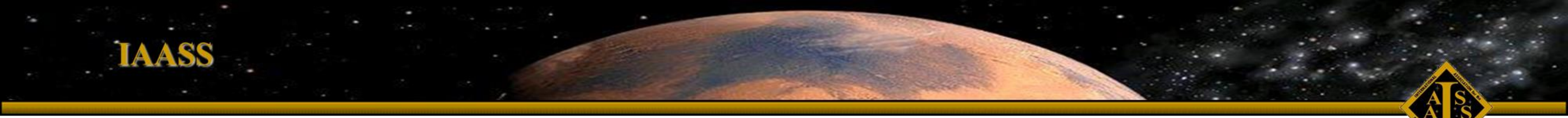


SPACE SAFETY & HUMAN PERFORMANCE

Accident Prevention – Learning and Changing from Investigations

Trondheim, October 15, 2015

Tommaso Sgobba – IAASS Executive Director

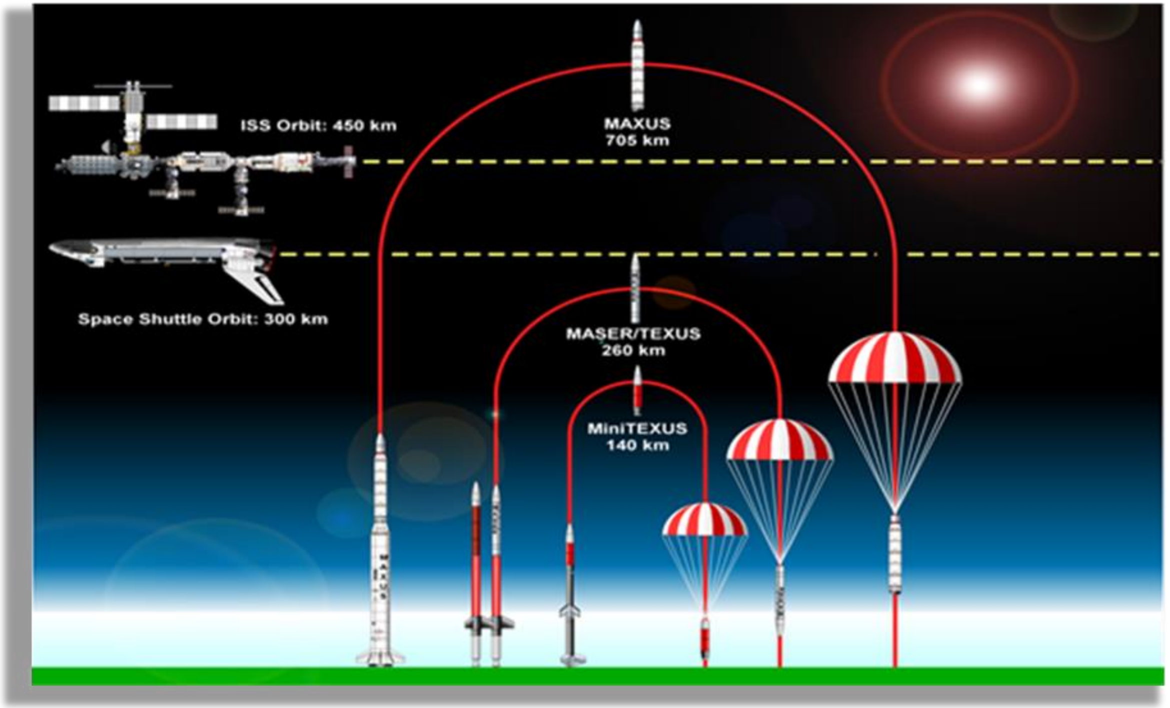
SpaceShipTwo Accident

On Oct. 31 2014, 13 seconds into the fourth powered suborbital test flight SpaceShipTwo broke-up killing 39-year-old copilot Michael Alsbury and injuring 43-year-old pilot Peter Siebold.

Note: The flight was operated by Scaled Composites company under contract to Virgin Galactic, LLC

What is a suborbital spaceflight?

A suborbital flight is a flight beyond 80-100 kilometers above sea level but in which the vehicle does not attain the speed to escape Earth's gravity field (40.320 k/h)



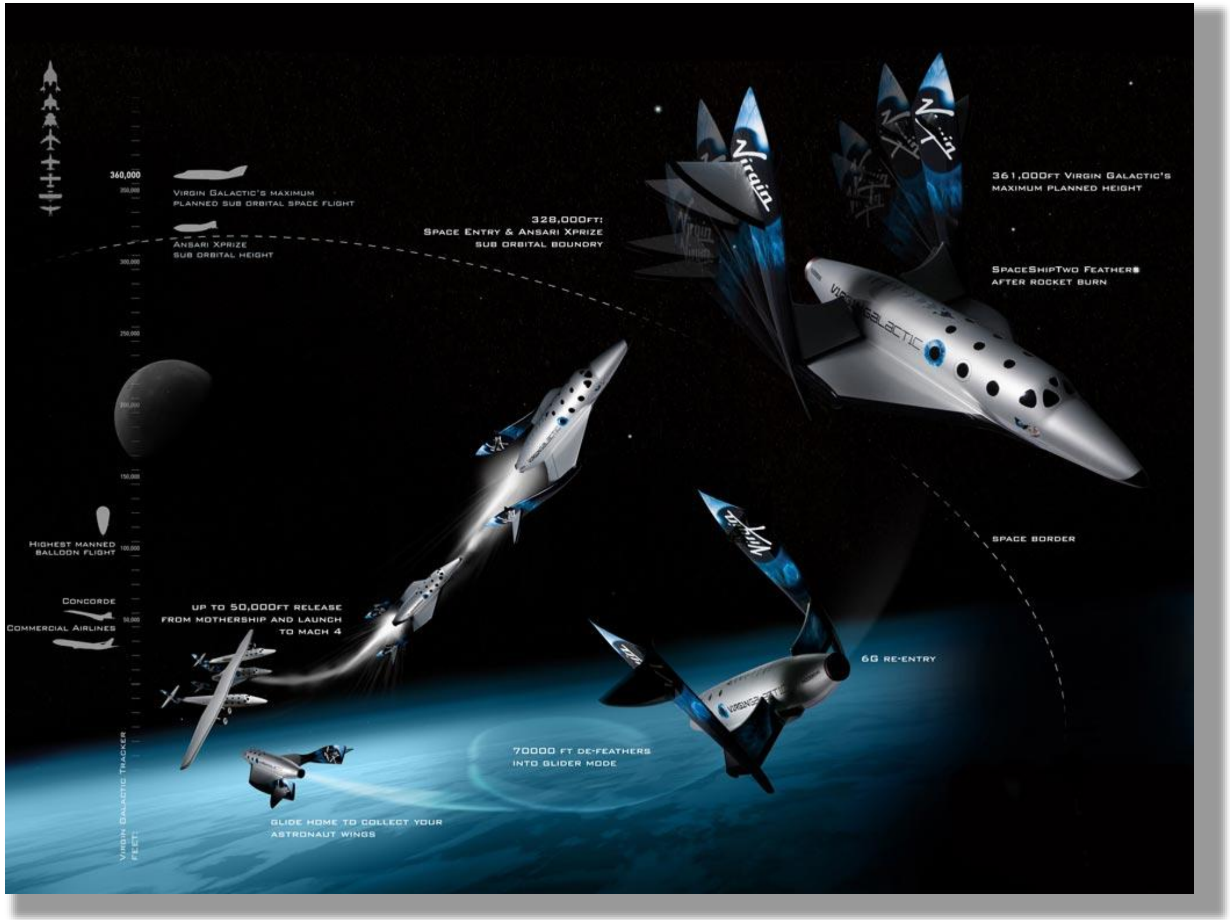
First suborbital human spaceflights more than half century ago

In 1961, Alan Sheppard on a suborbital flight reached **187 km** of altitude on board the first Mercury. A capsule on top a man-rated Redstone 3 rocket.

In 1963, NASA test pilot Joseph Walker reached an altitude of **108 km** in an X-15 aircraft, and returned to the runway from which he took off (attached to a B-52 mother ship).

SpaceShipTwo flight profile

- SpaceShipTwo (SS2) is released from its mother ship, WhiteKnightTwo, at 15.000 m
- After 3-4 sec. of free fall the single hybrid rocket engine is ignited.
- The speed reaches Mach 1 at 8 sec and Mach 3 at 30 sec. Maximum speed 4.180 km/h. Acceleration peak is 3.8 g
- After 70 seconds, the rocket engine cuts out and the vehicle will coast to its peak altitude of 110 km
- The tail is rotated to a feather position to increase stability and drag for entry. Max deceleration 6 g
- At 24.380 m, the glide phase begins with a return to an unpowered horizontal runway landing that will occur after a glide of 25 min.


360,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
Virgin Galactic's maximum planned sub orbital space flight
Ansari Xprize sub orbital height
328,000ft: Space Entry & Ansari Xprize sub orbital boundry
361,000ft Virgin Galactic's maximum planned height
SpaceShipTwo feathers after rocket burn
Space border
Highest manned balloon flight
Concorde
Commercial Airlines
up to 50,000ft release from mothership and launch to Mach 4
6G re-entry
70000 ft de-feathers into glider mode
Glide home to collect your astronaut wings
Virgin Galactic Tracker
Feet

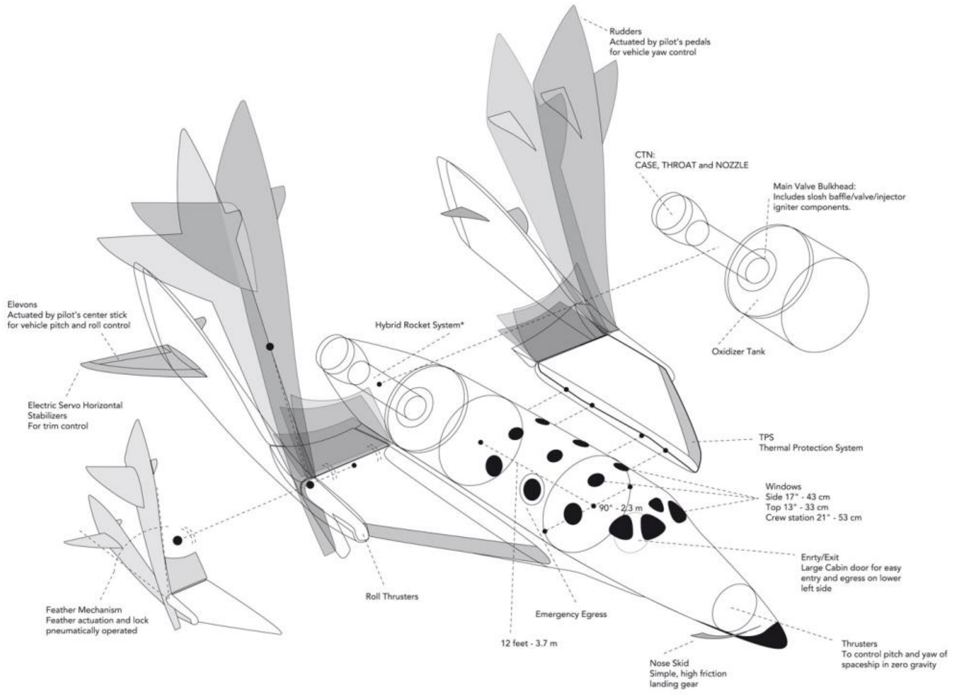
The feather system

- The feather system consist in the rotation of the tail of the vehicle to create higher aerodynamic drag at entry to improve stability and limit deceleration

- The feather system is a safety-critical mechanism.
  It is **must-not-work** system (1 time) during the ascent phase, and **must-work** (twice) during the descent phase

- Must not deploy too early, must deploy at entry, must retract before starting the gliding

- All what we know about the fether system was disclosed by the company or reported by the NTSB as part of the investigation.

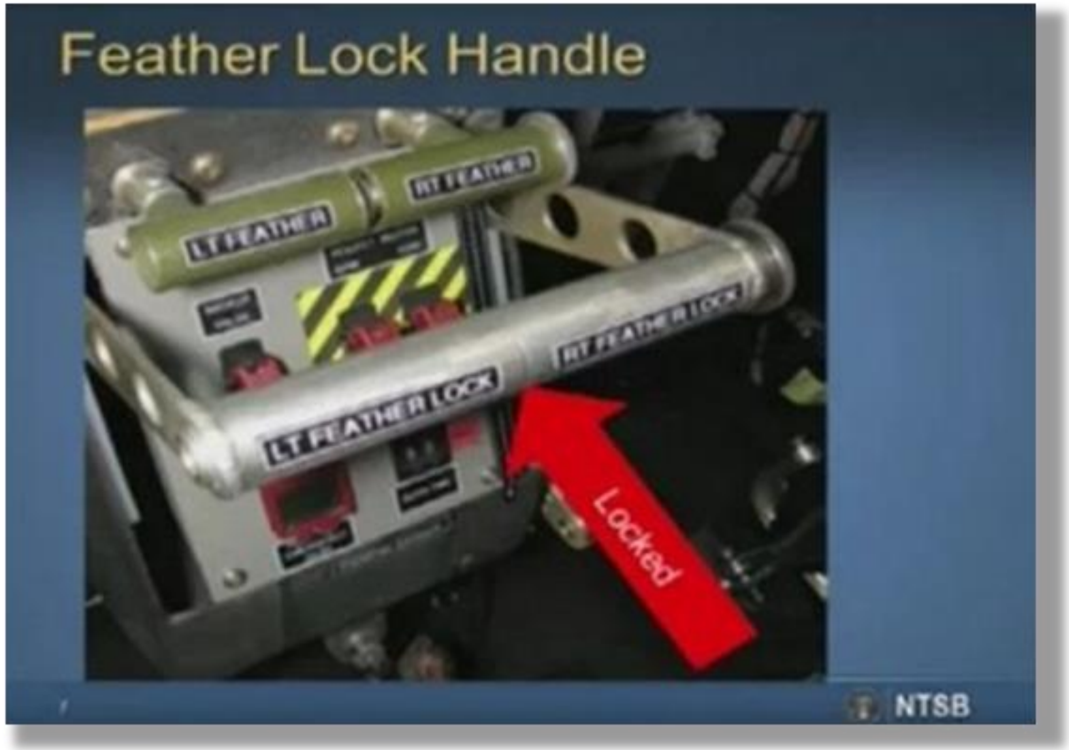


SpaceShipTwo immediate cause of accident

- As per procedures, the feathering system must be unlocked by the copilot no earlier than 1.4 Mach and no later than 1.8 Mach.

- In locked position a pair of hooks are engaged to provide structural integrity during transonic (approximately 0.8 to 1.2 Mach) flight region where large up loads on the tail can overpower the actuators and cause the feather system to deploy.

- **The copilot Michael Alsbury unlocked the system prematurely at 0.92 Mach** which resulted in the vehicle break-up. The premature unlocking was confirmed by telemetry, in-cockpit video and audio data.



Did a single human error cause the catastrophe?

While it is clear that the copilot’s procedural error **concurred** to the catastrophe, it is not clear why. Thus the investigation directed much of its focus to answer this question.

Training adequacy

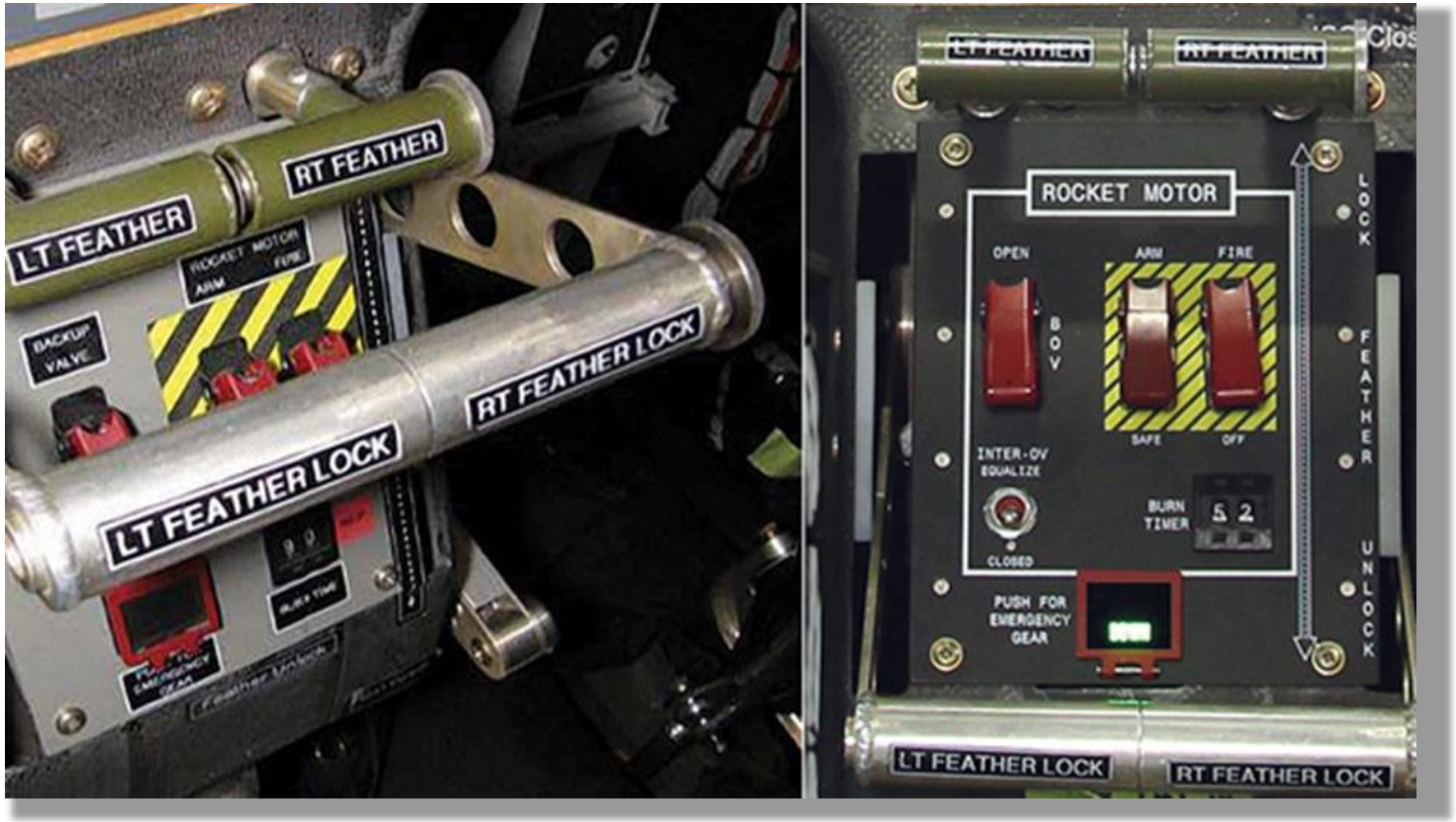
- SpaceShipTwo training included:
  - SS2 simulator training for nominal and non-nominal procedures
  - Full mission rehearsals. WhiteKnightTwo aircraft carrier has many similarities to SS2, including simulated glide through touchdown training
  - Extra EA-300L aerobatic airplane including G tolerance training and upset recovery training (i.e. loss of control prevention)

- However, while crews did practice normal and non-normal procedures in a mission scenario, many **critical aspects of the operational environment were missing**, including vibration and g-forces as well as elements of time pressure (e.g., completing tasks within 26 seconds, the consequences of a mission abort at 1.8 Mach if the feather system was not unlocked). When present, such conditions may result in much greater workload and stress than what would be experienced in a flight simulator.

Completeness of procedures

- Failing to acknowledge high levels of workload and stress also influence the development of procedures, which often serve as the pilots’ safety net.
- While the pilot and copilot had clearly defined procedures, many tasks were committed to memory and modified at the last minute, thus introducing additional error potential.
- According to NTSB interviews, the risk of premature unlocking of the feather system was “common knowledge” **but this risk was not explicitly called out in the Pilot’s Handbook** or emphasized during training. What was emphasized was the importance of unlocking the feather system before 1.8 Mach to avoid an abort.

Misleading commands panel

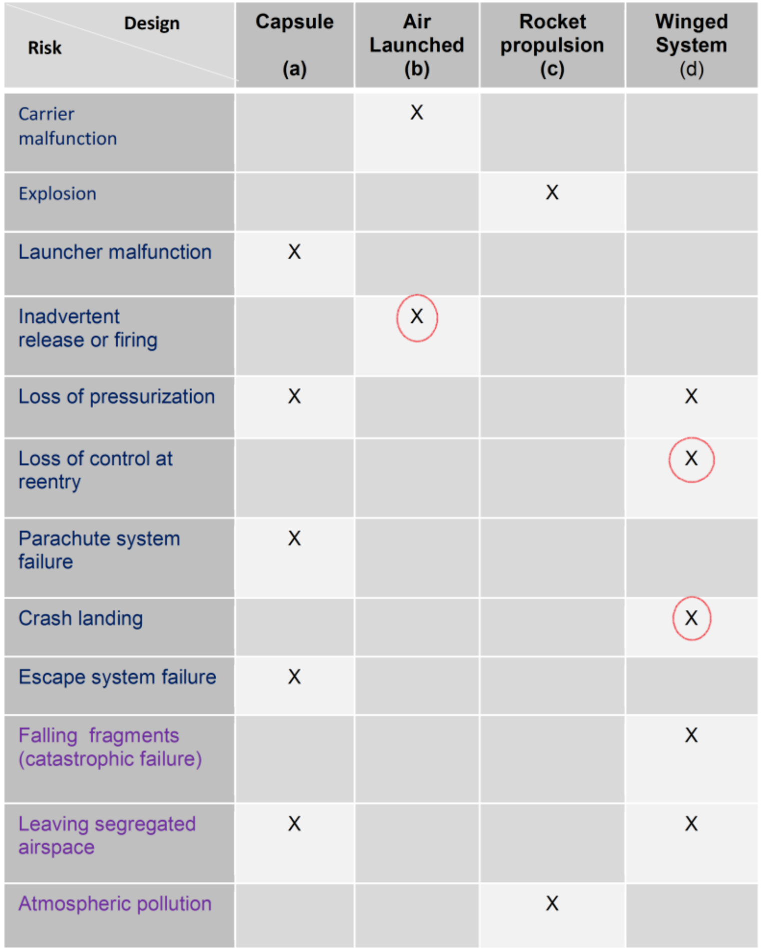


Human error prevention

- Although pilot error was considered in the hazard analysis, **it was only in the context of a system failure**, that is, if there was a systems failure, the analysis included consideration of incorrect pilot response.
- Unfortunately, pilot-command errors (untimely, inadvertent, etc.) were not analyzed. The NTSB human performance investigator summarized the following areas where there was a lack of consideration for preventing human error:
  - System not designed with safeguards to prevent unlocking of feather mechanism
  - Manuals/procedures did not have warning about unlocking feather early
  - Simulator training did not fully replicate operational environment
  - Hazard analysis did not consider pilot-induced hazards causes

Sub-orbital Vehicles Top Hazards

By combining the columns of the table, all current vehicles configurations are addressed. For example the top risks of an air launched winged suborbital vehicle like SpaceShipTwo are collectively those of columns (b) + (c) + (d)



Design Risk	Capsule (a)	Air Launched (b)	Rocket propulsion (c)	Winged System (d)
Carrier malfunction		X		
Explosion			X	
Launcher malfunction	X			
Inadvertent release or firing		X		
Loss of pressurization	X			X
Loss of control at reentry				X
Parachute system failure	X			
Crash landing				X
Escape system failure	X			
Falling fragments (catastrophic failure)				X
Leaving segregated airspace	X			X
Atmospheric pollution			X	

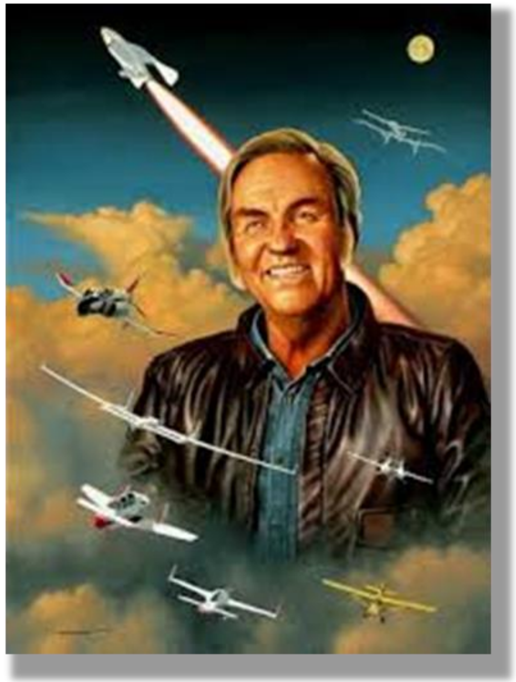
Cultural and regulatory causes

- Suborbital vehicles designers maintain that no safety requirement can be levied on industry until sufficient operational experience is accumulated, (several years, perhaps decades from now).

- Such misconception is rooted essentially in the aviation background of designers of new suborbital vehicles.

- Aviation is an “evolutionary” industry, where most standards are adopted when proven by use. They include detailed prescriptive requirements based on ‘lessons learned’ from past accidents. Hazard analyses are not generally used to drive the design.

- Space, on contrary, is a “revolutionary” industry, where standards are performance oriented. Hazards analyses are performed massively.



Cultural and regulatory causes (cont'd)

- The Commercial Space Launch Amendments Act of 2004 (CSLAA) made med Federal Aviation Administration, office of space transportation, responsible for regulating commercial human spaceflight for all aspects of uninvolved public safety, **but forbidding to levy any safety rule for crew and flight participants**, for an initial period unless there was an accident.
- During a February 2014 hearing of the U.S. House Science Space Subcommittee, George Nield, FAA associate administrator for space transportation, said that industry's plea for a longer learning period ignores government expertise about crewed space systems gathered by NASA's long-running human exploration program. It would be "irresponsible" to ignore the lessons from those programs and force regulators to collect a new set of data, Nield said.

Example of requirements of the International Space Station

3.3.6.1.1 Catastrophic Hazards
The system shall be designed such that no combination of two failures, or two operator errors, or one of each can result in a disabling or fatal personnel injury.

3.6.13.3 Inadvertent Deployment
Inadvertent deployment… which could result in inability to sustain subsequent loads shall be one or two failure tolerance consistent with the hazard level.

SSP 50021
Safety Requirements Document
International Space station Program
December 12, 1995

Hazard reduction precedence

Actions to eliminate/minimise the risk associated with identified hazards/hazard causes will be undertaken in the following order of precedence:

a) eliminate the hazard
b) develop design solutions and/or use safety devices
c) provide detection and warning/caution devices
d) develop special procedures and training
(including personnel protective equipment)

HAZARD CONTROLS

A lesser degree of desirability exists for each succeeding control method.

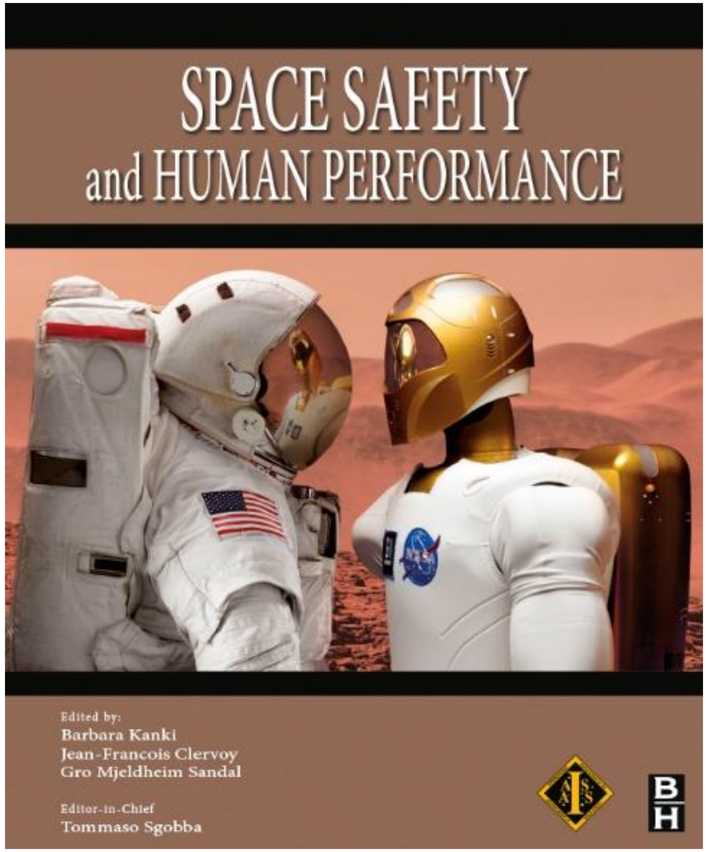
The essence of safety-by-design

Hardware and software can be designed at the best of our knowledge, but our knowledge is not perfect. We can apply the most rigorous quality control during manufacturing, yet perfect construction does not exists and some defective items will be built and escape inspection. Human can be selected and trained according to best practices, but they will not be exempted from errors.

A safe system is one that through additional margins, redundancies, barriers, and capabilities will “tolerate“ (to a certain extent) hardware failures, software faults, and human errors, mitigate harmful consequences, and/or lower the probability of their occurrence.

B.Z. Toons
by Brian Zaikowski
www.bztoons.com
Oh yuk, a snake! I hope they don't get any bigger than that.

IAASS Working on a new book



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