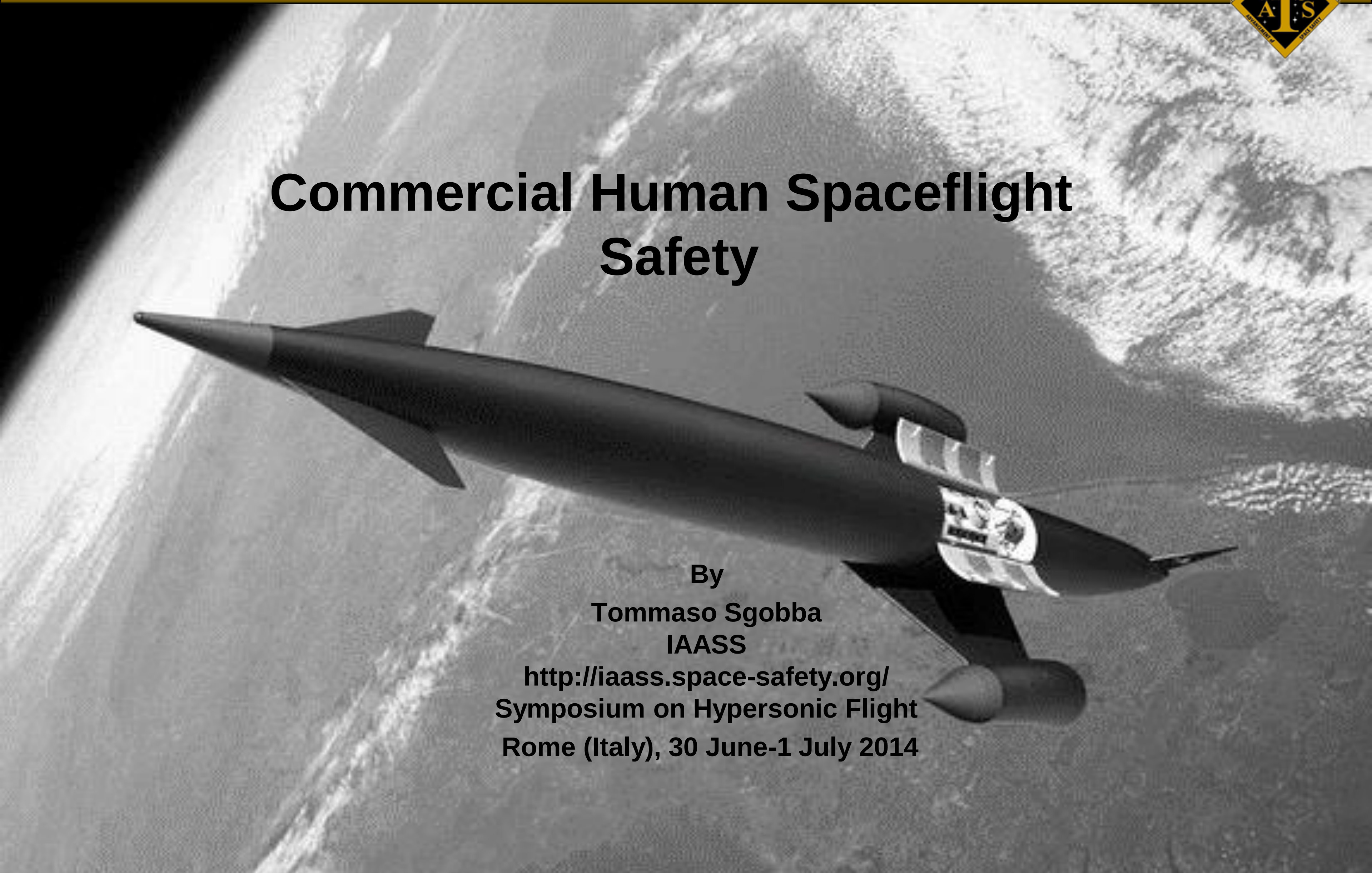


Commercial Human Spaceflight Safety

By

Tommaso Sgobba

IAASS

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

Symposium on Hypersonic Flight

Rome (Italy), 30 June-1 July 2014

The raising of commercial space

Outerspace “regions”

Today, referring to all space activities as exploration activities has become meaningless. Outer space is made of two functional regions: the **“space-exploitation”** region (ETR) and the **“space-exploration”** region (ERR). The border between the two regions lays currently at the upper end of the geosynchronous orbits (36,000 km).

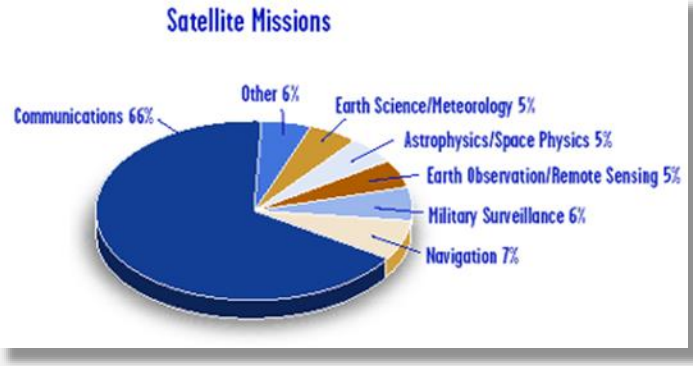
Exploitation
≤36,000 km

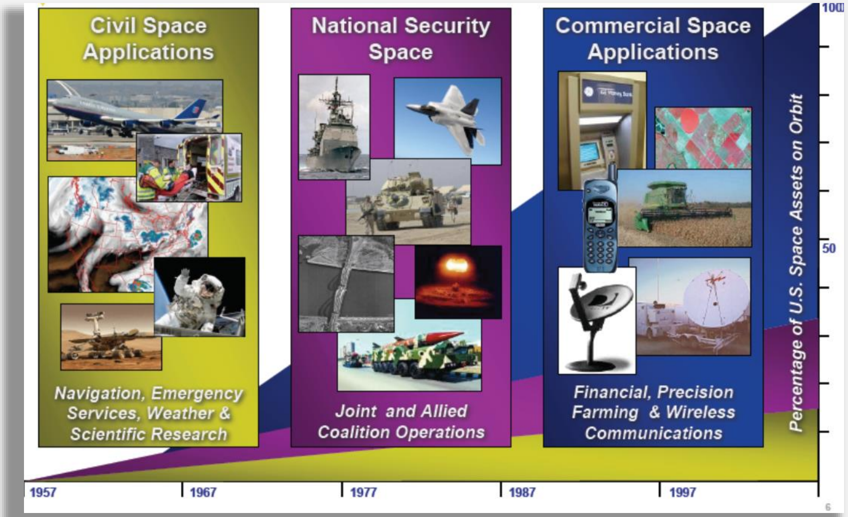
Exploration

(Note: according to dictionary ‘*exploitation*’ means making productive use, while ‘*exploration*’ means, traveling over new territory, for adventure, discovery or investigation).

Growing importance of commercial space

- The interests in the space-exploitation region, are mainly **commercial** and **military**
- The interest in the space exploration region are **scientific**





Note: military space strategy (US) to cope with vulnerability concerns, so-called "*Pearl Harbor in Space*", is evolving from seeking 'supremacy' to 'resiliency' (alternative non space-based systems and redundancy (e,g, for GPS), "disaggregation", military P/L on commercial satellites, rapid deployment systems, etc.)

Not a line but a **zone** separates airspace and outerspace

- Several "soft" boundaries between air and space have been defined:
  - 50 Km is the upper limit of atmospheric buoyancy (balloons);
  - 80 Km is the threshold altitude that defines "astronauts" in the US;
  - 100 Km, also known as the "Karman Line", is where aircraft aerodynamic controls become ineffective;
  - 120 Km begins the re-entry threshold for space vehicles; and,
  - 160 Km is the lowest practical operating orbit for satellites and spacecraft.

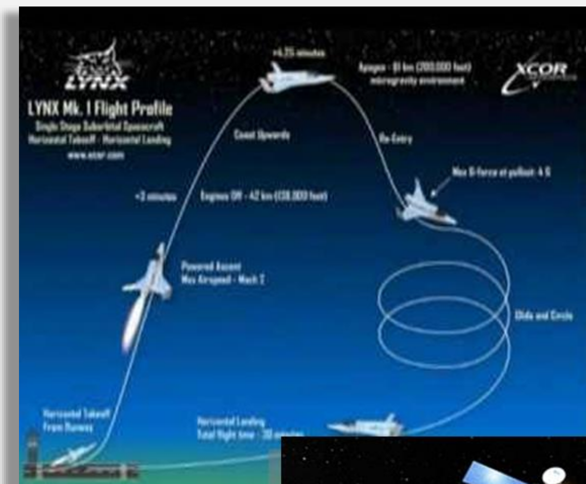
  ? (refers to the 80 Km, 100 Km and 120 Km boundaries)

- Currently there is no legally defined boundary in international aeronautical conventions and space treaties. The Karman-line, the 100 km theoretical separation between the field of aeronautics and that of astronautics has been recognized for the application of national space-related regulations only by few countries such as Australia. **The separation is truly a zone not a line.** It may be suitable to define such intermediate zone in analogy with the EEZ (Exclusive Economic Zone) of the UN "Law of the Sea" convention.

The fading divide between airspace and outerspace

- Important elements of aviation infrastructure and services (**air traffic control, communication meteorology**) are becoming space-based.

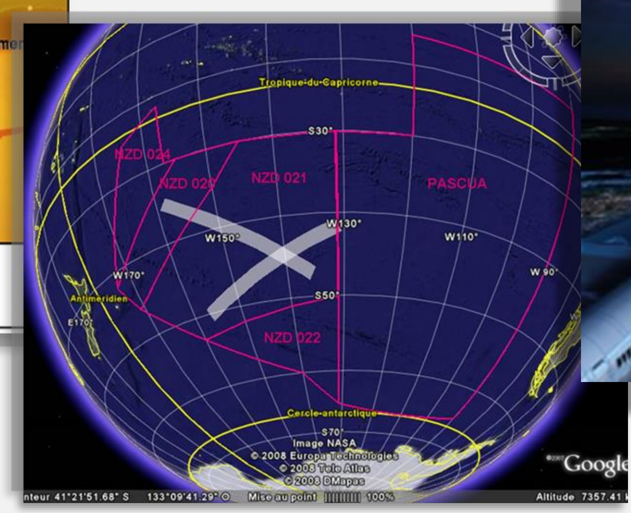
- Vehicles are being developed that will **operate in both domains**.



The fading divide between airspace and outerspace (cont’d)

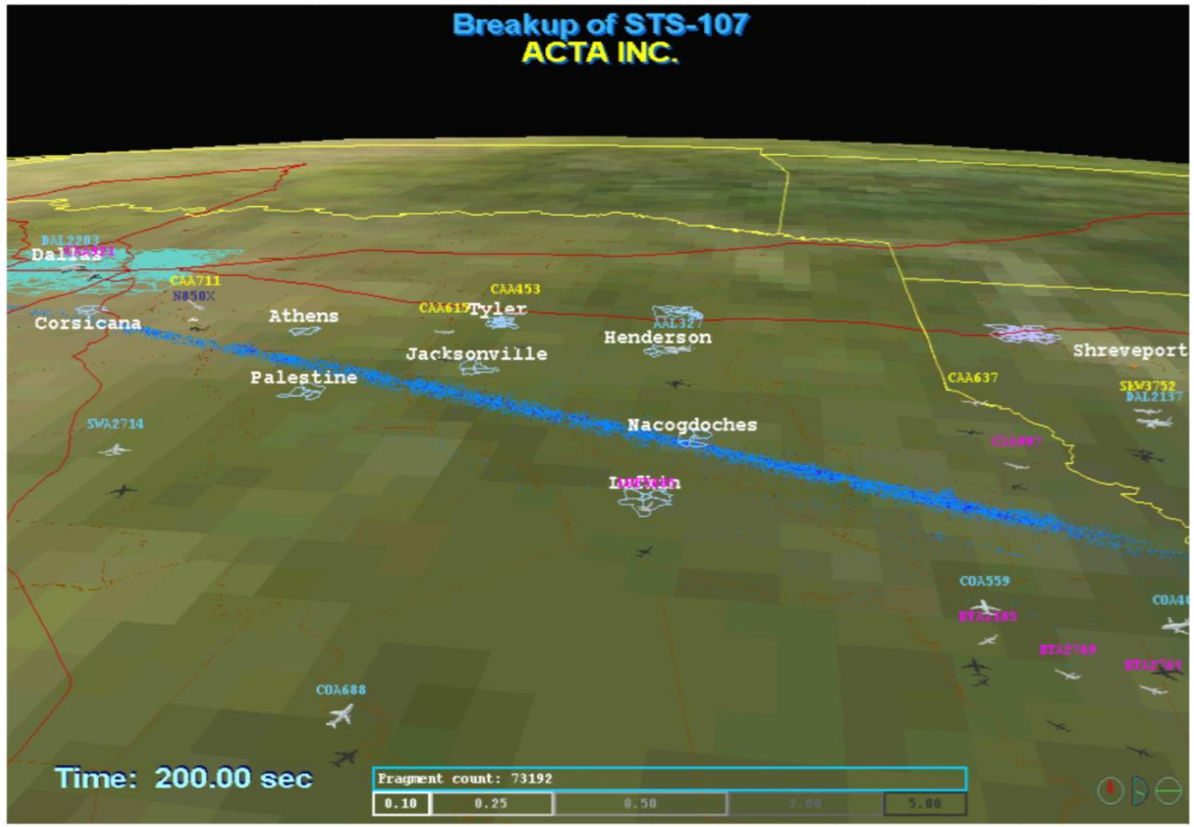
- There are common concerns like space weather, **sharing of airspace during launch and re-entry operations**, protection of the atmospheric and orbital environment (space debris).

- A large part of space launch and re-entry operations take place through the international airspace under the ICAO jurisdiction.



The Shuttle Columbia's aviation close call

- The disintegration during re-entry of the Shuttle Columbia on February 1, 2003 was a watershed moment in the history of re-entry safety. It highlighted the need to establish preplanned **measures to keep air traffic away from falling debris** if a re-entry accident occurs.
- About 100,000 fragments were recovered for about 40% of the original weight.



Current developments

Company: The Spaceship Company

SpaceShipTwo(SS2)	
Vehicle	Winged, hybrid rocket engine, Mach 4
Operation	- Air-launched at 15,000m by jet-powered Scaled Composites WhiteKnightTwo aircraft - horizontal landing
Mission	Sub-orbital flights, 2 pilots, 6 pax
Spaceport	Mojave Spaceport, California (USA)
Launches	2014, start of commercial operations

Safety certification authority: FAA
for public launch/re-entry public safety

Company: XCOR

Lynx	
Vehicle	Winged, 4 LOX-Kerosene rocket engines , Mach 3.5
Operation	Horizontal take off and landing
Mission	- Sub-orbital flights, 1 crew, 1 pax - Small satellites orbital
Spaceport	- Mojave Spaceport, California (USA) - Caribbean Spaceport, Curacao (NL)
Launches	2014, start of commercial operations

Safety certification authority: FAA
for public launch/re-entry public safety

Company: Space X

Dragon	
Vehicle	Capsule
Operation	Ground launched by Falcon 9 rocket
Mission	- Crew (7) orbital (LEO) - Cargo
Spaceport	- Launched from Cape Canaveral Air Force Station - Splashdown landing
Tests	Drop and abort test end 2013

Safety certification authority:
- NASA for human spaceflight
- FAA for launch/re-entry

Company: Sierra Nevada & Lockheed-Martin

Dream Chaser	
Vehicle	Winged – Lifting body
Launch Operation	Ground launched by Atlas V rocket
Mission	- Crew (2-7) orbital (LEO) - Cargo
Spaceport	- Launched from US launch range - Landing at NASA-KSC
Glide Tests	October- November 2013
Piloting	Unmanned or Manned

Safety certification authority:
- NASA for human spaceflight
- FAA for launch/re-entry

Company: Boeing & Bigelow Aerospace

CST 100	
Vehicle	Capsule
Operation	Ground launched by Atlas V rocket, (Delta IV, Falcon 9)
Mission	- Crew (7) orbital (LEO) - Mixed crew and cargo
Spaceport	- Launched from LC 41, Cape Canaveral Air Force Station - Splashdown landing
Tests	Subsystems test on going

Safety certification authority:
- NASA for human spaceflight
- FAA for launch/re-entry

Company: Blue Origin

New Shepard	
Vehicle	- Capsule powered by High Test Peroxide (HTP) and RP-1 kerosene. - Propulsion Module, with reusable liquid oxygen, liquid hydrogen rocket engines
Operation	- Ground launched by rocket-powered Propulsion Module - Propulsion Module lands vertically (VTVL) - Capsule lands with parachute
Mission	Crew (3) suborbital
Spaceport	- Launched from LC 39A, Cape Canaveral Air Force Station
Tests	Launch, landing and escape systems tests performed in 2012

Safety certification authority: FAA
for public launch/re-entry public safety

Company: Reaction Engines

Skylon	
Vehicle	Winged, 2 SABRE engines mix hydrogen jet and LOX-hydrogen rocket engine, Mach 5,4 as jet
Operation	Single-stage-to-orbit, horizontal take off and landing
Mission	- Orbital & sub-orbital flights, - Small satellites orbital
Airport	TBD
Tests	Flight tests 2020

Safety certification authority: UK CAA

Company: Swiss Space Systems

Swiss Space System (S3)	
Vehicle	Winged – lifting body
Operation	Air launched from Airbus A300
Mission	- Sub-orbital Intercontinental flights - Small satellites launch to orbit
Airport	- Payerne Airport (CH) - Malaysia - Morocco
Tests	Flight tests 2017

Safety certification authority: EASA (TBC)

Company: Airbus Space & Defence

Vinci Spaceplane	
Vehicle	Winged, Mach 3, 20 tons Double propulsion: jet engines, cryogenic methane/oxygen rocket engine
Operation	Horizontal take off and landing
Mission	- Sub-orbital manned, 6 pax, 2 crew - Small satellites launch
Airport	TBD
Development Status	Studies

Safety certification authority: EASA

Company: Dassault

VSH	
Vehicle	Winged – lifting body, Mach 3.5 Propulsion Lox/Kero, 11 tons
Launch Operation	- Air launched - Horizontal landing
Mission	Sub-orbital manned, 6 pax
Airport	TBD
Development Status	Studies

Safety certification authority: EASA
(as a high performance aircraft)

Company: Copenhagen Suborbital

TychoDeepSpace II	
Vehicle	Capsule
Launch Operation	Sea launched by HEAT 1600 rocket
Payloads	Sub-orbital
Spaceport	TBD
Development Tests	On-going, including tests of the escape system

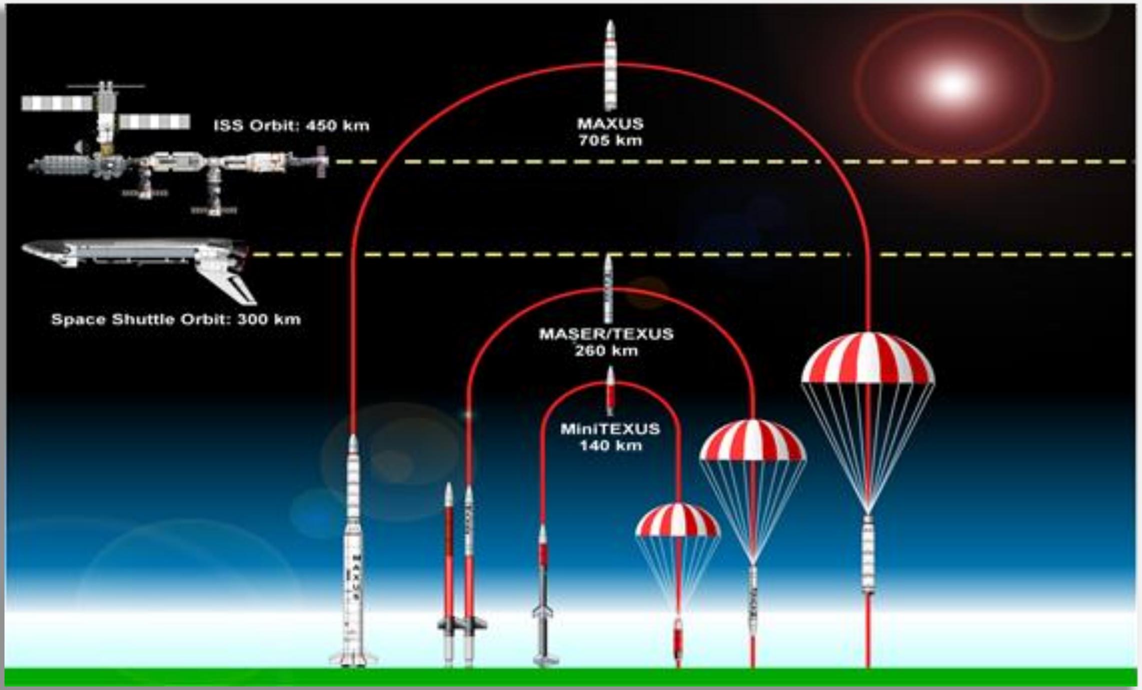
Safety certification authority: TBD

Aero-spaceports: a growing reality

Sub-orbital spaceflight safety

Unmanned suborbital spaceflight

- Unmanned suborbital flights have been common since the very beginning of the space age. A suborbital flight is a flight beyond 100 kilometers above sea level but in which the vehicle does not attain the speed to escape Earth's gravity field (40,320 kph).



ESA unmanned suborbital rockets -credits: © ESA/G. Dechiara

First suborbital human spaceflights half century ago

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

- 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).

- The commercial human suborbital space vehicles currently in development still basically follow such configurations, plus other two consisting into an airplane with either a rocket engine or jet engine plus rocket engine.

First rocket propelled airplane 70 years ago!

ME-163

It is a rocket or an airplane?

A space vehicle needs rocket propulsion to travel in vacuum. But a vehicle like a car or an airplane which uses rocket propulsion to accelerate on ground or in air is not a space vehicle! Since WWII there have been several types of (military) planes that have made use of rockets during take-off (RATO).


C-130 RATO

Parabolic flight

A person on a space vehicle orbiting Earth will experience weightlessness, but you can experience **weightlessness** also on a free fall or **on an aircraft performing a parabola**. Space agencies usually use aircraft parabolic flights to test equipment and train astronauts.

Most commercial human suborbital systems currently in development are **essentially high-performance aircraft that use rocket propulsion to accelerate in air** (rocket burn-out around altitude of 60 km) while **in a parabolic flight**.

Historical safety records

- **Capsule configuration** - The available (statistically significant) safety record for capsule configuration is that of Russian Soyuz (orbital vehicle). As of beginning of 2013 there have been 115 manned Soyuz launches with 4 failures in total: 2 during launch with no casualty (thanks to the activation of the abort systems), and 2 at re-entry with 3 casualties in total.

- **Air-launched configuration** – On a total of 199 flights X-15 flights there were 1 engine failure and 1 engine explosion with damages at landing (no casualty), and 1 crash with 1 casualty.

Suborbital spaceflight safety target

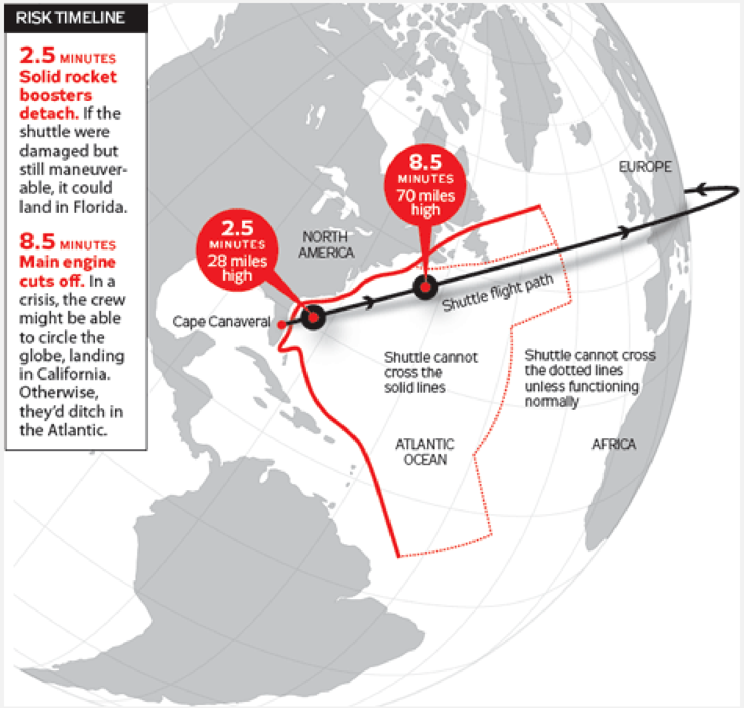
- The IAASS considers that a quantitative safety target of **1 accident per 10,000 flights** may be achievable in current suborbital vehicle developments by using proven, well understood and reliable rocket propulsion technologies, application of best safety practices from past and current aeronautical and space projects, performance of wide ground and flight testing program, and rigorous quality control program.

Suborbital vehicles top-risks

Risk \ Design	Capsule	Air launched	Rocket propulsion	Winged system
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	

Public safety issues

- Under US law, there are no regulations levied for the safety of passengers and crew, but only for the protection of the uninvolved public.
- Rocket powered unmanned and manned systems (see Shuttle) traditionally include a destructive Flight Termination System (FTS) to prevent departure from segregated airspace or flight path in case of malfunctioning. The suborbital winged systems currently in development do not include a FTS.
- The International Civil Aviation Organization (ICAO) is initiating a study group to assess risks for aviation from suborbital spaceflight, and propose operational risk control measures.

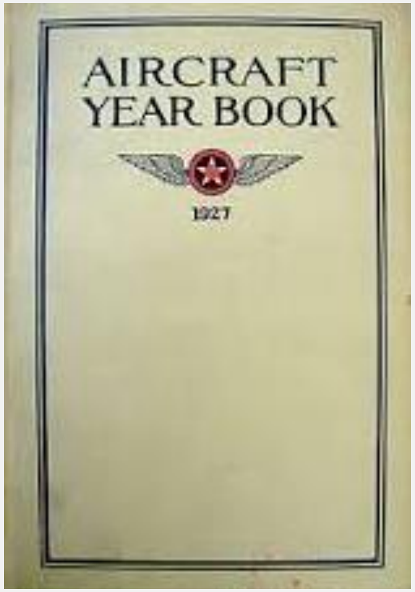


Which regulatory framework?

Those who cannot remember the past are condemned to repeat it

"Since the armistice (1918)when airplanes were first made generally available and came into hands skilled and unskilled, responsible and irresponsible, it may be conservatively estimated that more than 300 persons have been killed and 500 injured – many of them fatally – in flying accidents which could have been prevented had there been in existence and enforced a statute regulating the operation of commercial aircraft"

Aircraft Year Book - 1927



“No-regulation” is not an option

The nascent commercial human spaceflight industry maintains that safety regulations (apart public safety) would kill industry. For experienced safety professionals the opposite is true. It is time that operators get real about the extraordinary risks they face.

Lack of safety regulations could mean, in case of an early accident, an end to commercial human space flight before it has chance to get started. Safety regulations <u>protect the public but also industry</u>, by defining the **state-of-art** in the field of safety.

Believing that risks are inevitable, that substantial improvements are almost impossible, and relying on public acceptance of current level of risks while society is increasingly risk averse is a recipe for business failure.

The future of commercial human spaceflight is in advancing spaceflight safety within a regulatory framework either governmental or industry driven. “**<u>No-regulation” is not an option!</u>**

The myth of "too early for regulations"

The old-fashioned idea of prescriptive safety standards

Industry maintains that no safety standard can be issued until significant operational experience is accumulated. This is the old-fashioned idea of prescriptive safety requirements

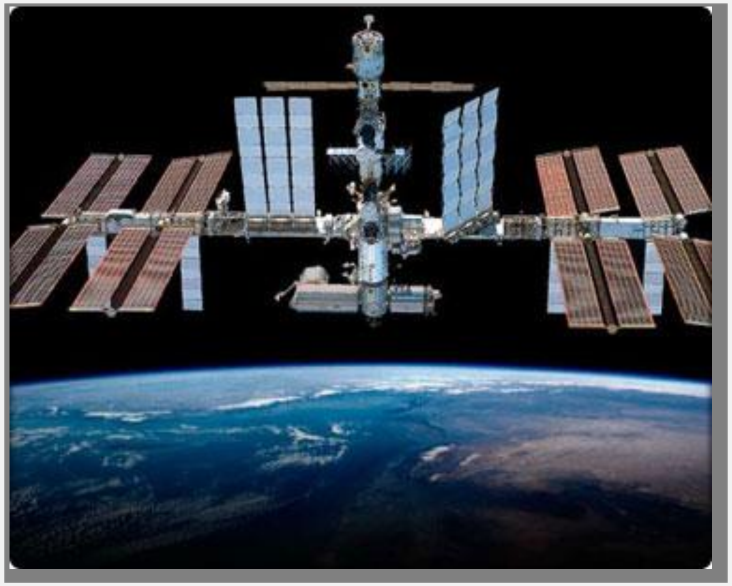
A prescriptive requirement is an explicit design requirement or technical solution for an implicit safety goal. Use of prescriptive requirements is an obsolete way to pursue safety. The modern approach revolves around generic goal-oriented requirements, to build the so-called "safety case".

In the early hours of 15 April 1912, the RMS Titanic struck an iceberg on her maiden voyage from Southampton, England, to New York, USA and sank. A total of 1,517 people died in the disaster because there were not enough lifeboats available, however the ship was fully compliant with the requirement of the tim. that all British vessels over 10,000 tons had to carry 16 lifeboats. The regulations were clearly out of date in an era where the size of ships had reached up to 45,000 tons.

Prescriptive standards not suitable for new hi-tech systems

The vast majority of standards in use in aviation are the result of accumulated experience (i.e. accidents and incidents) and steady technological evolution in the post-war period. They are detailed according to type and very prescriptive

In contrast there are industries in which building on experience is simply not possible, because the system is completely new, highly safety-critical and/or extremely expensive.



The safety-case approach

- The safety-case approach recognizes that the regulatory authority has the role and responsibility to **define "safety goals and objectives",** while the developer/operator must be in charge of **proposing valid detailed technical solutions**, due to its in-depth knowledge of the system design and operations.

- The safety case approach was developed at the time ICBM nuclear weapons were introduced in the sixties. It requires the performance of hazard analyses to identify hazards, determine hazard causes, and select design solutions in line with pre-defined safety goals.

- The implementation of a safety-case based regulatory regime has a number of important consequences. One is that both the design team and the **safety certification team must have a deep knowledge of how the system works in order to understand the relevant hazards** and the soundness of the design controls selected to mitigate the risks. In principle the safety certification team should be even more knowledgeable and experienced than the design team.

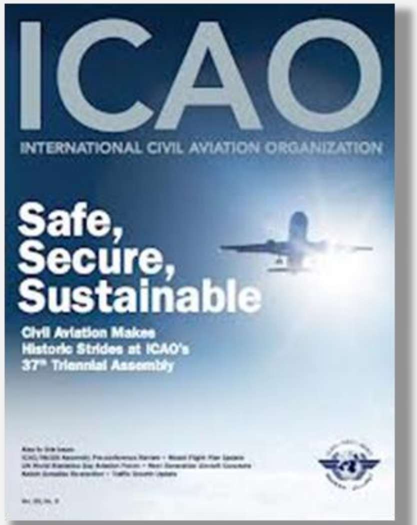
The misleading comparison with early times of aviation

State-of-art at beginning of aviation

State-of-art at beginning of commercial human spaceflight

Regulatory models

The ICAO Model



The IMO Model

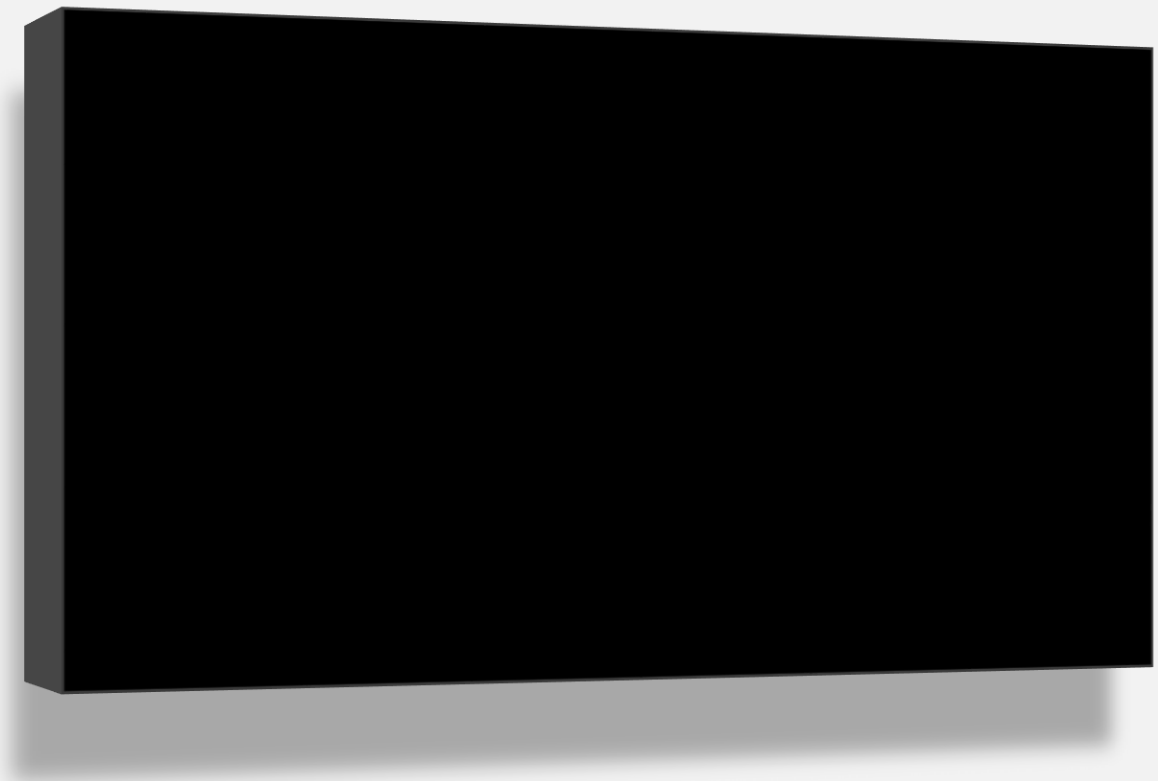
LLoyd's Register
ABS
DNV
BUREAU VERITAS

IMO INTERNATIONAL MARITIME ORGANIZATION

The Safety Institute Model

The future at the door

- Successful tests completed at the end of 2012 of the critical component (heat exchanger) of the revolutionary “Sabre” engine of Skylon may inaugurate within the next decade the era of point-to-point hypersonic commercial transportation, and single-stage to orbit space transportation.



Next IAASS Conference – October 2014

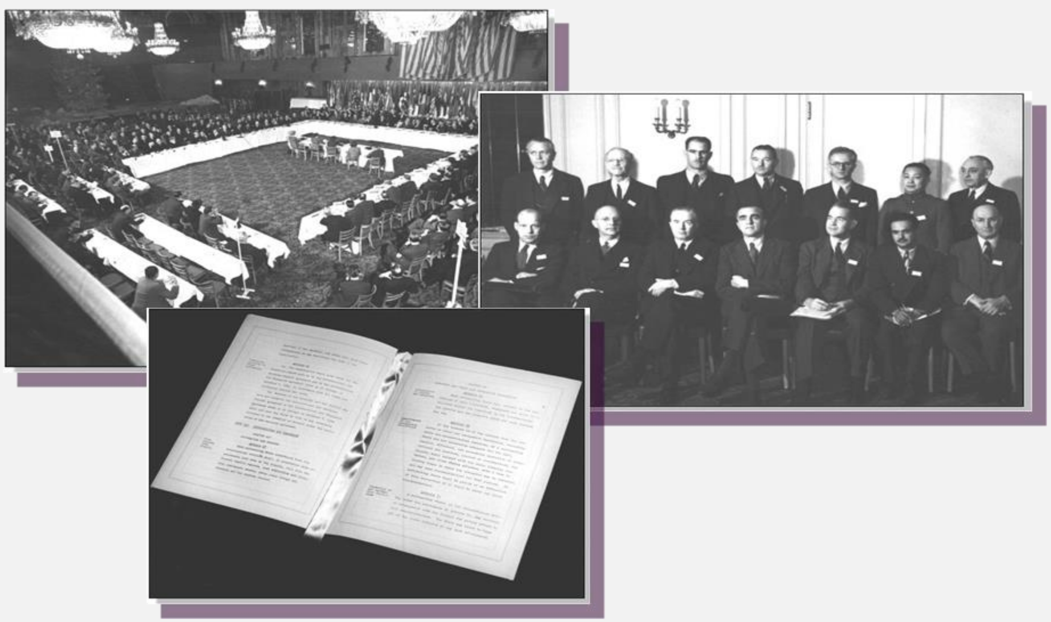
Back-up slides

The ICAO Model

The ICAO Model

The U.S. initiated in 1943 studies of post-war civil aviation, which confirmed that civil aviation had to be organized on an international scale to become a key element of the world economic development

At the end of 1944, the U.S. invited 55 states to attend an International Civil Aviation Conference in Chicago. The Convention on International Civil Aviation was signed on 7 December 1944. In 1947 ICAO became e specialized agency of UN.

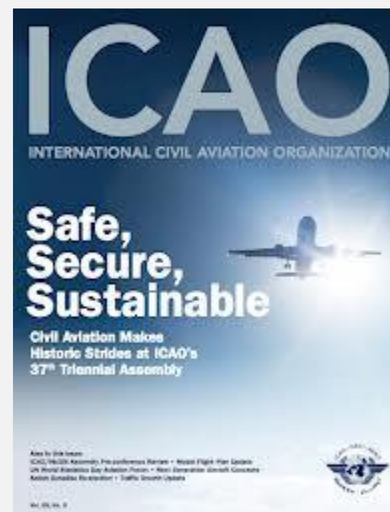


The ICAO Model

The 96 articles of the Convention established the adoption of **International Standards and Recommended Practices (SARPs**) to secure the highest possible degree of uniformity in regulations and standards, procedures and organisation regarding civil aviation matters

The ICAO Convention does not generate any prerogative, right or obligation for individual nationals of the contracting States. Only national laws and regulations apply. [“Each contracting State undertakes to collaborate in securing the highest practicable degree of uniformity in regulations, standards, procedures, and organisation…”]

The ICAO Council can make recommendations for changes (to national rules) but “No contracting State shall be guilty of an infraction of this Convention if it fails to carry out these recommendations.”



The IMO Model

Taking a page from maritime practice

http://www.thespacereview.com/article/2252/1

Classification Societies…..it all started over a cup of coffee

- In the second half of 18th century, marine insurers, based at Lloyd's coffee house in London, developed a system and established a committee for the independent inspection of the hull and equipment of ships presented to them for insurance cover.
- The condition of each ship was “classified” on an annual basis according to the excellence of its construction and its perceived continuing soundness (or otherwise).
- In 1828 Bureau Veritas was established as classification society, followed by the Lloyd's Register of British and Foreign Shipping as a self-standing classification society, and by other societies (RINA, ABS, DNV, ClassNK, etc.

Classification Society activities

- ✓ Promotion of safety of life, property and the environment
- ✓ Develop technical standards (rules) for design and construction of ships
- ✓ Approve designs against their standards
- ✓ Conduct surveys during construction to satisfy the ship is built in accordance with the approved design and to the requirements of the Rules
- ✓ Acts as a Recognised Organization carrying out statutory surveys & certification as delegated by maritime administrations
- ✓ Regulations for in-service inspection and periodic survey during operation
- ✓ Research and development programs
- ✓ Support international organizations (IMO, ISO, IACS, etc.)

Involved in all stages throughout the life of a ship: design, construction and in-service. Assessment of changes resulting from modification, repair, degradation, etc.

International Maritime Organization (IMO)

As a specialized agency of the United Nations, IMO is the global standard-setting authority for the safety, security and environmental performance of international shipping.

Its main role is to create a regulatory framework for the shipping industry that is fair and effective, universally adopted and universally implemented.

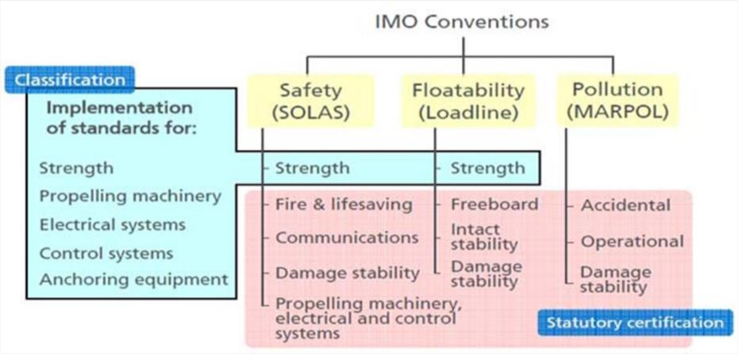
In other words, its role is to create a level playing-field so that ship operators cannot address their financial issues by simply cutting corners and compromising on safety, security and environmental performance. This approach also encourages innovation and efficiency.

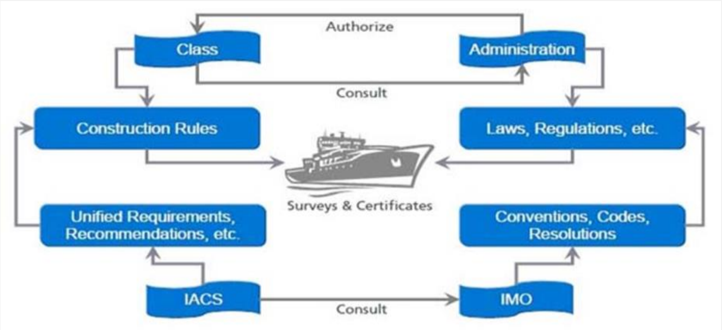
IMO INTERNATIONAL MARITIME ORGANIZATION

Classification Society statutory role and interfaces

- Many national administrations have opted to take advantage of Classification Societies experience by signing formal delegation agreements with one or more of them (for example Canada signed with Germanischer Lloyd, American Bureau of Shipping, Bureau Veritas, Det Norske Veritas and Lloyd’s Register).

- The rules published by Classification Societies, together with the requirements set down in the various International Conventions of the International Maritime Organisation (IMO) and the marine legislation of the flag states, form a comprehensive and coherent set of standards for design, construction and maintenance in operation of ships





The Safety Institute Approach

Taking a page from Formula 1 car racing industry

Formula 1 self-regulation

- In the first three decades of the Formula 1 World Championship, inaugurated in 1950, a racing driver's life expectancy was about two seasons. "*Driver raced, drivers died. In a world too familiar with the carnage of war it was accepted that total risk was something that went with the badge*" - (D. Tremayne, sport writer)

- Total risk was accepted by pilots, racing teams, and the public, but the deaths of Roland Ratzenberger and Ayrton Senna on live TV during the Imola Grand Pix of 1994 forced the car racing industry to look seriously at safety, or risk being banned forever.

- In the days after the Imola crashes the Fédération Internationale de l'Automobile (FIA) established the Safety Advisory Expert Group to identify innovative technologies to improve car and circuit safety, and mandated their implementation and certification testing. Thanks to such efforts, Formula 1 car racing evolved into a safe, self-regulated, multibillion dollar business funded by sponsorships and global television rights.

Lessons learned from deep water oil drilling

Deep water oil drilling is a high-tech industry. "*Everyone thought that exploring the deep sea would be as exciting as a trip into outer space. The reality, though, was different. Compared to conditions in the deep sea, flying to the moon looked easy*" (Klaus Wallmann, head of the Marine Geosystems Research Unit, Leibniz Institute of Marine Sciences, Kiel, Germany).

Gulf of Mexico – 20 April 2010

"*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*" (US Presidential Commission on Deepwater Horizon Disaster)