SPACE SAFETY GOVERNANCE

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Governance Instruments

1. Binding Legal Instruments and regulations – International treaties, conventions and agreements and National Space Legislations
2. Safety Guidelines and design standards
3. Codes of Conduct
4. Status Monitoring and information sharing
5. Institutional mechanisms
6. Transparency and confidence building measures
7. Methods of Intervention
8. Research Training and capacity building
9. Standard Operating Procedures
10. Best practices

UN Principles and Agreements

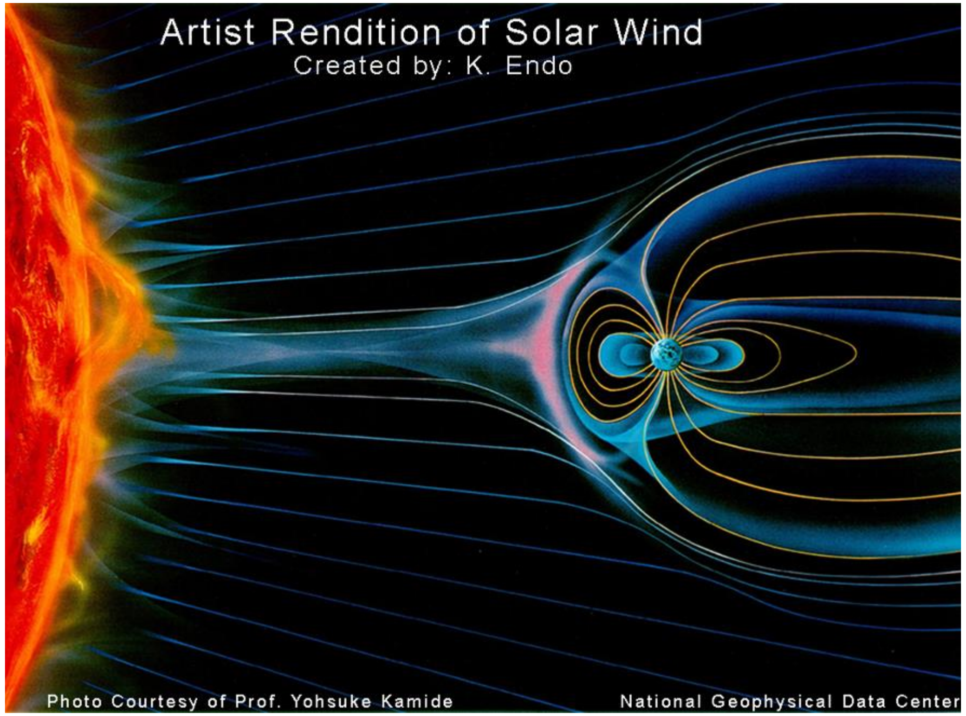
- 1967 - Outer Space Treaty
- 1968 - The Rescue Agreement
- 1972 - Liability Convention
- 1975 - Registration Convention
- 1979 - The Moon Agreement
- UN principles relating to International Direct Television Broadcasting by satellites, remote sensing, use of nuclear power sources and international cooperation
- Space debris mitigation guidelines
- Ref: [ST/SPACE/61/Rev.2: International Space Law: United Nations Instruments (unoosa.org)]

Status awareness and predictability of risks/dangers

Natural hazards
- Solar Flares
- Asteroids/ Meteorites

Space debris environment
- Tracked debris
- Untracked debris

Space situational awareness
- Methods of tracking / capability required
- International cooperation
- Information sharing



Impact on spacecraft design →

- Thermal control
- Spacecraft charging
- Radiation effect
- Vacuum/ corrosion (out gassing)
- Micrometeorites
- Debris
- Drag
- Sensors FOV constraints
- Manned presence constraints
- Micro gravity

Space debris and its mitigation

Space Debris environment

Refer [Orbital Debris Quarterly News 27-3 (nasa.gov)]

- About 27,000 tracked objects of size larger than 10 cm
- More than 10,00,000 particles of size varying between 1 to 10 cm (ESA)
- Several millions particles of size less than 1 cm

Sources

- Mission related - Satellites, Rocket bodies
- Accidental – Satellite break-ups, On-Orbit Collisions, Drop-outs from astronaut's extra-vehicular activities
- Intentional – ASAT tests, Intentional Destructions, Abandonment of space objects in LEO, launching of Space Objects non-compliant to UN debris mitigation measures, micro and small satellites … …

Remedial Measures

- Strict compliance, Mitigation, Active Removal, On-Orbit Servicing

UN Guidelines as per UNGA resolution 62/217 of 22 December 2007

Guideline 1: Limit debris released during normal operations

Space systems to be designed not to release debris (sensor covers, separation mechanisms etc) during normal operations

Guideline 2: Minimize the potential for break-ups during operational phases

Spacecraft and launch vehicle orbital stages disposal and passivation measures should be planned and executed to avoid break-ups.

Guideline 3: Limit the probability of accidental collision in orbit

Probability of accidental collision with known objects during the system's launch phase and orbital lifetime should be estimated and limited.

Guideline 4: Avoid intentional destruction and other harmful activities

The intentional destruction of any on-orbit spacecraft and launch vehicle orbital stages or other harmful activities that generate long-lived debris should be avoided. When intentional break-ups are necessary, they should be conducted at sufficiently low altitudes to limit the orbital lifetime of resulting fragments.

Guideline 5: Minimize potential for post-mission break-ups resulting from stored energy

All on-board sources of stored energy should be depleted or made safe when they are no longer required for mission operations or post-mission disposal.

Guideline 6: Limit the long-term presence of spacecraft and launch vehicle orbital stages in the low-Earth orbit (LEO) region after the end of their mission

Guideline 7: Limit the long-term interference of spacecraft and launch vehicle orbital stages with the geosynchronous Earth orbit (GEO) region after the end of their mission

[Ref: Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space (unoosa.org)]

IADC guidelines

- GEO disposal after mission life:
  - (1) A minimum increase in perigee altitude of: 235 km + (1000 * CR * A/M)

  - where CR is the solar radiation pressure,
  - coefficient A/m is the aspect area to dry mass ratio (square meters per kg),
  - 235 km is the sum of the upper altitude of the GEO protected region (200 km) and the maximum descent of a re-orbited spacecraft due to luni-solar & geopotential perturbations (35 km).
  - (2) An eccentricity less than or equal to 0.003.

- Low Earth Orbit Disposal
  - Spacecraft or orbital stages that are terminating their operational phases in orbits that pass through the LEO region, or have the potential to interfere with the LEO region, should be de-orbited (direct re-entry is preferred) or where appropriate manoeuvred into an orbit with an expected residual orbital lifetime of 25 years or shorter. The probability of success of the disposal should be at least 90%
- Ref: IADC Space Debris Mitigation Guidelines (nasa.gov)

Space debris control -reference points in regulatory frameworks for national space activities

- Space Debris Mitigation Guidelines of the Committee and/or the IADC Space Debris Mitigation Guidelines,
- the European Code of Conduct for Space Debris Mitigation,
- ISO standard 24113:2011 (Space systems: space debris mitigation requirements), and
- ITU recommendation ITU-R S.1003 (Environmental protection of the geostationary satellite orbit) .

UN COPUOS Guidelines for the Long-term Sustainability of Outer Space Activities (2019)

- B. Safety of space operation
  - Guideline B.1 Provide updated contact information and share information on space objects and orbital events
  - Guideline B.2 Improve accuracy of orbital data on space objects and enhance the practice and utility of sharing orbital information on space objects
  - Guideline B.3 Promote the collection, sharing and dissemination of space debris monitoring information
  - Guideline B.4 Perform conjunction assessment during all orbital phases of controlled flight
  - Guideline B.5 Develop practical approaches for pre-launch conjunction assessment

UN COPUOS Guidelines for the Long-term Sustainability of Outer Space Activities (2019)

- B. Safety of space operation
  - Guideline B.6 Share operational space weather data and forecasts
  - Guideline B.7 Develop space weather models and tools and collect established practices on the mitigation of space weather effects
  - Guideline B.8 Design and operation of space objects regardless of their physical and operational characteristics
  - Guideline B.9 Take measures to address risks associated with the uncontrolled re-entry of space objects
  - Guideline B.10 Observe measures of precaution when using sources of laser beams passing through outer space

  - Source: UN document A/AC.105/C.1/L.366

  V1805022.pdf (un.org)

Orbit , spectrum and interference

Ref: Radio Frequency Interference | Secure World (swfound.org)

Natural interference can be caused by solar storms and other forms of space weather, interaction with the Earth's atmosphere, and sometimes even clouds and rain.

Unintentional manmade interference can result from a satellite transmitting too close to another satellite on the same frequency or from terrestrial communications systems operating on the same or similar frequency to space systems.

Intentional RF interference, often referred to as jamming, is a way of temporarily or reversibly disrupting the normal functioning of a satellite without resorting to actual destruction of the satellite and the chance of creating long-lived space debris. Intentional interference is also relatively easy to accomplish, often requiring nothing more than an antenna and a transmitter.

Orbit , spectrum and interference

Ref: Radio Frequency Interference | Secure World (swfound.org)

Applications for jamming range from blocking undesirable radio and television broadcasts from being transmitted into a country to blocking satellite navigation signals to prevent an employer from tracking movements, to degrading the ability of an adversary to use precision munitions, among others.

International and national mechanisms currently exist to regulate RF communications. However, these mechanisms focus more on the allocation of spectrum and assignment of frequencies than on the prevention of interference. They also lack enforcement powers. As the instances of unintentional and intentional RF interference increase due to crowding and congestion on orbit, these regulatory shortcomings present a significant challenge to the long-term sustainable use of space.

Human Spaceflight failure history

Program	Flights	Fatal Accidents
X-15	199	1
Mercury		
Gemini	10	0
Apollo	15	0
Space Shuttle	135	2
SpaceShipOne	6	0
SpaceShipTwo	9	1
Commercial Crew	1	0
Total	381	4

Launch Safety

Ground Operations – Safety procedures and Manuals

Spacecraft checkout and Fuelling

Launcher assembly and tests, Fuelling

Launch site weather

Range safety

Automatic Launch sequence

COLA

Notifying Air and Maritime traffic

Launch abort

Commanding during flight, TTC and Mission support

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Spacecraft cyber threats

REF: Handbook of Space Security, second edition, Springer, p 251

Navigation:

Denial of service : On January 2010, a software update of the GPS Ground Segment caused a denial of service. Impact observed on 8,000 to 10,000 military receivers during several days

Spoofing: In 2009, a group of students at the University of Texas at Austin successfully tested a GPS spoofing device to remotely redirect an $80 million yacht

Communications

Deliberate Jamming : ARABSAT "Deliberate jamming incidents have dramatically increased in 2012 which indeed put a threat on services over Satellites"[5]

Unauthorized access : The conjunction of open standard and cheap DVB cards for computer made possible the rise of Open Source Software dealing with the automated capture of image flow or data flow. As a consequence, a "radio ham" captured the pictures/video of the NATO surveillance flights, during the Balkan War, as they were using an insecure satellite link.

Spacecraft cyber threats

Observation, exploration satellites

Deliberate interference and control loss:

On October 20, 2007 and On July 23, 2008, Landsat-7, experienced 12 or more minutes of interference. All steps required to command the satellite not achieved

Targeted interference and control take-over: On October 22, 2008, Terra EOS AM–1 experienced nine or more minutes of interference. Achieved all steps required to command the satellite but no commands.

Viral attack : The Windows XP-based laptops on the ISS were infected with a virus called W32.Gammima.AG in 2008, after a cosmonaut brought a compromised laptop aboard which spread the malware to the networked computer

REF: Handbook of Space Security, second edition, Springer, p 251

Cyber security in space

1. Cyber threat analysis, Vulnerability identification and analyses, mission critical elements, Risk scenarios and assessments and acceptable risks, identification of measures to counteract
2. Policy statement (General risk reduction services common to all and mission specific)
3. Variety of space missions (some providing services for safety of life)
4. Examples of approaches (Galileo program)

    Physical protection of ground segments, operational robustness through 4-5 level keys
    End to end protection of signal
    Payload protection for specifically defined services (data encryption)
    Choice of ground station locations which ensures control
    Strong Interaction for cooperation from partner/host nations
    Dynamic tele command, payload and HK telemetry for data protection
    Robust signal modulation

5. Increasing reliance on commodity hardware and software.. Opportunities for malicious modifications
6. NewSpace – Commercially Off the Shelf systems and parts, new supply chain elements.. Increased risks

SATELLITES FOR MORE SECURE WORLD

MILITARY COMMUNICATIONS - SATELLITES

- Secure connectivity
- Possibility of re-configuration
- Capability for high data rate to low data rate communications
- Flexibility to communicate with a variety of terminals including mobile terminals
- Ability to address better air traffic management
- Efficient networking

- TRENDS: Deployable laser-based communications capability
- Fully interoperable networks

MILITARY USES OF SPACE - BASED EARTH OBSERVATION

- Detection of changes over areas of interest
- Ability to capture topographic information
- Improved weather and sea state forecast
- Protection against jamming and deception
- Amenability for integration of various types of data and Worldwide coverage

SPACE BASED SIGNAL INTELLIGENCE

- Enables characterization and the location of telecommunications and radar systems
- Access to the content of the communications
- The monitoring of potentially hostile activities
- The detection and characterization of related human activity
- The support of counter-terrorism operations
- The detection of emitters with a high degree of accuracy

SPACE BASED EARLY WARNING SYSTEMS

- Alert the forces and national authorities of an incoming threat, providing impact prediction information (time and location) of the strike to enable defense and the use of protection measures
- Cue counterforce actions against the incoming missiles and counterforce actions against hostile launch capabilities
- Locate the launch site with a sufficient precision to allow the identification of the aggressor and provide evidence to high level decision makers.

Space weapons

1. Kinetic energy weapons (KEW) implying a physical effect on the target, either by direct impact (so-called “hit-to-kill” techniques) or nearby explosion creating killing debris (such as in the case of the co-orbital Soviet systems)
2. • High-altitude nuclear weapons (EMP) creating ionization and/or electromagnetic effects on objects in the affected zone
3. • Directed energy weapons (DEW) mainly using laser or microwave techniques depositing energy on the target

Examples of KE weapons: Fractional orbit bombardment systems, Anti Ballistic Missiles, ASATs- Use of ballistic missiles on spacecraft.

4. RF Interference/ Jamming

Private Mining of Asteroids & Space Natural Resources

✓The race back-to-the-Moon is heating up.

✓This race is more for the purpose of exploring possibilities for mining the natural resources of the Moon, as earthly resources are fast depleting.

✓Several countries (including developing counties like China and India), as well as several private companies,
are aspiring to reap potentially significant economic benefits from the natural resources of the Moon.

Credits: Prof Ram Jakhu, McGill University

Human presence in space and on planets - Safety aspects

1. Human spaceflight activities have been largely dominated by state- funded, state developed, and state-operated programs.
2. ISS is result of an Intergovernmental Agreement was signed between the United States, Canada, Japan, European Space Agency members, and Russia in 1998
3. Global governance in the form of regulation, coordination, and cooperation.
4. Article V of the Outer Space Treaty lays down the obligations and responsibilities associated with astronauts in outer space.
5. The Rescue Agreement, prompted by the sentiments of humanity regarding the peaceful exploration of outer space by astronauts and other personnel of a spacecraft, further develops these notions.

Space shuttle disasters

1. 1986 Challenger disaster
2. Exploded 73 seconds after liftoff, killing all seven crew members
3. Rogers Commission report: The entire failure could be traced to an O-ring, a rubber seal on the solid rocket boosters (according to Nasa Technical Reports Server) that degraded in the cold weather of the launch. If launch on such cold day was avoided, O-ring would have not caused problem
4. US HR CST report: A long-standing failure in safety protocols, combined with an unsustainable launch rate that led to the disaster (Also see The lessons learned from the fatal Challenger shuttle disaster echo at NASA 35 years on | Space)

Space shuttle disasters

5. 2003 Columbia - Break up during return to earth

6. Investigation board set up

7. Reason leading to failure: a large piece of foam falling from the shuttle's external tank and breached the spacecraft wing.

8. 2011 Retirement of Space shuttle Fleet

9. Astronauts sorties to the International Space Station - Soyuz rockets or commercial spacecraft such as Crew Dragon capsules (SpaceX) as space taxi service to the ISS (from 2020)

The cause of failure

.Infographic link

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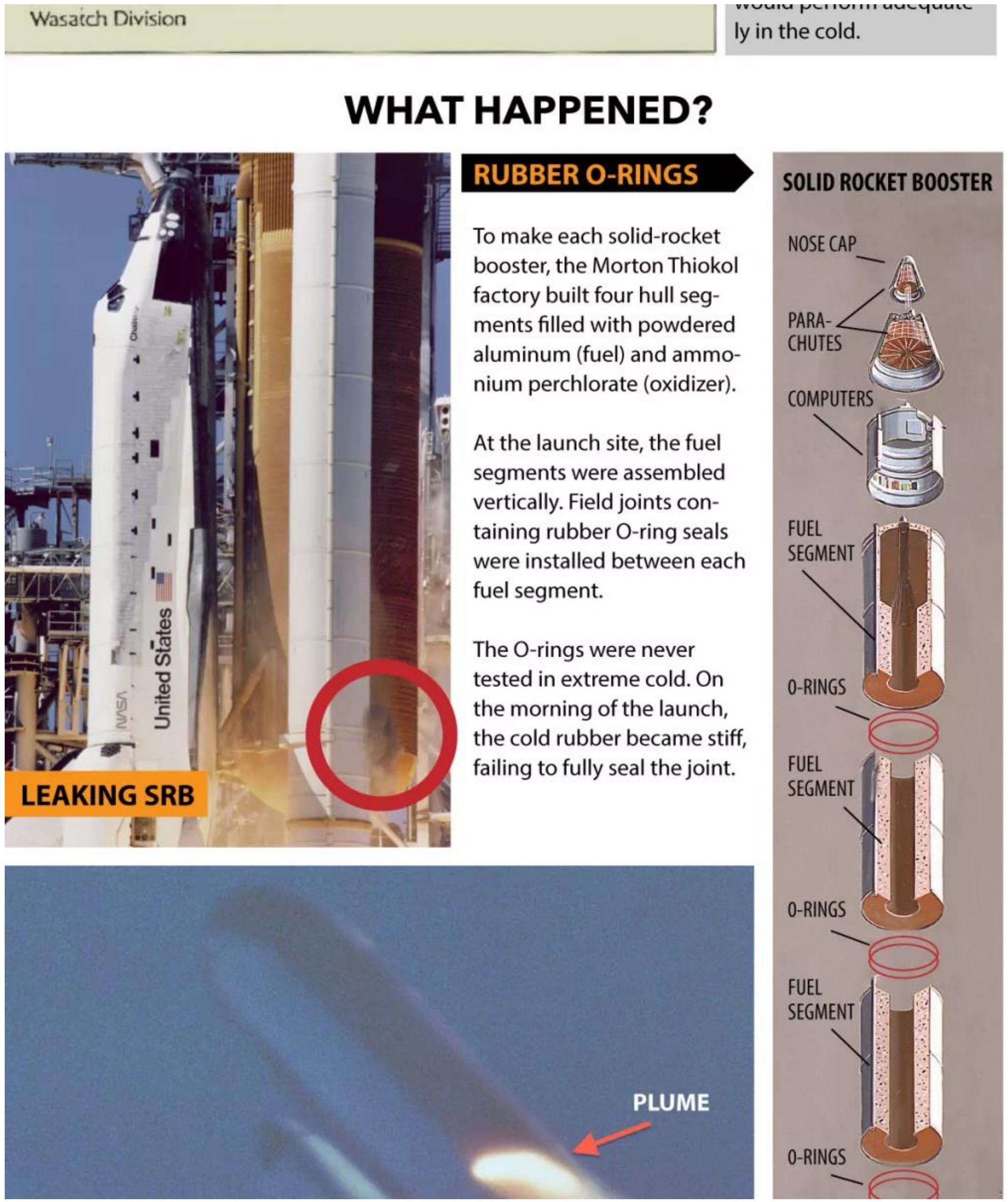

Commercial human space flight

1. The introduction of commercial human spaceflight operations
2. NASA moved from developer to service customer- NASA Commercial Orbital Transportation Services (COTS) program and the Commercial Crew Program (CCP), to deliver cargo and crew, respectively, to the ISS by private companies
3. Once current LEO space activities are taken over by commercial entities, the missions moving forward – such as scientific experiments in deep space, detailed observations of potentially life- sustaining celestial bodies, and establishing long-duration habitats – can benefit from multi-stakeholder input
4. The International Space Exploration Forum (ISEF) is a multilateral gathering of ministerial-level government officials meant to facilitate discussions on how to build support for global cooperation in space exploration.- 2014 Washington Meeting with 33 participating nations
5. International Space Exploration Coordination Group (ISECG) is a forum of 14 space agencies to exchange information regarding their interests, plans, and activities in the exploration of space

Commercial Space flight

1. human spaceflight operations for the U. S. government with NASA’s CCP (SpaceX and United Launch Alliance),
2. a company that will offer private citizens a ride to the “edge of space” using a reusable rocket and capsule (Blue Origin),
3. a company that aims to offer suborbital flights to paying customers (Virgin Galactic), and
4. two companies that seek to provide human-rated habitats and space stations in the near future (Bigelow Aerospace and Axiom Space).
5. Human missions to Mars and other planetary bodies - Exposure to new environment

Space Traffic Management (STM)

1. "Space Traffic Management is the set of regulatory rules to ensure safe access to outer space, safe operations in outer space and safe return from outer space." (IAA, 2006)
2. Trends of Mega constellations, on-orbit servicing missions, space tourism etc, a significant increase in space activities, comprising access to, operations in and return from outer space. Sub-orbital flights. Other developments are the increased variety of uncoordinated activities (e.g. platforms in between airspace and outer space, space tourism, assembly in outer space for example for energy).
3. a strong increase in active manoeuvring in orbit., reusable launch vehicles, horizontal or vertical landing
4. Existing legal environment wrt STM – UN Treaties, Space Situational Awareness, Work of Forums like IADC, IAA, Space debris mitigation guidelines, lack of international authority …National regulations like FAA spaceflight operation risk management (Standard 321- 07, for example to achieve one in 10 million chance of collision involving manned spacecraft and one in ten thousand chance for unmanned spacecraft)
5. Air Traffic Management and Space Traffic Management – Similarities and differences
6. Future air transport - Communication, Navigation, Surveillance (CNS) advances, …..CNS+ Avionics
7. Instruments for STM - Policies, rules, regulations, guidelines and best practices…. Institutions….. Technology upgrading and standards

Space Traffic Management (STM)… continued

1. STM – in different Phases:
   - Passage through Air space -launch phase (e.g. pre-launch notification, Collision on launch assessment (COLA),
   - 0n-orbit phase (operations until End Of Life (EOL); information duties, Collision Avoidance (CA) Manoeuvres),
   - re-entry phase (debris mitigation, Active Debris Removal (ADR)
2. Spatial norms (e.g. orbit zoning), Air space and outer space transition (…Proto zone)
3. Technical/ physical systems and traffic-related norms – spaceflight safety systems, collision avoidance software, COLA, space object identification and cataloguing, orbit determination, data sharing, sensor networks etc. Design robustness, Passivation/ venting, de-activation, EOL deorbit/reorbit
4. Conceptual organisational models…. international decision making (similar to ICAO)… or model of international coordination/registration/allocation/support roles of ITU.. or Hybrid versions
5. Agenda for UNCOPUOS Legal Subcommittee 2016; Intergovernmental experts (UN COPUOS)

Space Safety

1. Space safety can be defined as freedom from manmade or natural harmful conditions, where harmful conditions are those that can cause death, injury, or illness of human life, damage to or loss of systems, facilities, equipment or property, or damage to the environment.
2. Policy aim is to strive to reach an acceptable level of risk rather than absolute safety and by development of space systems that are affordable, practical, operational, and safe
3. Norms evolving over time due to socioeconomic changes and technological advancement.
4. Implementing proven best practices is necessary to establish the thresholds for an acceptable risk level.
5. Address the safety of activities in outer space, in Earth orbit, in transit through the so-called protozone or stratosphere, and on the ground prior to departure
6. the establishment of rules for space operations and the control of their implementation are responsibilities belonging to government regulatory bodies that at times require international agreement and coordination

Space safety.....

1. When developing a space system, safety can be achieved by designing measures for fault tolerance and fault avoidance into the system.
2. Another important element in the safety of human spaceflight systems will be the creation and implementation of standards
3. Intrinsic in the concept of a standard is that, whenever it is made applicable, compliance must be monitored and enforced
4. International Association for the Advancement of Space Safety (IAASS) can associate

Key elements and issues related to human spaceflight operations

• Key elements and issues related to human spaceflight operations			
• **Issues and challenges**	**Technical challenges (natural and manmade)**	• **Economic, business, demographic, health, and other challenges**	• **Risks/threat mitigation/equity issues**
• Lack of definitions as to where near-space (Protozone) and outer space begins and ends, and who has **responsibility for traffic control** and management	• Systems for tracking and control in these areas are lacking from both a technical and regulatory perspective	• Cost of new systems for tracking and control can be expensive and give rise to many issues as to how they might be implemented, controlled, and paid for globally	• Liabilities related to accidents are large and without clear controls and oversights, which could lead to disputes and legal claims tied up in the courts
• Increase in **orbital debris** and deployment of **large constellations** could make both State-based human space flight and commercial space and near-space travel higher risk	• On-orbit servicing and active debris removal still in early technical development; no formal coordination between unmanned satellite networks and space safety for human space flight	• Cost of developing needed capabilities are high and it is not clear who would pay for them and through what mechanism	• Growing risks to satellite networks, commercial space travel, and most space and near-space operations; however, no clear governance and safety systems in place or planned
• Rapid **development of technology** in areas related to near-space and suborbital **systems ahead of governance**, space traffic safety regulation, and environmental controls with regard to space plane operations	• Lack of regulation, potentially unsafe practices, and stratospheric pollution	• Business risk due to regulatory uncertainty; potential safety issues	• Uneven national rules for licensing/certification and approval
• Global development **of private human space** technology and different regulatory approaches in different nations	• Safety technologies vary in safety and sustainability	• Export controls and patchwork national regulations can hinder development of international cooperation	• Shopping for States with lax regulations, flags of convenience
• Uncertainties stemming from the **US Commercial Space Launch Competitiveness Act** of 2015; long-range experimental licensing and use principles are now seemingly in flux due to the US legislation	• Development of innovative space technologies may be hindered (such as for asteroid or Lunar mining); these may be robotic but involve humans at some point	• Legal uncertainty with regard to ownership of extracted resources	• Investment in space resource extraction enterprises risky in uncertain legal environment; requires cooperation internationally

Current Governance Structure and Needs of future

1. Article VI of the Outer Space Treaty with Respect to State Responsibility

   States … shall bear international responsibility for national activities in outer space … whether such activities are carried on by government agencies or by non-governmental entities, and for assuring that national activities are carried out in conformity with … [this] Treaty. The activities of non-governmental entities in outer space … shall require authorization and continuing supervision by the appropriate State Party to the Treaty.

2. Article IX of the Outer Space Treaty, which provides, inter alia, that a State must "undertake appropriate international consultations before proceeding with any such activity" that would "cause potentially harmful interference with activities of other States."
3. States have enacted domestic legislation and instituted a regulatory regime to ensure governmental approval is granted before private entities engage in space operations, whereas other States have simply outlined their policy positions
4. Certification requirements by states include the space vehicle(s) to be utilized, the ground-based management crew in charge, the space- based operations crew facilitating the activity, the participants benefitting or interacting with the activity
5. Other needs