ABSTRACT

For commercial human spaceflight to flourish and expand, industry has to develop a notion of safety as the collective responsibility and common strategic business goal of all members.

In 2004, the U.S. private spaceflight industry welcomed a law (i.e. the Commercial Space Launch Amendment Act (CSLAA)) postponing the ability of FAA to issue safety regulations, except for aspects of public safety until 2012. The deadline was later moved to 2015. The law, currently undergoing a second postponement until 2020, offers a historic opportunity for space industry to engage in the development of a comprehensive set of industrial consensus standards, based on the experience gained in more than 50 years of government programs.

This paper proposes framework and rules of an industrial cooperation for consensus standards, in the form of textual content for a Memorandum of Understanding (MoU). Those standards, when established, could become the basis of a mixed regulatory regime, where industry takes care of self-certifying the vehicles safety, while government regulators would continue to cover launch and re-entry operations for all aspect of public safety.

This paper also suggest to carry out standardization activities within the broader scope of a Space Safety Institute.

1. ACCEPTABLE RISK

To be “absolutely safe” a system, product, device or material should never cause or have the potential to cause an accident; a goal practically impossible to achieve. In the realization and operation of systems the term “safety” is generally used to mean “acceptable risk level”, not “absolute safety”.

Acceptable risk level is not the same as personal acceptance of risk, but it refers to risk acceptability by stakeholders’ community or by society in a broad sense. Acceptable risk levels vary from system to system, and evolve with time due to socio-economic changes and technological advancement. Implementing proven best-practices at status-of-art is a prerequisite for achieving an acceptable risk level, or in other words to make a system “safe”. Best-practices are traditionally established by government regulations and norms, and/or by industrial standards. Without such reference the term “safety” or “acceptable risk” becomes meaningless. In other words compliance with regulations, norms and standards represents the “safety yardstick” of a system.

2. SAFETY-BY-DESIGN

In the development of a space system, safety is achieved through the implementation of a combination of requirements that go under ‘Fault Tolerance’ and ‘Fault Avoidance’, plus requiring certain emergency response capabilities, (e.g. escape system).

Fault-Tolerance, consists in the designed-in characteristics that maintains prescribed functions or services to users despite the existence of faults. Fault tolerance is implemented for example by redundancies and barriers.

Fault-Avoidance, consists in reducing the probability of a fault by increasing the reliability of individual items (design margins such as factor of safety, designing to worst case scenarios, materials selection, use of hi-reliability components, de-rating, quality control, testing, etc.). Fault avoidance is essentially achieved through the use of proven best practices (i.e. technical standards).

3. STANDARDS

3.1 What is a standard?

“Today, standards are no longer considered to be just stacks of dusty papers containing unjustified requirements and constraints. Standardisation is generally viewed as a process that drives commercial viability and success. Successful companies recognise that developing and using standards is the path to remaining competitive and producing quality products”[1]. There are three major elements in the concept of “standard”:...
- something widely agreed
- minimum necessary
- approved and monitored for compliance by an authoritative organization

Often it is considered that wide agreement can be reached only as a result of long and successful application of a technical practice, which is then “promoted” to the level of standard. Traditionally, industrial standards, are not the enunciation of generic principles or goals, but they mandate specific design solutions. In other words, traditionally, safety requirements in standards tend to be detailed and prescriptive.

3.2 Technical standards and safety standards

Often technical standards are seen as something different or separated from safety standards just because they are under the authority of different groups, respectively Engineering and Safety & Mission Assurance (S&MA). As a matter of fact, a large number of requirements in space technical standards are aimed at safety.

As human space transportation transitions from government activity to commercial or mixed commercial and government activities, the need arises for industry to develop a notion of safety as its collective responsibility and common strategic goal for business growth. To that end it is in the best interest of industry to cooperate among themselves and with regulators at developing, adopting, and enforcing safety and technical standards.

In government space programs a large body of knowledge already exists in the form of standards, which has been accumulated for more than 50 years. Such standards cannot be directly used in commercial programs because on one hand the language identifies specific organizations (e.g. NASA), internal relationship and development processes, and on the other hand they weren’t established with industry concurrence.

3.3 Prescriptive standards and performance standards

In the early hours of 15 April 1912, the RMS Titanic struck an iceberg on her maiden voyage from Southampton, England, to New York, and sank. A total of 1,517 people died in the disaster because there were not enough lifeboats available. During the Titanic construction Alexander Carlisle, one of the managing directors of the shipyard that built it had suggested using a new type of larger davit, which could handle more boats thus giving Titanic the potential for carrying 48 lifeboats providing more than enough seats for everybody on board. But in a cost cutting exercise, the customer (White Star Line) decided that only 20 lifeboats would be carried aboard thus providing capacity for only about 50% of the passengers (on the maiden voyage) [2]. This may seem a carefree way to treat passengers and crew on-board, but as a matter of fact the Board of Trade regulations of the time stated that all British vessels over 10,000 tons had to carry 16 lifeboats. The regulation had become obsolete within a short period of time at the beginning of the 20th century that had seen ship tonnage raising up to Titanic’s 46,000 tons. In addition the RMS Titanic was believed to be unsinkable by design, therefore why to worry about lifeboats!

The Titanic accident illustrates what a prescriptive requirement is (i.e. an explicitly required design solution for an implicit safety goal), and how it can sometimes dramatically fail by obsolescence. The underlying motivation for prescriptive requirements is to prevent circumvention by avoiding any subjective interpretation in the implementation as well as in compliance verification. Violation of requirements can be unequivocally determined by simple inspections.

The vast majority of standards in use in aviation and other “evolutionary” industries are the result of lessons learned from incidents and accidents, and steady technological advancement. They are detailed according to type and prescriptive.

In contrast there are industries in which building on future experience is simply not possible, because the system is completely new, highly safety-critical (e.g. nuclear power plants) and/or extremely expensive.

4. GOVERMENT REGULATION AND / OR SELF-REGULATION

4.1 U.S. Government regulations

In 2004, the U.S. private spaceflight industry welcomed a law (i.e. the Commercial Space Launch Amendment Act (CSLAA) [3] postponing the ability by the FAA, to issue safety standards and regulations, except for aspects of public safety, until December 23, 2012, or until an accident occurs. The deadline was later moved to 2015. Currently a further postponement to 2020 is under approval. The CSLAA requires that a prospective spaceflight participant shall be debriefed about the risk of spaceflight and sign an informed consent. The CSLAA states that “for each mission the operator must inform a space flight participant, in writing, of the known hazards and risks
that could result in a serious injury, death, disability or total or partial loss of physical and mental function [...] and an operator should inform a space flight participant that there are also unknown hazards [...] The operator also must disclose that participation in space flight may result in death, serious injury, or total or partial loss of physical or mental function. An operator must inform each space flight participant that the United States Government has not certified the launch vehicle and any re-entry vehicle as safe for carrying crew or space flight participants.” [3].

We can reasonably expect that the average space flight participant will not have the necessary background and technical experience to truly grasp the risk of space flight.

Due to the fact that there is nothing as “absolute safety”, and that acceptable risk is the one defined by standards and regulations, without such reference in any litigation following an accident the operator would have a hard time defending his vehicle and demonstrating the thoroughness of the information he passed to the customer. The fleet would be grounded, and probably made obsolete by new (strict) standards issued in the emotional wake of the accident.

Having a safety certification of compliance against recognized safety standards serves the interests of the customer, but also protects industry from tort liability, by implicitly or explicitly defining the acceptable risk level at the current state-of-art. For instance, in 2008, the U.S. Supreme Court ruled in favour of a manufacturer of a balloon catheter that burst and severely injured a patient during an angioplasty. The Court wrote that the Food and Drug Administration (FDA) spent an average of 1,200 hours reviewing each device application and granted approval only if found there was a “reasonable assurance” of its “safety and effectiveness”. The manufacturer argued that the device design and manufacturing had been in accordance with FDA’s regulations and that FDA and not the courts was the right forum on imposing requirements on cutting edge medical devices, arguing that “nothing is perfectly safe”[4].

Standards and regulations protect the customer but also industry.

4.2 The NASA Commercial Crew Program case

NASA’s Commercial Crew Program (CCP) was formed to facilitate the development of a U.S. commercial crew space transportation capability with the goal of achieving safe, reliable and cost-effective access to and from the International Space Station and low-Earth orbit.

In the Commercial Crew Program, NASA performs safety certification activities without being a regulatory body. The International Space Station IGAs (Inter-Governmental Agreement) and related MoUs assigned to NASA the responsibility to manage the ISS Program and the safety of U.S. and international crews in all mission phases including transportation.

The companies involved in the CCP program are free to design the transportation system they think is best. They are encouraged to apply their most efficient and effective manufacturing and business operating techniques throughout the process. They will own and operate their spacecraft and infrastructure. However the companies must meet (or exceed) NASA’s pre-determined set of requirements. NASA engineers have no oversight role but the necessary insight into a company’s development process while the agency’s technical expertise and resources are accessible to a company. During safety reviews NASA will identify issues and make recommendations, but NASA cannot impose design or operational solutions.

In the initial phase of the Crew Commercial Program NASA made an inventory of existing technical standards and recommended them either as reference baseline (meet or exceed) or as good practices, stating that “In the course of over forty years of human space flight, NASA has developed a working knowledge and body of standards that seek to guide both the design and the evaluation of safe designs for space systems” [5]. Those standards should be considered also for non-NASA sub-orbital and orbital commercial projects. They can be easily adapted and re-used because they are performance oriented or deal with common sub-systems and technologies (e.g. pressurized systems, structural design, batteries, materials).

5. EUROPEAN COMMON SPACE STANDARDS

The ECSS (European Cooperation for Space Standardization) is a unique example of industrial and government cooperation for developing common standards. The ECSS is a 20 years old initiative to establish a coherent, set of technical, management and S&MA standards for use in all kind of European space activities.

In early nineties, European space industry, and national space agencies joined forces to start developing common space standards. The aim was to improve industrial efficiency and competitiveness, and to satisfy government and commercial contractual needs without differentiation. The movement towards common standards started in Europe in 1988 when Eurosace, a major trade association representing the European space industry, asked the directors-general of the European Space Agency (ESA) and of the French Space Agency (CNES) to standardize
their organizations S&MA requirements to better support major programs under way, namely: Ariane 5 man-rated rocket, Hermes spaceplane, and Columbus module for the International Space Station. The S&MA standards comprised at that time requirements on safety, reliability, quality control, configuration management, materials and EEE components. Later, the European space community was in a position to address a complete set of standards (i.e. including technical and management standards) rather than only the S&MA part to build a comprehensive and coherent system of standards, based on a commercially oriented strategy. In the autumn of 1993, the partners signed the ECSS terms of reference which defined the framework and the basic rules of the system, and concurrently the agencies committed to gradually discard and replace their standards in future contracts. According to such terms the European space industry assumed from the outset an equal role in the direction and development of European common space standards, and equal voting rights, The pillars of the ECSS standardization policy are effectiveness and consensus (that does not mean unanimity). The process starts with the decision to initiate the development of a new standard, and ends with the voting of the draft. The presence of a majority of voting members is required to constitute a quorum. A member who casts a negative vote, must identify all the changes which, if made, would allow the member to vote in a positive manner. It should be noted that the ECSS activities are undertaken and carried out without exchange of funds among the partners. The European Space Agency provides the secretariat.

6. MOU FOR INDUSTRIAL STANDARDS

This section provides the possible text (as study) for a Memorandum of Understanding to establish a cooperation among U.S. aerospace companies for commercial space safety and technical standards. The reason to limit it to U.S. parties is that export control constraints do not currently allow to enlarge such cooperation internationally.

Article 1
Purpose and Objectives

The purpose of this Memorandum of Understanding (MOU) is to establish arrangements between Subscribing Parties (SP) for a genuinely open and as wide as possible partnership in developing commercial space standards aimed at systems safety. U.S. companies and non-government organizations involved in space developments and operations can become a Subscribing Party. Experts from Government organizations can be invited to support standards development.

The objectives of this MOU are specifically to:

a) provide the basis for cooperation between Subscribing Parties and establish roles and responsibilities;
b) establish the management structure and interfaces necessary to ensure effective planning, funding and coordination;
c) provide a general description of the commercial standards within the scope of this MOU and the main groupings comprising it.

Article 2
Standards Groupings

This standardization cooperative initiative will establish the following coordinated groupings of standards:

1) Space Flight Safety
2) Materials & Processes
3) Propulsion Systems
4) Avionics and Electrical Systems
5) Structures, Mechanisms, and Thermal Systems
6) Life Support Systems
7) Recovery and Landing Systems
8) Computer Systems
9) Software

Article 3
Organization

The top body for guiding and co-ordinating, all aspects of this standardisation activity is the Standardization Steering Board (SSB). Each Subscribing Party shall have one representative as member of the SSB. Only companies and non-government organizations involved in space developments and operations can become a Subscribing Party and nominate a representative in the SSB. The Standardization Steering Board can invite qualified observers from institutional organization to attend their meetings.

Sub-board structure

The Standardization Steering Board is supported by Sub-Boards dealing with each specific areas of standardisation:

- **Space Safety Board (SAB)**, for standards dealing with safety engineering and risk management of space missions (flight and ground);
- **Materials & Processes Board (MPB)**, for standards dealing with materials and safety critical processes engineering;
○ **Propulsion Systems Board (PSB)**, for standards dealing with propulsion systems safety technical requirements (flight, ground, environment, testing);

○ **Avionics & Electrical Systems Board (AESB)**, for standards dealing with avionics and electrical systems safety technical requirements (flight, ground, testing);

○ **Structures, Mechanisms, and Thermal Systems Board (SMTSB)**, for standards dealing with structures, mechanisms and thermal systems safety technical requirements (flight, ground, testing);

○ **Life Support Systems Board (LSSB)**, for standards dealing with life support system safety design requirements;

○ **Recovery and Landing Systems Board (RLSB)**, for standards dealing with recovery and landing systems safety design requirements;

○ **Computer Systems Board (CSB)**, for standards dealing with computer systems safety design requirements;

○ **Software Board (SB)**, for standards dealing with critical software development.

Finally, the **Secretariat** will provide the overall administrative coordination and comanagement functions.

**Standardization Steering Board – Charter**

The SSB is the body responsible for the overall coordination of the space safety standardisation efforts. It is responsible for:

a) establishing a four years strategic implementation plan, including proposed secretariat funding profile, for Subscribing Parties Council review and approval;

b) deciding, on the basis of Sub-Board assessment and recommendation, when a standard has been approved by a Working Group with only a 2/3 majority decision;

c) nominating members and chairs of the Sub-Boards

The Standardization Steering Board Chair and the Sub-Boards Chairs will be elected at unanimity by the Standardization Steering Board members for a period of four years, which can be renewed for two times.

The Standardization Steering Board nominates members and chairs of the Sub-Boards on the basis of proven knowledge and experience in the specific field.

The Standardization Steering Board decisions are taken on the basis of unanimity. The decisions of the Sub-Boards and Working Groups can be either by unanimity or by a qualified 2/3 majority. In the latter case the Sub-Board and Working Groups decisions will need to be ratified by a decision of the SSB.

**Standardization Secretariat – Charter**

The Standardization Secretariat is funded and managed by the Subscribing Parties via the Space Safety Institute. It provides the secretariat and overall management support functions to the SSB and its subordinate Boards and Working Groups. The Secretariat is responsible for:

1. detailed annual planning of the standardisation activities;

2. issuing of operating procedures;

3. monitoring the progress of working groups activities;

4. publishing the standards;

5. maintaining the website of the organisation;

6. issuing a detailed annual report to the Sub-Boards concerning the status of Working Group activities including updating of the annual planning and recommendations for future work;

7. ensure performance of all administrative duties.

**Sub-Boards – Charter**

The Sub-Board is responsible for the overall coordination of the standardisation efforts of the Working Groups for their assigned grouping. It is responsible for:

- providing to the SSB input for the four years strategic implementation plan;
- approving the detailed annual plan prepared by the Secretariat;
- providing assessment and recommendation to the SSB when a standard has been approved by a working group with only a 2/3 majority decision;
- nominating members and chairs of the working Group (after confirmation of sponsorship availability by the relevant Subscribing Party see article 4);
- issuing an annual summary report to the SSB concerning the status of activities and proposed future direction.

Each Sub-Board nominates experts to be the members and chairs of each Working Group to which the development of one or more standards is assigned.

International Association for the Advancement of Space Safety
Article 4
Funding

Funding to the standardization activities are provided by Subscribing Parties directly, or indirectly. Direct funds are those that the Subscribing Parties will allocate internally to their company or organization to sponsor the participation of their representatives (staff, contractors, consultants, etc.) to the standardisation activities, including travel costs. Indirect funds are those provided to to cover the costs of running the Secretariat, including staff (3–4), office rentals, etc.

Article 5
Transitional Rules

○ Each Subscribing Party will propose an initial list of candidate standards among those existing in government programs and/or in their company, or considered to be useful. If no government program standard exist for a topic of interest but one or more company standards do exist for such topic, the Sub-Boards will decide to initiate a harmonization working group with the participation of members and chairs sponsored by the Subscribing Parties of those existing standards. Observers from other Subscribing Parties can attend the meetings.

○ If a government standard exists for a topic, as well as company standards, the former will be taken as primary reference by the working group that would be tasked to develop a consensus industrial standard.

○ If no companies standards exists on a topic and only a government standard exist, the language of the government standard will be adapted and the standard proposed for adoption as consensus industrial standard. Note: The entire modified document may be re-identified, or an accompanying ‘adoption note’ issued identifying any change to the original document as adopted.

NOTE: The list in ANNEX 1 represents potential candidate as initial industrial standards. The list is based mainly on NASA CCT-STD-1140 [5]. It should be noted that differently from systems specifications such standards are discipline oriented and not system-configuration specific. Therefore they can be applied to a variety of systems developments from suborbital to orbital vehicles, payloads and station modules. The list includes also the “heritage” standard IAASS-ISSB-S-1700-Rev-B “Space Safety Standard Commercial Human-Rated System” [7], based on safety policies and requirements from Shuttle and ISS safety standards.

7. THE NEED FOR A SPACE SAFETY INSTITUTE

7.1 Safety-case regime

Space systems are highly innovative, and it is simply impossible to prescribe detailed design safety solutions for something that never existed before. For such reason space agencies issue safety and technical requirements that are goal/performance oriented. The key concept of the safety-case regime, differently from the classical verification of compliance applied for prescriptive standards, starts with the consideration that the regulatory authority sets broad safety criteria and goals to be attained while the developer will identify and propose the most appropriate design solutions and relevant verification methods. In other words, the regulatory authority (usually a space agency for government space programs) provides criteria and general rules that define where the limit lies between “safe” and “unsafe”, but it is the developer that having the best knowledge of system design and operations can identify the most appropriate design solutions.

Because of the broad, generic nature of top-level requirements, the design solutions need to be validated by the developer through an analytical process using techniques like Hazard Analysis, Fault-Three Analysis, etc. The results will be documented in a safety-case report that typically includes: a) the summary description of the system, and operational environment; b) identified hazards and their severity; c) performance requirements considered applicable to each hazard; d) possible causes of each hazards; e) description of how causes are controlled (i.e. eliminated or mitigated); e) description of relevant verification plans, procedures and methods for each control.

As previously mentioned, intrinsic in the concept of standard is that whenever it is made applicable, compliance must be monitored and enforced. Otherwise requirements become simply a set of guidelines. Monitoring and enforcement can be done by any party to which such authority is assigned, non-necessarily by a government regulatory body. In any case the organization must have the following three key prerequisites: authority, competence, and independence (from the specific project or program).

For example, the safety of the entire International Space Station (ISS) program is based on a process of incremental safety reviews of safety cases reports by independent panels. In response to NASA ISS safety requirements, the developers prepare safety case reports (called safety data packages) at various levels of integration.[6] In the course of ISS operations, further safety data packages submittals are made to account for configuration changes, previously unforeseen operations, and corrective actions following on-orbit anomalies.

The competence of NASA’s multi-disciplinary safety
review panels, and of the specialist teams and labs that support them is well known, but this is a rather unique circumstance, that has no match in traditional regulatory organizations. This means that an obvious substitute for NASA's technical skills does not currently exists for non-NASA commercial human spaceflight orbital and sub-orbital projects, although badly needed. If tomorrow FAA/AST would be allowed to regulate crew and participants safety, the problem would become apparent. Industry, collectively, has the means to solve it.

7.2 A Space Safety Institute

An alternative to government regulations are self-regulations. They are essentially motivated by the need to promote an ‘acceptable’ level of safety as business case.

Take the example of Formula 1 car racing. In the first three decades of the Formula 1 World Championship, inaugurated in 1950, a racing driver’s life expectancy could often be measured in fewer than two seasons. It was accepted that total risk was something that went with the badge [8]. The turning point was the Imola Grand Prix of 1994 with the deaths of Roland Ratzenberger and Ayrton Senna (in direct TV) that forced the car racing industry to look seriously at safety or risk to be banned forever (and lose television rights in the process). In the days after the Imola crashes the FIA (Fédération Internationale de l’Automobile) established the safety Advisory Expert Group to identify innovative technologies to improve car and circuit safety, and to mandate implementation and certification testing. Few years later the advisory group became, the FIA Safety Institute. Nowadays Formula 1 car racing is a very safe multi-billion dollars business of sponsorships and global television rights. Entertainment for families that can be enjoyed without risking shocking sights.

Another example comes from the oil industry. The report of the Presidential Commission that investigated the Deepwater Horizon disaster in the Gulf of Mexico in April 2010 (11 workers killed plus an oil spill that caused an environmental catastrophe), made, among other, the recommendation that “the gas and oil industry must move towards developing a notion of safety as a collective responsibility. Industry should establish a “Safety Institute”...this would be an-industry created, self-policing entity aimed at developing, adopting, and enforcing standards of excellence to ensure continuous improvement in safety and operational integrity offshore”[9].

8. CONCLUSIONS

For commercial human spaceflight to flourish and expand, industry has to establish a coherent set of safety and technical standards, taking as starting reference the experience accumulated in more than 50 years of government programs. Collectively, industry has all the necessary intellectual and organizational resources for the task, but sound business strategy always demand to advance space safety. For that end the standardization activities would greatly benefit from a systematic cooperation with universities and research centres.

The overall cooperation, within industry and with academy, could take the form of a Space Safety Institute. The institute would network industry experts and university researchers, and perform ad-hoc studies, develop educational programs, run standardization efforts, and provide skills in support of independent safety certification of commercial space systems.

9. REFERENCES

[1] A New Approach to European Space Standards


[3] Commercial Space Launch Act and amendments


http://iaass.space-safety.org/publications/standards/


## ANNEX 1

<table>
<thead>
<tr>
<th>Reference</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>JSC 20793</td>
<td>Crewed Space Vehicle Battery Safety Requirements</td>
</tr>
<tr>
<td>JSC 62809 Rev D</td>
<td>Human-Rated Spacecraft Pyrotechnic Specification</td>
</tr>
<tr>
<td>JSC 65827</td>
<td>Thermal Protection System Design Standard for Spacecraft</td>
</tr>
<tr>
<td>JSC 65829</td>
<td>Loads and Structural Dynamics Requirements for Space Flight Hardware</td>
</tr>
<tr>
<td>JSC 65985</td>
<td>Requirements for Human Space Flight for the Trailing Deployable Aerodynamic Decelerator (TDAD)</td>
</tr>
<tr>
<td>NASA-STD-4003</td>
<td>Electrical Bonding For NASA Launch Vehicles, Spacecraft, Payloads, And Flight Equipment</td>
</tr>
<tr>
<td>NASA-STD-4005</td>
<td>Low Earth Orbit Spacecraft Charging Design Standard</td>
</tr>
<tr>
<td>NASA-STD-5001</td>
<td>Structural Design and Test Factor of Safety for Spaceflight Hardware</td>
</tr>
<tr>
<td>NASA-STD-5009</td>
<td>Nondestructive Evaluation Requirements for Fracture Critical Metallic Elements</td>
</tr>
<tr>
<td>NASA-STD-5012</td>
<td>Strength and Life Assessment Requirements for Liquid Fueled Space Propulsion System Engines</td>
</tr>
<tr>
<td>NASA-STD-5017</td>
<td>Design and Development Requirements for Mechanisms</td>
</tr>
<tr>
<td>NASA-STD-5018</td>
<td>Strength Design and Verification Criteria for Glass, Ceramics and Windows in Human Space Flight Applications</td>
</tr>
<tr>
<td>NASA-STD-5019</td>
<td>Fracture Control Requirements for Spaceflight Hardware</td>
</tr>
<tr>
<td>NASA-STD-6016</td>
<td>Standard Manned Spacecraft Requirements for Materials and Processes</td>
</tr>
<tr>
<td>MSFC-SPEC-164</td>
<td>Cleanliness of Components for Use in Oxygen, Fuel and Pneumatic Systems Spec</td>
</tr>
<tr>
<td>NASA-STD-8719.13B</td>
<td>Software Safety</td>
</tr>
<tr>
<td>NSTS 22648</td>
<td>Flammability Configuration Analysis for Spacecraft Applications</td>
</tr>
<tr>
<td>NASA-STD-6001</td>
<td>Flammability, Offgassing, and Compatibility Requirements and Test Procedures</td>
</tr>
<tr>
<td>JSC 20584</td>
<td>Spacecraft Maximum Allowable Concentrations for Airborne Contaminants</td>
</tr>
<tr>
<td>MSFC-SPEC-486</td>
<td>Standard, Threaded Fasteners Torque Limits for</td>
</tr>
<tr>
<td>MSFC-SPEC-521</td>
<td>Electromagnetic Compatibility Requirements for Equipment and Subsystems</td>
</tr>
<tr>
<td>MSFC-STD-1800</td>
<td>Electrostatic Discharge (ESD) Control for Propellant and Explosives Devices</td>
</tr>
<tr>
<td>IAASS-ISSB-S-1700-Rev-B</td>
<td>Space Safety Standard Commercial Human-Rated System</td>
</tr>
<tr>
<td>JSCM 8080</td>
<td>JSC Design and Procedural Standards Manual</td>
</tr>
</tbody>
</table>
Progress in space safety lies in the acceptance of safety design and engineering as an integral part of the design and implementation process for new space systems. Safety must be seen as the principle design driver of utmost importance from the outset of the design process, which is only achieved through a culture change that moves all stakeholders toward front-end loaded safety concepts. Superb quality information for engineers, programme managers, suppliers and aerospace technologists.