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Montreal Recommendations on Aviation Safety and Uncontrolled Space Object Reentries

These recommendations are the result of discussions held at a workshop on February 17 and 18, 2023, organized by the Outer Space Institute, the McGill Institute of Air and Space Law, and the International Association for the Advancement of Space Safety.

The workshop began with opening remarks from Mr. Juan Carlos Salazar, the Secretary General of the International Civil Aviation Organization (ICAO).

The signatories to these recommendations are expressing their personal views only. Their contributions to this document do not necessarily reflect the official policy or position of their institutional affiliation, whether a university, company, non-governmental organization, government (including departments, agencies and national militaries), or intergovernmental organization.

There are over seven thousand objects in low Earth orbit (LEO) with large radar cross sections, consisting of abandoned rocket bodies, active and inactive satellites, and large debris fragments.[1] Since 2019, the amount of such objects has roughly doubled, driven mainly by the launch of constellations comprising of hundreds or thousands of satellites.

Tens of thousands of additional satellites are being licensed, while hundreds of thousands of further satellites are proposed. The vast majority of these satellites will be in LEO, meaning many of them will reenter Earth's atmosphere in the years and decades ahead. The number of rocket launches needed to construct and maintain these space systems will also increase, and with it, rocket body reentries.

Uncontrolled reentries of space objects pose risks to people on the ground, at sea, and in aircraft in flight, while also causing potential environmental and economic damage.

The probability of impact to any single person, ship, or aircraft is small, but the risk should not be ignored. The potential casualty probabilities of some proposed satellite constellations are tens of a percent per replacement cycle. The aviation industry is particularly vulnerable to collisions with reentering space objects during flight. Due to their relative speed of impact, even small or light pieces of debris that may be harmless for people on the ground could fatally damage an aircraft in flight or otherwise necessitate emergency action by its crew.

[1] "Large" here means > 1 m^2. In addition, it should be kept in mind that the debris population greatly increases with decreasing debris size. There are approximately 1 million pieces of debris in Earth orbit with sizes between 1 cm and 10 cm. See ESA's "Space debris by the numbers".

Fortunately, uncontrolled reentries of rocket bodies are no longer necessary in most circumstances, due to technological developments and improved mission designs. Uncontrolled reentries of satellites are not yet generally avoidable; however, steps can be taken to reduce reentry risks.

Although there are no verifiable reports of space objects striking aircraft, several aircraft have been damaged by collisions with unidentified objects at high altitudes. The risks are not confined to debris strikes, either. On at least one occasion, airspace was temporarily closed on account of an uncontrolled reentry of a rocket body. Airspace closures provide one example of how the economic risks from uncontrolled reentries are potentially larger than the physical risks, creating a further imperative for policy action.

Thus *desiring* to raise awareness of the growing problem of uncontrolled reentries of space objects;

Recognizing that uncontrolled reentries create casualty risks to people on the ground, at sea, and in aircraft in flight;

Understanding that aircraft are especially vulnerable to strikes with space objects;

Identifying that uncontrolled reentries of rocket bodies have become unnecessary in most circumstances, due to technological developments and improved mission designs;

Acknowledging that uncontrolled reentries of satellites are still not generally avoidable, but that steps can be taken to reduce the reentry risks from them;

Identifying that the consequences of uncontrolled debris reentries extend beyond personal injury or physical damage to include economic risks; and

Recognizing that avoiding uncontrolled reentries is one necessary step toward the sustainable and safe use of space;

We recommend the following:

A. TOWARD A CONTROLLED REENTRY REGIME

A.1

States should establish a new international body or build upon an existing one to provide a focus on the safety implications of uncontrolled reentries

1. Actions by one actor can affect all actors.
2. The use of space by any single state has global implications, with risks potentially exported from launching states to other states.

3. The safety implications of uncontrolled reentries include risks on the ground, at sea, and to aircraft in flight.
4. As space use further develops, states should take coordinated steps to maintain a strong safety culture.
5. Part of this coordinated safety culture may require recognition of limits to the space-Earth system, such as carrying capacities and maximum tolerable reentry rates.
6. A strong safety culture will require recognition that both mass and satellite numbers will need to be considered in determining acceptable limits.
7. Global standards are required, consistent with applicable international legal instruments.

A.2

States should establish requirements to avoid uncontrolled reentries of space objects

1. Uncontrolled reentries are generally unacceptable in today's context.
2. Transition phases will be needed for new state entrants and legacy satellites.
3. Appropriate thresholds will be needed to exempt satellite operations that have been determined to pose low risk based on widely agreed standards.
4. There needs to be consideration for on-orbit failures that will result in some amount of uncontrolled reentries.
5. States should assess risk based on entire space systems, especially those involving many objects, instead of on the basis of individual constituent objects. A large satellite constellation is an example of a space system involving many objects.
6. Constellations should meet specific requirements that consider the aggregate risks associated with the number of satellites, satellite mass, satellite lifetime, and reentry cadence.
7. Transparency and validation should be required to facilitate enforcement.

A.3

States should promote the development of advanced reentry prediction capabilities for unavoidable uncontrolled reentries involving space objects that exceed determined risk thresholds

1. The granting of licenses to large constellation operators has involved an implicit acceptance of increased uncontrolled reentries from satellites and rocket bodies.
2. Satellites with properties, such as mass, above certain thresholds may pose heavy burdens on society due to the potential for casualties, property damage, and economic losses to third parties.
3. Closures or effective closures of airspace constitute a burden on airlines, aviators, controllers, and passengers. Such closures also create new safety risks due to, for example, sudden increased stresses on air traffic control systems.
4. Increased uncontrolled reentries without better prediction capabilities will lead to further airspace closures or higher risks for airlines and passengers.

5. Satellites above certain thresholds should be required to have autonomous emergency tracking and/or transmitting capabilities to aid in prediction efforts during the initial stages of atmospheric reentry. Such capabilities should avoid interference with other uses or exploration of space.

B. PREDICTION, VERIFICATION, AND WARNINGS

B.1

States should develop standards for issuing and responding to precautionary safety warnings related to uncontrolled reentries or related space activities

1. The standards should build upon existing standards, such as the aviation coordination regime.
2. The standards should enable rapid decision-making and achieve consistent results.
3. The standards should accommodate conditions of rapidly evolving uncertainty of the uncontrolled reentry footprint location close to reentry time.
4. The standards should seek to maintain operational safety, keeping in mind that inaction could be the safest course.
5. Cooperation, especially among neighbouring states, in any reentry situation will be facilitated by common risk criteria, use of accepted information sources, and clear identification of the responsible state authorities.

B.2

States should require independent validation of predictions of breakup and demise of reentering space objects

1. Between 10% and 40% of the mass of large reentering space objects has historically survived reentry.
2. The potential casualty probabilities of some proposed satellite constellations are tens of a percent per replacement cycle.
3. Recognizing the heightened risk, some companies have proposed to develop fully demisable satellites.
4. As part of the licensing process, claims of full demisability of fragments must be verified independently through design review, inspection, simulation, and as practicable, through constrained destruction or other tests.
5. An independent body will be needed to respect and safeguard proprietary information.

C. LIABILITY AND ECONOMIC INJURY

C.1

States should review the scope of "damage" under international liability instruments, including as it pertains to economic injury

1. Given the substantial growth of aviation and space activities, including future growth, liability rules must be continually reviewed.
2. Damage from space activities to aviation, marine, and related activities should be part of this review.
3. There should be further consideration of risks to people and property on the ground, as well as environmental and economic damage.
4. Discussions could take place within and outside existing fora and should be open to all stakeholders.
5. Discussions should consider material injury to the economic interests of third parties. Although the damage to a single aircraft or other asset is a discrete incident, injury includes any wider economic consequences, such as the temporary grounding of aircraft.

C.2

States should consider enabling recovery or compensation for economic injury from uncontrolled reentries or related space activities that necessitate precautionary safety warnings

1. There are economic consequences that arise from issuing precautionary safety warnings, which may include disruption of Earth activities, such as aviation.
2. An example of a precautionary safety warning that may give rise to economic injury to aviation operators is an airspace closure in anticipation of an uncontrolled reentry.
3. To assist in determining whether a space actor has caused economic injury, thresholds should be established for states issuing a precautionary safety warning.
4. States should develop mechanisms that determine whether a space operator whose activities necessitate precautionary safety warnings should be held responsible for any associated economic injury.
5. There are various methods for ensuring partial or full recovery or compensation arising from injuries due to the issuance of precautionary safety warnings. These may include liability, government compensation, insurance, surety bonds, and compensation funds that are supported by contributions from spacecraft manufacturers, launch providers, satellite operators, and other space actors.
6. Regulations on compensation for economic injuries should not compromise on safety.

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