effect to Environment
		1st Parties	2nd Parties	3rd Parties	Human Rated	Unmanned	
Catastrophic	Accident	More than one 1st Party deaths (for 2 or more flight crew); single death for single pilot operations	Multiple 2nd Party deaths	One or more 3rd Party death	Loss of spacecraft	Loss of spacecraft as unable to continue safe flight and landing	Extreme widespread environmental damage
Hazardous	Serious Incident - Asset or Accident (people death)	Single 1st Party death (for 2 or more flight crew); serious injury (single pilot ops) ; or excessive workload impairs ability to perform tasks	Single 2nd Party death	Serious injuries to more than one 3rd Party	Severe damage to spacecraft Large reduction in Functional capabilities or safety margins	Loss of spacecraft due to controlled (directed) termination over unpopulated emergency site	Severe environmental damage
Major	Major Incident	Serious injuries/ illnesses to 1st Parties (for 2 or more flight crew); minor injury (single pilot ops) ; Physical discomfort or a significant increase in workload	Serious injuries/ illnesses to 2nd Parties Physical discomfort	Serious injury to a single 3rd Party	Major damage to spacecraft Significant reduction in functional capabilities or safety margins	Severe damage to spacecraft Large reduction in Functional capabilities or safety margins	Major environmental damage
Minor	Minor Incident	Minor injuries/illnesses to 1st Parties (for 2 or more flight crew); serious injury (single pilot ops) ; Slight increase in workload	Minor injuries/illnesses to 2nd Parties	Minor injuries to more than one 3rd Party	Minor damage to spacecraft Slight reduction in functional capabilities or safety margins	Major damage to spacecraft Significant reduction in functional capabilities or safety margins	Minor environmental damage
Negligible	Occurrence without safety effect	Inconvenience	Inconvenience	Minor injury to a single 3rd Party	Less than Minor damage system	Minor damage to spacecraft Slight reduction in functional capabilities or safety margins	Less than minor environmental damage

Table 2: Severity Classifications

Accident Risk Classifications

(g) The following table presents an Accident Risk Matrix (ARM) for conducting Operator Safety Risk Management. This is to assess the risk of the different accidents concerning the operations (see Table 3 further below). This ARM provides classification of an accident risk as a result of the cumulative failure conditions plus operator controls; therefore it is applicable to the safety target approach.

(i) The Accident Risk Acceptability Criteria is detailed in Table 4 further below. The accident risks are deemed to be:

(A) A Class – Unacceptable

(B) B Class – Tolerable with mitigation plan and justification analysis

(C) C Class – Acceptable

	Severity (Safety Event)				
Likelihood/Probability	Negligible	Minor (Minor Incident)	Major (Major Incident)	Hazardous (Serious Incident)	Catastrophic (Accident)
Frequent $> 10^{-2}$	**B**	**B**	**A**	**A**	**A**
Probable 10^{-2} to 10^{-3}	**C**	**B**	**B**	**A**	**A**
Occasional 10^{-3} to 10^{-4}	**C**	**C**	**B**	**B**	**A**
Remote 10^{-4} to 10^{-5}	**C**	**C**	**C**	**B**	**B**
Extremely Remote 10^{-5} to 10^{-6}	**C**	**C**	**C**	**C**	**B**
Extremely Improbable $<10^{-6}$	**C**	**C**	**C**	**C**	**C**

Table 3: Operator's Accident Risk Matrix

Note: details Acceptable Level of Safety (Catastrophic Safety Target of $1x10^{-4}$)

Accident Risk Classification	Accident Risk Acceptance and Authorisation Criteria
A	**Unacceptable**
B	**Tolerable** but only with the authorisation of the Spacecraft Designer/Operator's President/Company Board and with an action plan to mitigate the risk supplemented by analysis (Decision Analysis) to justify the risk
C	**Acceptable**

Table 4: Accident Risk Acceptance Criteria

ICAO based Accident List/Safety Significant Event List

(h) To assist the Operator Safety Risk activities the following accident list and safety significant event list (SSE) is derived (and modified) from the ICAO approved list within Annex 13. This list is not necessarily exhaustive. Its purpose is to be able to join-up the design-level failure conditions (hazards) to the accidents (in fault trees/event trees). These relate to flight activities; for ground activities i.e. at the Spaceport see Chapter 4.1 in regards to health & safety based targets as part of the Spaceport SMS:

Accident No.	Accident Title	Accident Description	Notes/ Accidents Not Used (due subset of other SSE)
A1	CFIT	Controlled Flight Into Terrain – CFIT leading to loss of suborbital vehicle [assumes loss of all personnel on board]	
A2	MAC	Mid-Air Collision (MAC) leading to loss of suborbital vehicle [assumes loss of all personnel on board]	
A3	LOC-I	Loss of Control – In flight (LOC-I) leading to loss of suborbital vehicle [assumes loss of all personnel on board]	System/Component failure or malfunction – non-power-plant Note – this would lead to LOC so is not included. 1. Includes loss or failure of re-entry capability [assumes loss of all personnel on board] 2. Includes Failure of life support including depressurization hazard. [assumes loss of all personnel on board]
A4	LOC-G	Loss of Control – Ground (LOC-G) leading to loss of suborbital vehicle [assumes loss of all personnel on board]	
A5	Explosion	Explosion (Fuel Related) leading to loss of suborbital vehicle [assumes loss of all personnel on board]	
A6	Fire (flight)	Fire during flight* leading to loss of suborbital vehicle [assumes loss of all personnel on board]	*Flight considered from engines running to engine shutdown) – 'smoke' in itself will lead to incapacitation and/or loss of visibility in cockpit for example and therefore would lead to a different accident such as CFIT or LOC-I/G
A7	Fire (non-flight)	Fire on the ground not in flight, including post survivable crash and pre-engine start leading to loss of suborbital vehicle [assumes loss of all personnel on board]	
A8	Loss of Thrust	Loss of Thrust (system/component failure or malfunction – power-plant) leading to loss of suborbital vehicle [assumes loss of all personnel on board]	
A9	Structural Failure	Structural Failure leading to loss of suborbital vehicle [assumes loss of all personnel on board]	
A10	ECLSS failure	Failure of life support including depressurization hazard. [assumes loss of all personnel on board]	Includes failures of air supply, CO2 removal, heating/cooling, pressure, excessive noise, excessive vibration
A11	TPS failure	Loss or failure of re-entry capability [assumes loss of all personnel on board]	Potentially to be broadened to failure of re-entry capability also covering excessive g-loads

Table 5: Derived ICAO-based Flight Accident List

(i) The following Table 6 contains the ICAO based Safety Significant Events List;

Accident No. (SSE)	Safety Significant Event Title	Safety Significant Event Description	Notes/ SSE Not used (due subset of other SSE)
SSE1	Near MAC	A near collision requiring an avoidance manoeuvre, or when an avoiding manoeuvre would have been appropriate to avoid a collision or an unsafe situation (near MAC)	
SSE 2	Near CFIT	Controlled flight into terrain (CFIT) only marginally avoided An aborted take-off on a closed or engaged runway, or a take-off from such runway with marginal separation from obstacle(s)	A landing or attempted landing on a closed or engaged runway Take-off or landing incidents, such as undershooting, overrunning or running off the side of runways
SSE 3	Fire/Smoke	All fires and smoke in the passenger compartment or in cargo compartments, or engine fires, even though such fires are extinguished with extinguishing agents	
SSE 4	Near LOC-I (System failures In-Flight)	Multiple malfunctions of one or more suborbital vehicle systems that seriously affect the operation of the suborbital vehicle	Failure of more than one system in a redundancy system which is mandatory for flight guidance and navigation. Includes operation outside planned re-entry sequence leading to excessive heat load and/or excessive g-loads
SSE 5	Crew Incapacitation	Any case of flight crew incapacitation in flight	
SSE 6	Emergency Oxygen Use	Any events which required the emergency use of oxygen by the flight crew	Includes failure of life support including depressurization hazard.
SSE 7	Near Structural Failure	suborbital vehicle structural failure or engine disintegration which is not classified as an accident	
SSE 8	Fuel Emergency	Any fuel state which would require the declaration of an emergency by the pilot	
SSE 9	Near LOC-I (performance)	Gross failure to achieve predicted performance during take-off or initial climb/rocket phase	
SSE 10	Near LOC-I (Ops)	Weather phenomena, operation outside the approved flight envelope or other occurrences which could have caused difficulties controlling the suborbital vehicle	'System failures' removed from this category as they are really covered by the description in SSE4

Table 6: Derived ICAO-based Flight Safety Significant Event List

3.2. SOFTWARE QUALIFICATION

GENERAL

One of the key aspects for the success of future suborbital flights industry will rely on the QUALITY of the service provided (understanding QUALITY as a synonymous for customer's trust that can be measured in terms of compliance with functional, reliability, safety, robustness or security expectations). Particularly SAFETY, as a system property, must be present from the very beginning of the development life cycle of any suborbital system or component.

The purpose of this section is not to re-invent the wheel in terms of software development and qualification but to inform the community that there are differences in the development processes between aviation-based standards and space-based standards and as such suborbital vehicle developers need to be aware of this. The rationale is that although aviation standards (such as DO-178B/C) provides effective guidance on demonstration of reliability of the software by requirements traceability, functional test coverage and robustness testing, it does not provide guidance on direct analysis of the safety related features of the software i.e. the potential contribution of anomalous behaviour of the software to an aircraft (platform) failure condition at the system level. The space standards (such as ECSS-Q-80C) call for this software safety analysis approach, and therefore compliance with those aspects of the ECSS standards (for instance) that do not duplicate DO-178B guidance will enable cross-compliance to be achieved. Hence the suborbital vehicle designer needs to be aware of both sets of requirements and this section examines both sets and provides additional guidance.

The role of software is becoming more and more important because of the number of critical functionalities supported by software is increasing on new aircrafts and specifically in avionics; this may also be the case for suborbital vehicles. The safety assurance process must ensure the deterministic behaviour of Software during operation. But this process may be undermined by major restrictions stemming from the intrinsic complexity of these types of developments and from the market constraints demanding to shorten system's time-to-market.

The big issue is then how to guarantee software QUALITY and SAFETY in this context for suborbital flights. SAFETY and QUALITY properties should be equally understood by all partners and system QUALIFICATION is a way for guaranteeing not only that the required level of SAFETY and QUALITY is achieved but also to ensure this common understanding. It is clear that embedded software in suborbital aircraft must be supported by a systematic, formal and documented Safety Assurance Process. In order to deal with the complexity and constraints of the Software development process and guarantee expected SAFETY and QUALITY, the Safety Assurance Process should have the following characteristics (synonymous with most aviation and most space based software standards):

- It should support SW Specification and Design with a thorough Hazard Analysis and Risk Assessment processes.

- Risk Assessment should not only consider technological risks to reach quality, functional and performance expectations, but human factors or operational environment considerations, like for instance Interfaces (with operators, other systems or input/output data), Operation states or maintenance and reparation actions.
- It should support appropriate SW Validation and Verification processes.
- It should ensure compliance with relevant guidelines.
- It should be compatible with state-of-the art software development processes and technologies.

The objective of using these systematic methodologies is to improve the safety, reliability and quality of the system functionalities controlled by software while reducing development costs and schedule. However, whereas the benefits and advantages of it may be evident from the development side of the equation, it also poses significant challenges to the verification and validation portion of the development process.

GUIDELINES
(a) Potentially applicable Software Safety Guidelines

Suborbital vehicles may eventually use per-qualified subsystems and/or software components. If the development of such items has followed one of the guidelines listed next in this subsection or similar ones they can be included in safety critical functions aboard a suborbital vehicle provided the following properties can be demonstrated:

- The equivalency of the software criticality in the original context of the item with the SO-Level (suborbital level) assigned to it in the suborbital vehicle under consideration. This includes an impact analysis, a justification for the suitability of the software component for the intended use and an assessment of the software integration into the vehicle systems.
- The availability of appropriate process and product assurance material.
- Safety analysis of Subsystem/component integration has been carried out.
- Subsystems / components fulfil with System safety objectives and requirements.
- Identification and validation of the COTS

Software of unknown origin or without the aforementioned credentials cannot be considered suitable for safety relevant application in a suborbital vehicle. Given the lack of operational experience in suborbital flight, a “proven in use” argument without the abovementioned substantiation is not acceptable for software.

Software Re-Use

Suborbital vehicle designers should also take into account SW Re-use. The utilization of already available SW components reduces the total cost of the development; however be aware that Software Re-use/COTS must be reviewed for appropriate 'context' i.e. the Ariane 4 to Ariane 5 case.

Ground Software should also be considered i.e. Mission Control SW, Ground Station SW and Training SW.

User SW interface should also be considered, with reference to the Human I/F (Pilots) and Human Errors.

The next list provides some potentially applicable software reference standards/guidelines:

- **FAA**
  - *Launch Safety Software and Computing System Requirements* (AFSPC 91-712)
- **EASA References**
  - CS23-1309
- **NASA References**. NASA-STD-8719.13B – Software safety standard. NASA Software Safety Guidebook. NASA-STD-8719.13B specifies the software safety activities, data, and documentation necessary for the acquisition or development of software in a safety-critical system. It describes the activities necessary to ensure that safety is designed into software that is acquired or developed by NASA and that safety is maintained throughout the software and system life cycle
- **ESA References**. ECSS software standards, in particular ECSS-E-40 (Software Engineering) and ECSS-Q-80C (Software Product Assurance)
- **European Air Traffic Management safety regulation references** (based on EC Commission Regulation laying down common requirements for the provision of air navigation services). Particularly, Software in ATM Functional Systems, referred by ESARR 6, which deals with the implementation of software safety assurance systems, which ensure that the risks associated with the use of software in safety related ground-based ATM functional systems, are reduced to a tolerable level. The purpose of this requirement is to provide ATM safety regulatory bodies and ATM service providers with a uniform and harmonised set of safety regulatory requirements for use of software in ATM ESARR 4 - Risk Assessment and Mitigation in ATM functional systems.

- **DO-278/ED109**, for CNS/ATM (or ground plus satellite) systems.
- **DO-178/ED-12** for airborne systems and equipment certification.
- **IEC 61508**, for general application, for example being mandated for a/o European railway industry. Particularly, the part IEC 61508-3 covers the lifecycle of safety-critical software.
- **IEC 60880-2** for software in the nuclear industry
- **FDA 1252** and **IEC 62304** dedicated to software in medical devices
- **UK SW01**, for software safety assurance in Air Traffic services, similar in reach as DO-278/ED109

(b) Recommended Approach for Suborbital Vehicles

Deriving appropriate process and product assurance rigor

The initial risk identified during preliminary hazard analysis is to be chosen as starting point to assure the use of appropriate software development methods, indicators and verification/validation to prevent systematic faults with the necessary rigor. As software does not exhibit probabilistic failure behaviour, no failure likelihood consideration is meaningful. Further guidance on what may be considered appropriate product and process assurance is given in subparagraph (d).

Assigning identified software criticality levels to architecture elements

Software levels shall be assigned on the assumption of a serial functional link between systems/subsystems from sensor to actuator to perform a vehicle level function unless the system architecture clearly demonstrates the potential to systematically contain or limit subsystem errors/failures.

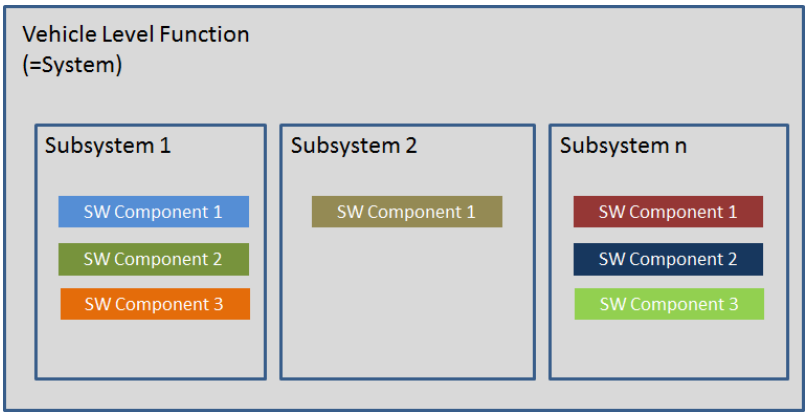

Figure 1: Relationship System-Sub-system-Component for Software considerations

A reduction of the assigned SO-Level is possible if suitable evidence for low risk exposure or credits for system architecture aiming at overall risk reduction is presented. Credit from architecture and/or design decisions can be taken, if a risk reduction from the point of view of

systematic errors and potential common cause failure scenarios is credible. This would apply for example for dissimilar redundancy or real time diagnostics. The relevant tolerable hardware failure rate may be influenced by such design choices as well.

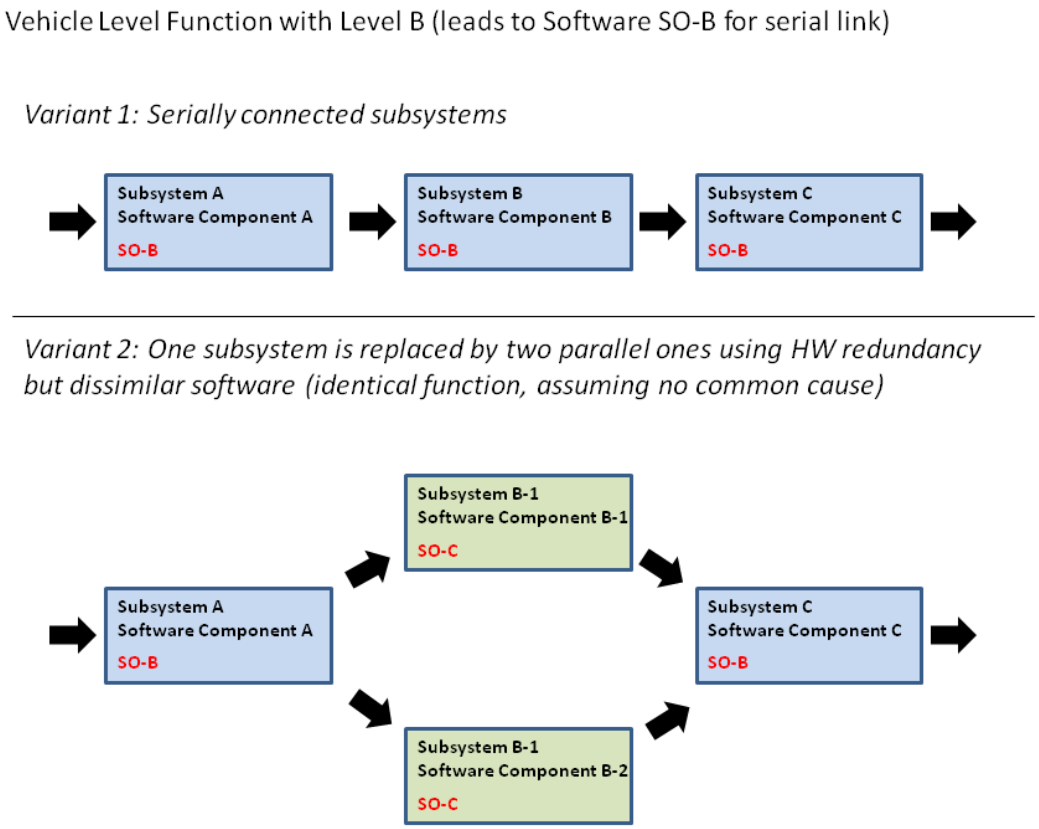

Figure 2 : Example assigning software criticality levels

Recommended Assurance Levels for Suborbital Vehicles

In terms of deriving software levels of assurance for suborbital vehicles, DO-178B/C (chapter 2.2.2) is the recommended standard and the derived levels are detailed in Table 7.

SW Level for suborbital vehicles	Associated Severity	SW Level in Do-178B/C
SO-A	Catastrophic	DAL A
SO-B	Hazardous	DAL B
SO-C	Major	DAL C
SO-D	Minor	DAL D
SO-E	Negligible	DAL E

Table 7: Equivalence of SW criticality levels for suborbital application with aircraft DAL in DO-178B/C

Recommended Processes for Suborbital Vehicles

(A) All safety-critical software used in on board or in associated ground systems of suborbital vehicles should be qualified in accordance with appropriate recognised standards considering the context of the suborbital flight profile.

(B) A risk assessment and mitigation process should be conducted to an appropriate level to ensure that due consideration is given to the software systems for the suborbital vehicle functions (on-board or ground systems) and to identify safety objectives and requirements.

(C) The risk assessment and mitigation process should be documented.

(D) The assurance level required for safety related software items, which determines the rigour of the software development process, should be based on the risk classification provided in Table 7 in this document and must give sufficient confidence that the software can operate and be operated tolerable safely.

(E) The assurance level allocated to software should be commensurate with the most severe effect that software malfunctions or failures may cause.

(F) Software safety assurance activities should be defined and implemented to meet safety objectives and requirements. The rigour of assurance activities shall increase with the criticality of the software.

(G) Software systems considered separately and in relation to other systems must be designed so that the software contribution to the risk of an accident has been reduced to a tolerable level.

(H) Software safety assurance activities should be documented, as part of the risk assessment and mitigation process, in a verifiable and auditable manner to demonstrate that :

a. All safety issues have been successfully addressed to reduce to a tolerable level with a level of confidence according to the criticality of the software.

b. Software safety requirements are complete and correct and compliant with the system safety requirements.

c. Software safety requirements are traceable and are satisfied.

d. The verification of the software requirements are correct and complete.

e. Software implementation contains no function whose improper functioning would reduce adversely affect safety or perform unintended under the operating and environmental conditions.

f. Systems will provide with timely, accurately and appropriate warnings when a corrective action is needed.

g. Any Human-Machine Interface (HMI) has been designed to minimise human errors.

h. Information will be provided describing unsafe system operating conditions and their corrective actions

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3.3. SOFTWARE/HARDWARE SAFETY & SYSTEMS REQUIREMENTS

In development

3.4. SUBORBITAL PROPULSION SYSTEM SAFETY

In development

3.5. PAYLOADS SAFE RELEASE FROM SUBORBITAL VEHICLES

In development

3.6. SAFETY FACTORS FOR STRUCTURES & LARGE SCALED PRESSURIZED STRUCTURES

In development

3.7. ABORT MODES/REDUNDANCY/SURVIVAL SYSTEMS & EQUIPMENT FOR SUBORBITAL VEHICLES

In development

4. GUIDANCE ON OPERATIONAL CONSIDERATIONS

4.1. SPACEPORT SAFETY

GENERAL

There are no explicit regulations concerning SMS for Spaceports, however the FAA-AST have stipulated that Spaceports are 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 SMS as required of existing airports and hence the IAASS consider that Spaceports should have a formal SMS that is tailored to the requirements of suborbital vehicles and their unique operations.

This Guidance Manual is based on the ICAO Doc. 9859 – Safety Management Manual and tailored to include Spaceport safety criteria.

GUIDELINES

Safety management is the systematic management of all activities of an operator to secure an acceptable level of safety. Systematic management entails a plan-do-check-act cycle. An acceptable level of safety is defined by a statement explicitly specifying the safety objectives of the involved spaceport, meeting as a minimum the provisions of the applicable regulatory requirements, if available.

An 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 poses too high a risk by mitigating the risk, and assure that the mitigation action works.

At spaceports that have only a manager and perhaps minimal support staff to carry out the responsibilities, the manager may handle most of the SMS processes alone. At larger spaceports, the complexity and departmentalization of duties may require that more personnel be involved in the SMS.

The SMS does not necessarily generate a 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

The two core operational activities of an SMS are safety risk management and safety assurance. These two core operational activities take place under the umbrella provided by

safety policy and objectives and are supported by safety promotion. Safety risk management and safety assurance are the operational activities underlying a performing SMS. Safety policies and objectives and safety promotion provide the frame of reference as well as the support that allows the operational activities underlying safety risk management and safety assurance to be effectively conducted.

(a) Safety Policy and Objectives

(i) The safety policy should include a safety goal-setting statement by the highest management. It should include the commitment to make safety the highest priority, and the commitment to continually improve safety. It should be part of a wider policy, integrating capacity, economic, environmental and social aspects.

(ii) The safety policy should include a clear statement about the provision of the necessary resources for the implementation of an SMS.

(iii) The safety policy should include which personnel is consulted and informed on safety related matters, and should encourage all personnel to report safety issues without fear of reprisal.

(iv) A safety objective should be focused on one thing only, it should be possible to measure if the objective is met, the objective should be within the spaceport operator's capabilities, the objective should be relevant to safety, and there should be a defined deadline for meeting the objective.

(v) The decision making process of defining safety actions should be clearly defined. Safety actions should be formulated in response to the results from either:

(1) The safety risk management process, in case risks associated with potential threats to safety are considered unacceptable and therefore require risk mitigating actions.

(2) The safety assurance process, in case the current level of safety is perceived not to be in conformance with the desired standard and therefore requires corrective actions.

(vi) It should be recognised that results of safety actions may have unwanted side-effects, and therefore it always has to be assessed to which extent they could invoke a new safety threat.

(b) Safety Risk Management

(i) Safety risk management should be considered as an early system design activity, aimed at initial identification of hazards, analysis and assessment of the risks posed by these hazards, and formulation of controls to mitigate the risks to as low a level as is reasonably practicable, of the operations related to suborbital vehicle launches. Safety risk management should be considered as a one-time activity that is conducted either during system design or when facing significant changes to the original system. Safety risk management provides the initial frame of reference against which assurance of safety is conducted on a continuous basis.

(ii) The inputs, methodologies applied, and outputs of the Safety Risk Management process should be documented in a safety case, or a collection of safety cases. A safety case is a structured argument, supported by evidence, which provides a comprehensible and valid case that the spaceport is as safe as reasonably practicable for the intended suborbital operations i.e. that the safety targets and safety requirements (per Chapter 3.1) have been met.

(iii) The importance of safety risk management for spaceports for the emerging industry of commercial suborbital flight should not be underestimated. Proper tools should be available to assure the risks of spaceport operations can be assessed credibly, without the benefit of historic data on safety performance. Since commercial sub-orbital operations from spaceports are new, proper hazard identification, risk assessment and mitigation are of paramount importance to attain an acceptable level of safety from the start of operational readiness of the spaceport.

(iv) The process of safety risk management should strive to identify all hazards in all departments and operational activities of the spaceport, including those that interface the hazards faced by ATM, suborbital vehicle operators and supporting entities that operate at and directly around the spaceport, and describe all controls in place to prevent hazards from evolving in accidents or serious incidents. The identified hazards should cover both flight safety of crew and passengers, and occupational safety of the people on the ground.

(v) The spaceport operator should determine the severity and likelihood of the worst credible outcome of each hazard using qualitative and/or quantitative methods. The spaceport operator should develop its own definitions and categories of severity and likelihood, to commensurate with its operational needs and complexity.

(vi) The following operational activities should be considered when identifying hazards, assessing the risk of these hazards and determining controls of these safety risks:

(1) Spaceport operator core operational activities, i.e. the facilitation of the launch of suborbital vehicles and, in some cases, the facilitation of the landing of suborbital vehicles.

(2) 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.

(3) The maintenance of the spaceport.

(4) Support activities on the spaceport, e.g. servicing and ground-handling of the suborbital vehicle, transporting crew and passengers to the suborbital vehicle.

(5) 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. The public should not be exposed to hazards due to the initiation of explosives by lightning.

(6) The operations of the customers of the spaceport, i.e. the operators of suborbital vehicles.

(vii) It is noted that significant safety risks could arise from security hazards. The identification, assessment and mitigation of these hazards should be part of a separate Security Management System.

(c) Safety Assurance

(i) Safety assurance should be a continuous activity that is conducted non-stop to ensure that the operations related to suborbital vehicle launches are properly protected against hazards.

(ii) The key activity of safety assurance should be the monitoring and measurement of the actual safety performance. To do so safety performance indicators (SPI) should be defined.

(iii) Defined SPI should be measurable, and the spaceport should be able to influence the processes that affect the SPI such that safety can be actively managed and safety objectives are met.

(iv) The organization should be aware of what is measured by the SPI. An SPI can be used to:

(1) Estimate the probability of an accident of serious incident by assessing the relation between the SPI and the occurrence of an accident or serious incident.

(2) Measure the performance of risk controls in place to prevent hazards to develop into accidents and serious incidents.

(v) The spaceport should consider the use of a combination of reactive, proactive and predictive safety performance indicators:

(1) Reactive indicators measure events that have already occurred and that impact the safety performance, e.g. serious incidents and accidents.

(2) Predictive indicators measure events that in itself do not impact the safety performance, but which, when combined with other events, may lead to an accident or serious incident.

(3) Leading indicators measure parameters of the organization or operation that do not cause harm, but are believed to have a relation with safety. There should always be a connection between a leading indicator and the unwanted outcomes that their monitoring is intended to warn against. This connection should be determined and verified.

(vi) The spaceport should ensure that lessons-learnt on the management of safety are documented, promulgated throughout the spaceport organization, and used when relevant.

(vii) The spaceport should develop and maintain a formal process to identify new insights in the working of an SMS, and should act if these insights can offer an improvement to the current SMS.

(d) Safety promotion

(i) A spaceport and its personnel should have sufficient competence to perform the assigned functions and the underlying tasks. Therefore the safety training program that ensures that personnel are trained and competent to perform the SMS duties should have a scope appropriate to each individual's involvement in the SMS.

SPACEPORT SAFETY MANAGEMENT MANUAL

The spaceport should develop and maintain a safety management manual (SMM) to communicate its approach to the management of safety throughout the organization.

Typical sections in the SMM should include:

- Spaceport Safety Management System
    - Spaceport Air Traffic Management
        - Spaceport ATM Safety Analysis/Safety Case
        - Spaceport Functional Safety Criteria (see below)
    - Spaceport Health & Safety Management
        - Spaceport Health & Safety Analysis/Safety Case
        - Spaceport Health & Safety Criteria (see below)
- Spaceport Safety Organization
- Safety Review Board
- Spaceport Emergency Planning
- Safety Communication & Reporting

SPACEPORT SAFETY CRITERIA

(e) Loss of Suborbital Vehicle at Spaceport

The maximum tolerable probability of the spaceport directly contributing to a catastrophic accident involving a **suborbital vehicle** shall not be greater than $3x10^{-5}$ **per mission**[28]. The maximum tolerable probabilities of less severe accidents and incidents shall be derived from this safety target[29].

(f) Loss of Life at Spaceport

[28] This figure is based on 1 catastrophic accident every 10 years for a spaceport with 10 missions each day.
[29] For definitions of likelihood and severity levels one is referred to Task 1 (Safety Criteria) of the Technical Working Group.

The maximum tolerable probability of any hazardous condition at the spaceport that may cause death or serious injury to the **uninvolved public or supporting personnel** shall be extremely improbable, and shall not be greater than 10^{-6} per spaceport **operating hour** for an accident at or around the spaceport involving a suborbital vehicle, a rocket, or rocket propellant and resulting in death or serious injury to the uninvolved public or supporting personnel.

4.2. FLIGHT CREW & SPACEFLIGHT PARTICIPANT MEDICAL & TRAINING

GENERAL

There is currently limited experience for manned suborbital flights and much discussion has taken place at conferences and within working groups as to what guidelines are required for the nascent industry. It is anticipated that much can be learned from the early test flights of leading suborbital companies however these initial flights will be conducted with flight crew having had test pilot or astronaut experience and hence will be generally fit and competent to deal with the complex and demanding suborbital flight profile (including non-nominal situations). The IAASS believes that it is important to set guidelines now even before the first flights and that these guidelines must be based on global opinion from within the safety, operations and aerospace medical field of expertise.

Where current complimentary work is being carried out then this work may be included as references if deemed by the IAASS SS TC to be applicable for **worldwide suborbital operations**.

GUIDELINES

(a) Flight Crew – Guidance on Qualifications

(i) Pilots license must be valid with an instrument rating. As a minimum requirement it is desirable that the pilots have had previous experience of high performance aircraft so that it is more representative of flight conditions (than say air liners). Additionally previous test pilot experience is desirable:

- **Commercial Pilot License (CPL)** + Instrument Rating and High Performance Airplane Rating (HPA), or
- **Airline Transport Pilot License ATPL**

(ii) Class I Aerospace Medical Certificate must be current and the operator must satisfy themselves with the fitness and health of the pilot for future suborbital flights i.e. the operator should include a questionnaire regarding operations, conditions etc. that may contraindicate a pilot from suborbital flights.

Pilot Medical certification should be assessed by:

- Aero Medical Examiner (AME), **and**

- Operator Medical Center (like NASA Medical Center)

Flight Crew Training

(b) Flight Crew – Guidance on Training;

(i) Ground training

(A) Technical aspects of vehicle (technical manuals)

(B) Operating aspects (flight manuals, normal and emergency operating)

(C) Crew Resource Management (CRM). As well as appropriate CRM between the flight crew, additional training is necessary for the interaction with and between the SFPs (see below).

(D) First Aid training. Depending on vehicle type and sortie profile, if medical first aid equipment is carried then the flight crew and SFPs (see below) must be trained in its use in order to provide first aid medical assistance in the event of a medical emergency. This should not interfere with the control of the vehicle i.e. the crew must prioritize the situation (hence the need for item 3 above – CRM).

(E) Fire Fighting training. Depending on vehicle type, fire-fighting equipment (for the cabin) may be provided and therefore the flight crew must be trained in its use.

(F) Emergency Egress and Landings. Briefings and relevant simulated training (see ii(c.)(3) below) should be scheduled within the crew training (with survival training as appropriate)

(ii) Simulator training. The simulator devices must have high fidelity, concurrency and a reasonably realistic capability (notwithstanding that g-forces will not be representative – the mitigation for this is that there is separate centrifuge training mandated). The simulator training required should include;

(A) Familiarization of the cockpit and cabin layout including use of all equipment

(B) Nominal Flight Sorties

(C) Off-Nominal Flight Training

(1) Flight Aborts

(2) All identified Flight Emergencies

(3) Emergency egress training for all crewmembers (if the sortie is over any water then this should cover ditching and egress drills within a simulated water environment)

(iii) Physiological Training;

(A) G-Force Training. It is essential that all flight crew undergo g-force training (high g-force, microgravity, rapid changes) in order to cope with the flight profile and any off-nominal

situations that may subject the flight crew to excessive g-forces. Flight Crew should maintain g-force currency and operators should retain records for this purpose.

(B) Hypobaric Training. It is essential that all flight crew in control of the vehicle undergo hypobaric training (altitude chamber) in order to recognize the signs and symptoms associated with decompression including hypoxia.

(C) Parabolic flight training. It is desirable that flight crew undertake Parabolic training to simulate specific flight conditions such that they are able to understand and deal with SFP issues.

Flight Crew Medical and Other Relevant Beneficial Guidelines[30]

(c) Pre-flight medical evaluations would be beneficial in the very early developmental flights to reduce risk and liability if any unpredicted medical issues occur

(d) Post-flight medical debriefs with data collection, especially in the early stages of suborbital space flight experience

(e) Periodic re-evaluation of the current medical guidelines during the early stages of developmental flights to respond to any medical issues that may be discovered

(f) Anti-G suit use on early flights until more experience has been obtained as there will be significant (>3) +Gz acceleration forces in the flight profile and deterioration of +Gz tolerance may occur due to the "push-pull effect" after several minutes of 0g. There is no data concerning +Gz tolerance following four minutes of 0g

(g) Pressure suit use may be adopted by some commercial space flight operators as it would be beneficial in the case of failure of the pressurized vehicle.

(h) Wearable Biomedical Monitoring Equipment for flight crew should be considered (especially during training and flight crew evaluation)

(i) Radiation limits. Although the COEST paper[31] suggests that standard American health and safety limits could apply to the suborbital domain and this is a 1mSv/year, the IAASS SS TC consider more rationalized limits should be applied as per the following table. Additionally the following should be considered;

(1) Female Flight Crew. Those female flight crew who become pregnant should be restricted from flying until after birth

(2) Solar Flares. These occur once or twice a decade and can deliver doses of 1000mSv to 5000mSv. These events should be monitored and no suborbital spaceflights allowed during the period due to the limits mentioned below.

[30] As recommended by the Aerospace Medical Association (AsMA) position paper
[31] Center of Excellence for Commercial Space Transportation (COECST): Flight Crew Medical Standards and Spaceflight Participant MEDICAL Acceptance Guidelines for Commercial Space Flight, June 30, 2012

(3) Dosimeters should be worn by all crew. In particular during the test flight phases the dosimeters will provide valuable data from which the flowing table could be modified.

(4) Portable Breathing Apparatus (PBA). PBA could be part of the minimum equipment list for in-flight fire-fighting capabilities.

Population	Normal Annual Exposure	Annual Limit	Career Limit
General Public	1mSv	1mSv	-
Frequent Flyer of Future long distance Suborbital flights (participants)	1-2mSv	2mSv	-
Nuclear Radiation Workers	6-50mSv	20mSv	100mSv (20mSv/yr averaged over 5 years)
Future long distance Suborbital flight (pilots)	7-15mSv	50mSv	-
Suborbital Pilots	**7-15mSv**	**50mSv**	**100mSv**
Orbital – NASA Astronauts	36mSv	500mSv (Blood Forming Organs)	2000mSv + 0.0075 x (Age – 30(male) or 38(female))

Table 8: Guidelines on Suborbital Radiation Limits

Note on table rationale: For the Suborbital Pilot, the table assumes 3 trips per week with 1-hour exposure time (launch from 50,000ft, microgravity, re-entry to 50,000ft). This equates to 144 hrs per year compared to 400 hrs for the 'future suborbital long distance pilots'[32]. The annual nuclear radiation worker limit of 20mSv is from the National Radiation Protection Board occupational exposure limits. A sub-orbital pilot career limit (possibly 5-10 yrs) would have to be investigated such that the radiation exposure limits remain below cancer forming levels i.e. The reason for a 100mSv career limit for the pilots is that above 100mSv, the probability of cancer (rather than severe illness) increases with dose. Higher exposure can lead to radiation sickness and illness (levels of up to 10,000mSv would cause death).

Space Flight Participant Medical Guidelines

(j) SFP Guidance on Medical Requirements;

(i) SFP's own General Practitioner (GP) certificate of wellness. The operator should provide the GP with a list of aspects to consider for the preliminary medical of the SFP

(ii) Operator's medical certificate (assessment of the SFP) by a Flight Surgeon/ aerospace medical practitioner

[32] NASA Technical Report by Wilson JW et.al. – *Radiation Safety Aspects for Commercial High-Speed Flight Transportation,* NASA, 1995

(A) This should be a more in-depth medical and may include ECG etc. This should be conducted 6-months prior to the flight.

(B) Within days to hours before the flight the SFP should undergo a final medical by the operator to satisfy them that the SFP's condition and fitness has not changed from the initial medicals

(iii) Wearable Biomedical Monitoring Equipment for SFPs should be considered.

Space Flight Participant Training

(k) SFP – Guidance on Required Training

(i) Ground School; an operator should provide basic information regarding all aspects of the flight including the space environment, about the vehicle and the flight profile.

(A) Human Performance and Limitations should also be part of the Ground Training.

(ii) Simulator Training.

(A) Familiarization of the cockpit and cabin layout including use of all equipment to be used by the SFP

(B) Emergency egress training for all SFPs

(iii) Physiological Training;

(A) G-Force Training. It is essential that SFPs undergo g-force training (high g-force, microgravity, rapid changes) to provide them with experiential 'training' and to introduce them to Anti-G Straining Manoeuvres or similar depending on equipment (such as anti-g suits or anti-g seats).

ECLSS

(l) Environmental and Life Control Support Systems

(i) In addition to the flight crew (per CFR 460.11) the operator should provide an alternate method of oxygen supply for the SFPs

Note: this is included for completeness however this guidance is more relevant for technical systems consideration (as opposed to medical or training guidelines) – though it is implicit that if oxygen systems are required for SFPs then appropriate training should be included in their usage

Smoke Detection and Fire Suppression

(m) Per CFR 460.13 'An operator or crew must have the ability to detect smoke and suppress a cabin fire to prevent incapacitation of the flight crew'

(i) The design of the vehicle should also permit smoke detection and excess temperatures (and pressures) outside of the fire bulkhead and within the vehicle compartments

Note: this is included for completeness however this guidance is more relevant for technical systems consideration (as opposed to medical or training guidelines) – though it is implicit that if fire suppression systems are required for flight crew then appropriate training should be included in their usage.

4.3. SUBORBITAL FLIGHT – AIR TRAFFIC MANAGEMENT INTEGRATION

In development

5. CONTINUING BEST PRACTICE

The IAASS Suborbital Safety Technical Committee will continue to develop guidelines for the emerging industry. The guidelines will be developed from the TC's agreed topics for consideration as well as reacting to emerging issues within the field. The aim is to incorporate the TC's Working Group's guidelines as an updated Manual to be presented at each IAASS Conference i.e. every 18 months.

APPENDIX 1

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