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The Safety Management Approach to Space Tourism

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ABSTRACT

Travelling at three times the speed of sound during the ascent and experiencing five times Earth's nominal gravitational forces during re-entry is not a normal flight profile. How will the general public, let alone highly trained flight crew, cope with these and other exacting environmental factors during suborbital spaceflight? To enable the industry to be successful, designers and operators must constantly view the challenge from a safety perspective. This paper examines the challenges using a Safety Management System (SMS) approach. A high-level Safety Case methodology was employed, using a Goal Structured Notation (GSN) model, whereby evidence was examined to support arguments that the overall goal of safety is satisfied. A GSN is useful because of the complexities inherent in the platform(s) and in human interaction with the platform(s). Moreover, using the GSN gives an overarching framework that clearly highlights the requirement for an SMS approach; including safety by design in the early stages as a critical factor. Operators also need to consider the psychological and physiological management of the space participants as well as the Flight Crew. This report concludes that exacting environments require high levels of safety management, both in design and operation; an RLV with in-built safety features still requires an effective safety culture embedded within an operator's effective SMS to avoid future disasters. Space tourism can be successful, so long as safety management principles are proactively employed from the beginning and with commitment at all levels of the industry.

INTRODUCTION

Commercial space operations can only be considered viable if they are also safe. Herein lays the challenge for the fledgling space tourism industry. Safety is paramount, as in general aviation; however, the risks in sub-orbital flights will be far greater due to the spaceflight environmental aspects. In the USA, space tourism sits in the grey area between the regulated National Aeronautics and Space Administration (NASA) and the regulated National (Federal) Aviation Administration (FAA), with its new space tourism proposals [1] & [2]. This uncharted area therefore requires new regulations and standards. To give the industry impetus, it clearly requires a 2-way dialogue between the regulator and the operator of the Re-Launch Vehicle (RLV). This will ensure safety and also the required flexibility (in the form of disclaimers and insurances). An approach based on unyielding bureaucratic practices would be too restrictive for the general public if they are to become space participants. Thus far, the dialogue between the regulator's and operators has enabled the draft guidelines to be flexible enough to give the designers and operators the required freedom to move forward – the dialogue also being in the form of Notice to Proposed Rulemaking (NPRM). The FAA/Associate Administrator for Commercial Space Transportation (AST) guidelines [3] stated the safety requirements for permits (during the test phase) and the operator's licence which satisfies the Commercial Space Launch Amendments Act of 2004 (CLSAA). The guidelines clearly state the Hazard Analysis required of the designer/ manufacturer to obtain a permit, and mention a comprehensive system safety management program for operators. So what is a system safety management program?

SAFETY MANAGEMENT SYSTEMS (SMS)

A system safety engineering program covers the development, build and testing of the platform(s) and uses qualitative and quantitative data as part of the hazard analysis process. In the early stages of the space tourism industry, there will be insufficient data to perform effective quantitative analysis and the FAA has recognized this.

A system safety management program should cover all aspects of the project and have oversight of the designer/ manufacturer's system safety engineering program to ensure synergy between the two.

The Safety Management approach employs a proactive, formal and auditable methodology to ensure an acceptable level of safety and confidence.
The UK Civilian Aviation Authority CAA CAP712 [4] defines Safety Management as:

> *'the systematic management of the risks associated with operations, related ground operations and aircraft engineering or maintenance activities to achieve high levels of safety performance.'*

In a high-risk and complex venture, involving new and groundbreaking operations, safety will be of paramount importance. Indeed, the CAA CAP712 [3] states:

> *'A Safety Management System is as important to business survival as a financial management system.'*

This same SMS principle applies to the space industry. A fundamental factor in the management of safety is the safety culture that prevails. Culture is a reflection of the overall attitude of the management and personnel within a company. Professor James Reason [5] argues that a culture is something that an organization 'is' rather than something that it 'has'. Diane Vaughan [6] concurs, citing the Challenger Space Shuttle disaster:

> *'...flying with ''acceptable risks" was normative in NASA culture. The five-step decision sequence I found that characterized work group decision-making about the SRB (Solid Rocket Boosters) joints was nothing less than the working group conforming to NASA's procedures for hazard analysis….in fact the listing and description of the ''acceptable risks" on the Space Shuttle prior to the first launch in April 1981 filled six volumes.'*

This can be summed up in the title of her book – 'The Challenger Launch Decision: Risky Technology, Culture and Deviance'.

Why do we need a SMS, including effective Risk Management? - To prevent catastrophic disasters; disasters that could have been averted had the corporate culture been better. With the eyes of the world anticipating the first tourism launch, effective SMS and culture will prevent 'short-cuts' and 'press-on-it-is', especially on launch day.

To achieve this, a demonstrable board-level commitment towards an effective formal SMS must exist. Equally, every level of management must accept appropriate safety accountability. Safety Management must be broadcast from the top, it must be seen to be visible from the top and the conviction must be carried out from the top during tough safety decisions of risk management. A dedicated Safety Manager should be nominated and have responsibility and resources for safety-related issues, including:

- Forming a close working relationship with the designer's Safety Manager at an early stage to ensure the safety case, safety standards and engineering quality assurance practices are of a high standard and meet or exceed current best practice.

- Instigating a Safety Improvement Plan (Astronaut and Spacecraft aspects).

- Facilitating a hazard management and risk assessment process.

- Advising management on safety matters.

- Instigating an Emergency Response Plan (ERP).

<u>RLV Operator's SMS Components.</u>

The corporate SMS, together with the safety case, should be the cornerstone to safety success. The Safety Manager will be responsible to the accountable manager (i.e. the Chief Executive Officer) for ensuring the following components are defined, implemented and given due priority:

- Senior management policy

- Accountabilities and Responsibilities

- Safety Programme/Plan

- Hazard & Risk Management

- Safety Management Training

- Safety Documentation

- Operational Safety

- Accident/Incident Reporting

- Verification, Audits and Review

- Communication & Feedback

The RLV Operator's SMS should compliment the designer/manufacturers' SMS to ensure synergy between the two, ensuring there are no gaps especially at the boundary layers between the two parties.

<u>Hazard & Risk Management (RM)</u>

The processes involved in RM are continuous and include identifying hazards (an activity or condition that poses a threat) and ensuing risks (the potential for an undesirable consequence), analysing the risks and planning to counteract or mitigate the risks - i.e. making safety orientated decisions.

RM challenges can be Mission related or Environmental related, with the main goals being:

- To prevent accidents occurring (risk avoidance/mitigation)

- To reduce the impacts of an uncontrolled accident (prepare and adapt the ERP)

- To transfer the risks (insurance liability/RLV-Customer-Regulator waivers)

For RM to work effectively, risk assessments must be carried out. The following 6-step method, discussed in the City University SMS course notes [7], is one example:

- *Scoping;* definition of the purpose of the risk assessment and scope of the issues to be addressed. This fundamental step is often overlooked or taken to be obvious;

- *Identification of hazards;* what can go wrong? Systematic and comprehensive hazard identification is crucial for a robust risk assessment;

- *Assessment of likelihood or frequency;* how often can it happen? Methods range from qualitative judgments to formal quantitative analysis;

- *Consequence assessment;* how bad could the outcome be? Again, the assessments can be qualitative or quantitative. In safety risk assessments consequences are typically measured in terms of fatalities, major injuries, minor injuries and negligible effects;

- *Control Measures;* decide on the barriers or control measures, or mitigate using the As Low As Reasonably Practicable (ALARP) principle (see figure 1) and cost benefit analysis (CBA) techniques. This is where the project safety criteria can be derived according to the principle that safety risks are to be reduced to ALARP and whereby the cost can be taken into account in relation to the benefits;

- *Monitor and Review;* during tests and the first few flights, risks should be monitored. They can then be ratified, adjusted, removed or added to in the review phase.

The above process is also similar to the NASA 5-step risk assessment process [8], using 'Identify, Analyse, Plan, Track and Control.' Indeed, the designer/ manufacturer should take heed of lessons learned from the NASA disasters, concerning the platform(s) and their structural integrity and design safety features. The Space Tourism Operator's should also take heed of the lessons learned from the management and human factors interventions that may have been attributed as contributory factors in the disasters.

The FAA have provided basic requirements for RM in an Advisory Circular (AC) [9] and have opted for a three-pronged approach to ensure the safety of the crew, passengers and any third-parties:

- Acceptable public risk as determined through a calculation of the individual and collective risk, measured by expected number of casualties (Ec).

- Logical, disciplined system safety process to identify hazards to mitigate and control risk.

- Operational requirements.

From these requirements, the platform(s) development will undoubtedly incorporate risk management in the form of systems safety engineering; Preliminary Hazard Analysis (PHA) and Event Tree Analysis (ETA) to identify safety-critical issues, Failure Modes, Effects and Criticality Analysis (FMECA) and Probabilistic Risk Analysis (PRA).

The Spaceport's involvement, together with the operator, will focus on the first of the three FAA requirements. Calculations will have to be made in respect of the launch criteria of the platform(s). This will depend on the type of platform(s) – for instance a vertical take-off (and landing) will have a higher risk category for third-party expected casualties than for a horizontal, twin ship, two-stage RLV.

From an Operator's management perspective, a PHA, including HAZOP and brainstorming for Hazards (Hazard Identification) should be carried out and management action carried out to mitigate the Hazards. This will involve training and procedures as part of the mitigating measures, along with the technical measures highlighted for discussion/action with the designer/manufacturer.

All of the above must then be integrated to be included in a cohesive Hazard Risk Index Matrix, which would then give the overall status of risks, categorised in Likelihood and Severity. With the Hazards identified and assessed, the 6-step RM process can then be continued and applied with control measures to eliminate or reduce the hazards.

Those that have not been eliminated must be entered into a Risk Register and managed to the ALARP principle, shown in Figure 1.

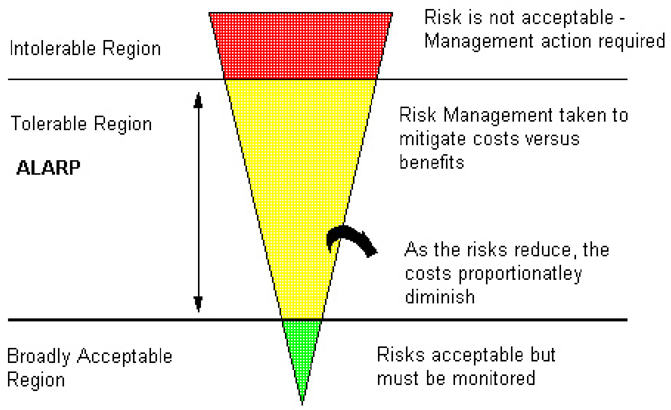

Figure 1 – The ALARP principle.
Shows the risk areas where management need to take action and with what priority. The red area depicts risks that are unacceptable, requiring immediate senior management attention. The yellow ALARP area depicts risks that are acceptable, but require management mitigation, on a sliding scale. The green area depicts acceptable risks that need to be formally noted.

SAFETY BY DESIGN

The safety management programme should be a close working concept between the Reusable Launch Vehicle (RLV) operators, designers/manufacturers and regulators. The following 5-M model [10] depicts the relationship:

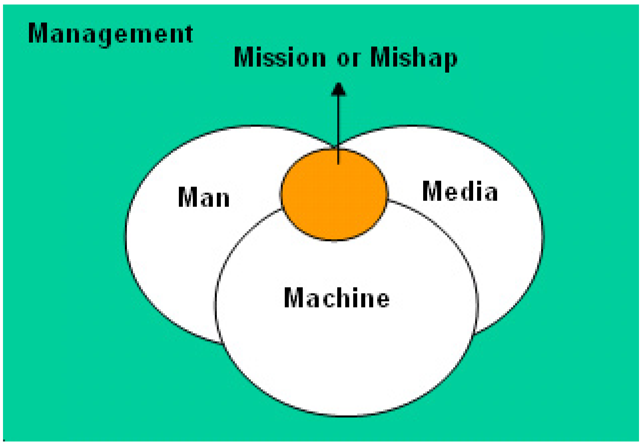

Figure 2 – The 5-M Model (UK Ministry of Defence [MoD] Risk Management, Joint Service Publication 551, Vol 3 – adapted from E A Jerome, 1976).

The 3 interacting component parts (man, media and machine) are controlled by the surrounding management component. A successful mission or unsuccessful mishap is dependent on how well the components interact.

The space mission success or failure will be a direct function of the safety management and interaction between the elements. Management is often the controlling factor in mission success or failure; civilian and military safety studies cite management processes in as many as 80% of reported occurrences [10].

Safety Management Interactions

The interactions of people with people, people with machines, people with organisations and people with the environment are commonly known as Human Factors. In the complex and new field of space tourism, these interactions must be carefully considered at a very early stage to ensure a successful mission (rather than mishap).

- *Man & Machine.* An example is Scaled Composite's methodology [11], which epitomises Safety by Design; the hull, double window and seals design, 'hybrid' (solid and liquid) rocket motor that is integral to the aft fuselage and high drag 'shuttle-cock' folding wings for re-entry. This history of innovation must now be continued in the design of the passenger-carrying SpaceShip Two; reclining seats for G protection is a start, but to what angle must the seat recline? Should the pilot have a reclining seat? What can be done to assist the pilot in reducing the spacecraft stressors (noise, vibration and radiation)? How will the ground control maintain communications? Are the 'Turnaround' maintenance practicalities (fuel storage, damage repair resources and procedures, maintenance schedule) being discussed now? These are the human factors that must be considered both in 'safety by design' and for operations.

- *Man & Media.* The environment will be exacting on the crew and even more so, on the participants. Understanding the environment leads the designers onto constructing the 'machine' but at the end of the day man and the media must meet. How will man cope with the machine-assisted environment? Part of assisting the interaction of man with the media is training, both psychologically and physiologically and medical assessment. The draft FAA requirements [1] state:

The RLV operator should provide safety training to each space fight participant prior to flight on how to respond to any credible emergency situations, which may include but are not limited to cabin depressurisation, fire, smoke, and emergency egress'. It then states the rationale that '*the space participants will have a chance of survival'* and that *'proper training can reduce the chances of panic occurring, which could interfere with the flight crew's response to emergency situations*'.

- *Management & Media/Machine/Man.* Along with the responsibilities of regulation, legislation, policy and procedures, management must give a purpose and direction to the business plan. To do this, management must understand the aforementioned interactions in order to make sound decisions for the business; decisions based on safety. The suborbital business is full of risks emanating from the interactions of man & media & the machine. A problem in any of the above interfaces could mean that a decision is required from the management. Pressures of the launch date with the world's press and stakeholders looking on will no doubt challenge the management, as it has previously challenged NASA. Management hold responsibilities and accountabilities and part of that is the 'accountable' Safety Manager (this may be the Chief Executive, or Head of Operations, even in companies with a dedicated Safety Manager). Either way, the 'Go/No Go' decision must rest with the appropriate accountable level.

SAFETY IN OPERATIONS

An effective Safety Management System (included as part of the evidence of a Safety Case) would call for effective training and procedures to ensure that the flight is 'acceptably' safe. Included in the training should be:

- *Synthetic Simulators (Full & Specialist Mission Simulators).* A Full Mission Simulator is an essential part of the safety programme. It allows familiarisation training, standard operating procedure training and emergency training. This is vital for the crew and certain elements are essential for space participants. As long as the simulator has motion, visual and sound, then the flight profile will be replicated (except gravitational forces) which will benefit the crew and participants by conditioning them to the extraordinary environment. An AIAA,Inc joint United States/ Russian publication [12] amplify this statement:

'Spacecraft simulators are crucial for preparing crews for flight. The use of actual space flights for training purposes is neither cost-effective nor safe, but the use of simulators creates training opportunities in

which the perception and motor responses of the (cosmonauts) are identical to those of actual flight.'

- *Centrifuge (tolerance and anti-g straining manoeuvre).* Launch, ascent and re-entry acceleration forces in a suborbital space flight are anticipated to be in the range of 3 - 5G. This may not seem a great deal but the tolerance of G varies with the individual. The centrifuge enables G-forces to be exacted upon an individual in a controlled environment. The individuals can then experience G and be given simple training instruction on how to help them by straining (the anti-g straining manoeuvre – AGSM). G-training could be vital to the participant, both from an experiential point of view and as a medical test or pre-conditioning, especially for participants with medical and fitness issues.

- *Parabola flight (zero-g experience).* A parabola flight enables a weightlessness (zero-g) environment to be simulated for a short period (approximately 20 seconds). Although the flight profile of the aircraft (20 parabolic trajectories) probably exacerbates the autonomic reactions, the space participant would be subject to only one, 'smooth' five-minute period of weightlessness and therefore the effects should be minimal. The AIAA, Inc publication [12] state:

'Individual responses to these flights were found to vary, with most subjects belonging to one of 3 broad groups:
- Those who felt well, could tolerate flight conditions easily, and did not exhibit any impairments;
- Those who experienced illusions and exhibited mild symptoms of motion sickness
- Those who had difficulty adapting and developed autonomic reactions such as weakness, pallor, sweating, nausea and vomiting.'

The experience of weightlessness is relevant; indeed it is one of the major attractions of the space flight. It would also let the participant know how they would feel and how they could move, including adjusting their body to take a photograph, perhaps.

-*Psychological Training.* The physiological conditioning of the space participant will also lead to psychological benefits. The dual approach of psycho-physiological training will give the participants the best opportunity to enjoy a positive experience from the space flight. Prof. Bor's comments [13] regarding general aviation, state:

'When evolutionary barriers to motion are exceeded, numerous penalties are exacted, the most common of which are motion sickness, jet lag, and increased arousal and stress.'

This will be replicated, and perhaps amplified, in the space tourism environment. The pre-flight training, take-off, launch, supersonic flight, weightlessness, re-entry and landing will give rise to anxiety and increased arousal in the space participants and crew. Stress will be a factor for participants and this must be counteracted to provide a positive experience, as opposed to a negative one. To assist in giving the participants the knowledge and confidence of the space flight, physical and psychological countermeasures will be essential in the safety strategy. This would include design ergonomics, briefings, conditioning (training) and stress management. The aim of a psycho-physiological countermeasures programme would be twofold: to increase the participant's knowledge and awareness, thereby increasing their perception of the unknown and adding confidence to their mental state (to decrease their anxiety levels); to increase the participant's ability to cope, by physical conditioning and relaxation.

Although space participants will have volunteered to fly into space and will not, presumably, have a fear of general flying, the extraordinary circumstances and high-risk flight phases they will be subjected to merit the intent of Prof. Bor's Intervention methods [13].

- Education about the physical principles of flight and the process by which the flight crew control the aircraft.
- Experiential learning through participating in a simulated or actual flight situation.
- Training and techniques to manage the physiological symptoms of anxiety.

-*Medical Training and Standards.* Medical requirements and standards are also part of mitigation measures of the SMS. The FAA draft guidelines [1] state:

'Each space flight participant should provide his or her medical history to a physician experienced or trained in the concepts of aerospace medicine. The physician should determine whether the space flight participant should undergo an appropriate physical examination.'

The main reason for the regulators stipulating minimum medical requirements is the additional hazards inherent in the space environment. The space participant will be subject to acceleration forces in the region of 3 to 5G and also micro gravity for up to 5 minutes (environmental issues such as radiation are considered to be negligible for one trip at the low space altitudes). To counteract the low to moderate G-forces, the designers could use a reclined seat, so that the acceleration is more in the Gx direction for launch (possibly up to +3Gx for approximately 90 seconds) and re-entry (possibly up to -3 to 5Gx for approximately 20 - 30 seconds). These forces could aggravate medical conditions in space participants, which could result in an in-flight medical emergency or death (not only is this undesirable for the individual, it could compromise the crew and/or other participants in their duties or in their health). The centrifuge will prove invaluable in assessing medical issues.

THE OPERATOR'S SAFETY CASE

Part of an effective and 'live' SMS is the Safety Case. The UK MoD Defence Standards 00-56 [14] defines a safety case as:

> *'a structured argument supported by a body of evidence that provides a compelling,*

comprehensive and valid case that a system is safe for a given application in a given environment.'

There are various safety-case models in use and they are generally applied to physical systems. However, some models could be appropriate for determining the safety of the human, or space tourist. The GSN model by Kelly & Weaver, 2004 [15] is one example that could be used because of the complexities of the whole operation, whereby the interactions and arguments used by the technique, delve deeply until the evidence is provided to support the arguments. The GSN model sets out a claim (goal), proposes an argument (strategy), and asks for evidence (solutions) to quantify the initial claim. Figure 3 shows an exemplar high-level GSN basic configuration, examining the Development, Operations, SMS and Equipment.

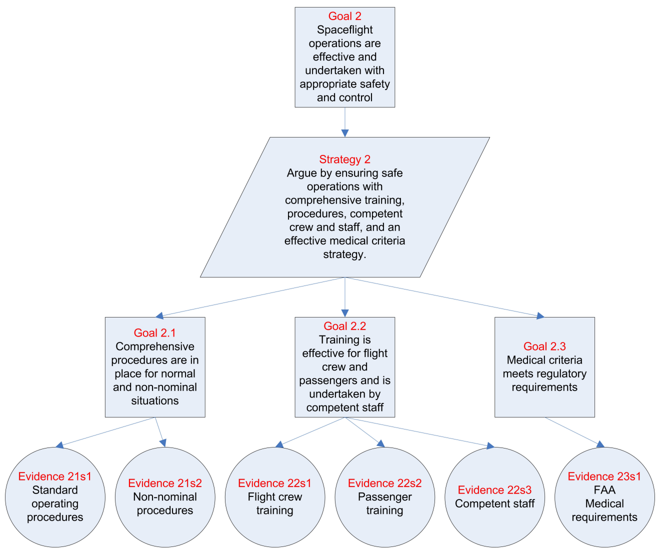

Figure 3 – The Operator's Safety Case.

The purpose of the high-level GSN is to show how design and analysis decisions meet the requirements. A goal is a requirement, target or constraint. The context reflects the conditions that the requirement applies to. The strategy involves justifying the requirements, which can be made using assumptions from another system or relevant field. The solution is where evidence is provided to substantiate the requirement.

For the safety case to be effective each goal requires a strategy to be fulfilled and this should be delved down sufficiently until all evidence provides the solution for the said goal. A safety case approach is a more formal and proactive method that integrates with a Safety Management Plan to form part of the overall SMS. It is important that the RLV operators involve themselves with the designers/manufactures to ensure a positive safety culture and a cohesive approach to safety management. The main feature of a safety case approach is that after each goal has been further sub-divided with arguments and goals, ultimate solutions are provided or remain open as risks. These risks can be easily highlighted and managed accordingly, via mitigation or elimination. The benefit of such an approach, whether the designer and operator are the same organisation or 2 separate organisations, is that synergy will exist and any inherent weaknesses at the interface or boundary layers will be evident. It is of no use for a 'safety by design' spacecraft being handed over to an operator without an embedded SMS and operational safety case approach – this is where accidents will happen; it is the nature of human beings to have slips and lapses which ultimately lead to disaster.

<u>Designer/Manufacturer's Responsibilities - Goal 1</u>

To obtain a permit for test purposes, the FAA have decreed [3] that Hazard Analysis will suffice for designer/manufacturer. In the case of separate designer/manufacturer and operator, then this analysis may be the only form of safety management undertaken prior to handing over to the operator.

<u>Operator's Responsibilities Goals 2 & 3</u>

From Figure 3, it is clear that much work can be achieved now, to fulfil goals 2 & 3; operations, including training and medical issues, and safety & environmental management. All of these aspects need a safety focus with appropriate resources and safety management oversight. By employing the safety case methodology, risks should not 'slip between the cracks' and accountable executives will have a 'live' overview of their operations – essential for Through Life Management of the business. They will also be more aware of their organisation's safety culture, which if they start now, will be a positive and generative one, rather than a reactive one.

Taking Goal 2 ('spaceflight operations are effective and undertaken with appropriate safety and control') a step further, additional goals can be added which require examining by argument and solutions – in this high-level example, the goals are focussed on procedures, training and medical issues. Figure 4 gives a pictorial view of the next steps in the process.

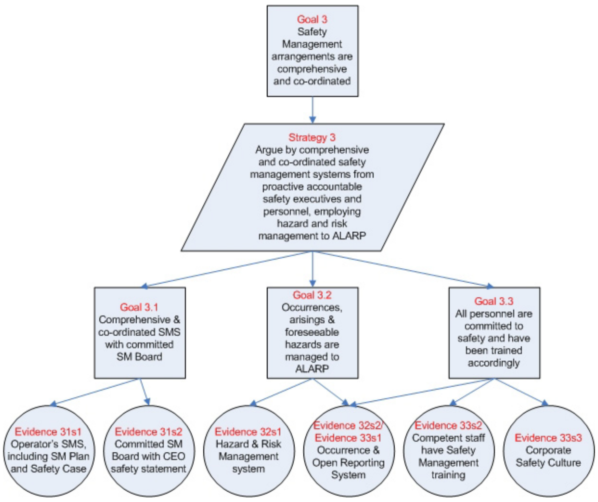

Figure 4 – Goal 2 expanded to examine the high-level procedures, training and medical aspects of the safety case.

Applying the same process to Goal 3, operators can ensure they have a comprehensive and co-ordinated Safety Management approach now, from the beginning, to ensure a positive and pro-active safety culture – right from the very top. It is of no use, if the company President/CEO espouses safety as a top priority, only to then believe the designers/manufacturers are responsible for safety. The operator's responsibilities are just as vital in ensuring a successful mission, rather than a mishap. A dedicated Safety Manager should be appointed, along with appropriate funding for safety-related resources to fulfil the safety case goals. Figure 5 represents the high-level example for Safety Management arrangements.

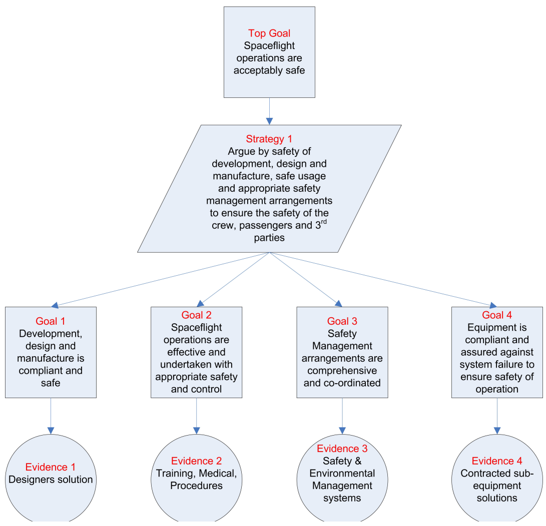

Figure 5 – Goal 3 expanded to examine the high-level Safety Management functions.

As more questions are asked of the safety function of the business, the more comprehensive the answers will be to the top-level goal (overall safety).

Employing a strategy such as a safety case, not only for the design/manufacture of the platform(s), but from an operator's standpoint would ensure that all aspects are covered in a formal and auditable methodology. The purpose of such methodology is safety, safety, safety.

SUMMARY

A coherent Safety Management System is vital, both for the vehicle designer, manufacturer and the Re-Launch Vehicle operator. For operations, Risk Management will be a key function and part of that process will involve assessing the complex risks associated with the new venture. The inherent hazards must be managed and regulatory requirements adhered to. The space participant will encounter rigorous sensory stimulation during the flight profile, including gravitational forces up to 5G. This is no 'theme-park-ride' for the space participants; the environment aspects are exacting for the general public – they are not highly trained military pilots.

CONCLUSION

This paper recommends that extensive measures are required not only by the regulator and designer/manufacturer, but also by the RLV operators, to assure the safety of space participants and crew. The countermeasures discussed include psycho-physiological methodology for preparing the participants. These measures should part-condition the participants so that they will have a positive experience.

This experience must have Safety Management as the over-arching driver to ensure a successful mission, rather than mishap. Using an Operational Safety Case approach can highlight risks to be mitigated and also prevent inherent interface weaknesses between designer/manufacturer and the operator. The hazards involved must be identified, managed and mitigated to 'As Low As Reasonably Practicable', using the Cost Benefit Analysis technique when required. Ultimately, this Risk Management process will involve decision making from senior management based on cost 'versus' safety.

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