THE FUTURE OF SUB-ORBITAL AND ORBITAL SPACE ACCIDENT INVESTIGATION

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ABSTRACT

In the past, it has been assumed that space missions were the exclusive domain of state-controlled agencies. In consequence, the international agreements enshrined in 'Space Law' only indirectly addressed issues of certification and liability that arise when fare-paying passengers are transported on sub-orbital flights. Conversely, international conventions on commercial aviation are difficult to apply because space operations differ significantly from those of conventional aircraft. The following pages describe the tensions that exist between the legal and regulatory frameworks that govern sub-orbital flights. Subsequent sections illustrate these conflicts by focussing on the need to develop international agreements over the conduct of accident investigations involving commercial space flights. We argue that urgent action is required *before a mishap occurs* to encourage information exchange and prevent the recurrence of future accidents.

INTRODUCTION

The early days of space flight were dominated by state programs in the United States and the Soviet Union. However, the creation of the European Space Agency and their counter-parts in Brazil, China, India, Japan etc. opened up the launch market and brought many more companies into the space industry. The creation of the Russian Federal Space Agency also created opportunities for commercial involvement, mirroring the priority given by the Obama administration to private industry. Other initiatives, including the Ansari X-Prize have sustained interest in the development of commercial space technologies. Companies now develop and operate communications satellites, observation and monitoring platforms as well as space-based navigation and timing infrastructures. In the near future, it is likely that they will support sub-orbital space tourism. Commercial organizations now offer astronaut and supply transportation services to the state agencies that first dominated spaceflight.

The rise of commercial space creates a host of new opportunities. Market forces reduce costs and encourage the use of agile development methods. Companies can exploit flexible recruitment practices and human resource mechanisms to maximize the potential of teams drawn from different countries and different technical backgrounds. Commercial organizations can also offer career development and remuneration packages that would be difficult for many public organizations. Together these changes can drive the technical innovations that will reduce the long-term impact of space operations on finite environmental resources. Cost reductions also create opportunities for more people to experience space flight and for engineering teams to exploit sub-orbital and orbital

environments in ways that would not previously have been possible. However, the growth of commercial space operations raises a host of safety issues:

- *Risks during launch.*
  Commercial organizations have, typically, shared the launch facilities that were originally developed to support state-sponsored missions. Increasingly, however, companies need to control their launch schedules; particularly for space tourism where delays can lead to legal liability. Leading practice documents, including the US Range Commanders Council 321-10 'Common Risk Criteria Standards for National Test Ranges' (2010) cannot easily be applied to the 'concept of operations' behind many commercial space ports. For instance, this states that "People on aircraft, ships, and other modes of transportation and people on oil rigs and offshore platforms should be protected to a level commensurate with the background risk associated with those activities". However, 321-10 deliberately does not consider any risks to passengers and crew on board any vehicle. Hence there is a growing need to develop standards and regulatory documents that ensure consistent approaches to the operation of launch facilities that support the next generation of missions; including sub-orbital space tourism.

- *Risks to other forms of aviation.*
  The disintegrating of Columbia (STS-107) illustrated the possible risks to air traffic during the uncontrolled re-entry of space vehicles. Any impact involving debris of more than 300 grams is likely to cause the loss of a commercial aircraft. Such concerns led to the development of the FAA's Shuttle Hazard Area to Aircraft Calculator (SHAAC). This tool helped analysts to plan Temporary Flight Restrictions (TFRs) that were intended to protect aircraft from subsequent orbiter failures (Murray and Mitchell, 2010). However, a growing number of sub-orbital operations will increase the risk exposure for conventional aviation to space debris. The diversity of commercial designs and varying operational profiles means that Air Navigation Service Providers face a more and more complex task when planning future TFRs.

- *Risks to other space vehicles.*
  The hazards to other space vehicles can be illustrated by the collision of Iridium 33 and Kosmos-2251 in 2009. This hypervelocity collision occurred at 26,200 miles per hour, creating more than 2,000 items of debris. As the numbers of space missions increase, debris poses a growing threat to satellites. These objects include obsolete satellites, exhausted rocket stages, fragments from collision or other forms damage. They also include paint flakes and aluminium particles from solid rocket motors. Even small objects can inflict damage on vulnerable areas, including the solar arrays, of satellites. Commercial space operators must ensure that their missions are not affected by these objects. For example ground based tracking and alert systems can be used to resolve conflicts with large objects in much the same way that conventional Air Traffic Management and Collision Avoidance Systems, such as ACAS, protect aircraft. However, existing systems are monitoring more than 20,000 objects larger than 10cm in diameter. Many of these are in orbits needed by new satellites. Monitoring the location and assessing the risks of debris will be complicated by rising numbers of commercial space flights. For example, agencies such as US Strategic Command SPACETRACK program can rely on relatively stable ephemeris data when considering conflicts between debris and satellites. However, this becomes far more difficult with the dynamic trajectories planned for tourist excursions. Further problems stem from the difficulty

of anticipating conflicts not only with debris but also with other vehicles. At present there are limitations on the disclosure of ephemeris data and operator information by US Federal agencies. Such disclosures provide significant insights into the US monitoring capabilities. By alerting both parties of the identity of the other vehicle in a potential conflict, there is also a concern not to reveal strategically or commercially sensitive information. It seems likely that more systematic approaches will be needed to ensure 'space situation awareness' through the provision of 'air' traffic services;

- *Risks to passengers and crew.*
  Although most commercial space operations are unmanned, the advent of space tourism and the development of private launch capabilities to support state-sponsored and private space programmes creates a host of concerns over the risks to the crew and passengers. For instance, there are few international agreements about the training that is required in order to operate sub-orbital missions (Johnson et al, 2011). Although 'gold standard' solutions exist in the training programs offered by ESA, NASA and the Russian Federation, these initiatives are expensive and often assume levels of ground support and mission control that are not envisaged for many commercial operations. Other concerns focus on the airworthiness of the vehicles being used and their associated maintenance regimes. The technical requirements for environmental control and life-support are very different from those on existing airlines. Most regulatory organizations lack the necessary technical expertise to determine whether or not commercial space operations pose an acceptable degree of risk to crew and passengers. As we shall see, these concerns are compounded by the lack of applicable legislation in this area;

- *Risks during re-entry.*
  Debris created during the re-entry of space vehicles can increase the hazards to people and property on the ground. For example, public concern focused on the risks created by the return of NASA's 5,900kg Upper Atmosphere Research Satellite during 2010. Similar anxieties were expressed over the uncontrolled reentry of Russia's Phobos–Grunt Mars Craft in January 2012. In both cases, debris fell into the Pacific. However, these incidents triggered further studies into the risks posed for aviation and shipping. It is particularly important to alert other airspace or maritime users when retrieval operations involving human space flight or reusable components are deliberately targeted on specific areas of the sea (Hitchens, 2005, Smirnov, 2002). The proliferation of commercial space operations arguably makes it more difficult to ensure that all organizations follow the same standards of care during re-entry. It will also be more difficult to anticipate the dispersion of debris from an ever-increasing range of vehicles.

The following pages argue that a systematic overhaul is required to update existing legislation as it applies to both sub-orbital and orbital legislation. Existing provisions do not consider the changing nature of commercial space operations. They are often characterized by ambiguity and inconsistency, especially in terms of the interpretation of key concepts and definitions when applied to sub-orbital space tourism. At the heart of this matter lies uncertainty over whether aviation or space law should be applied to sub-orbital operations. One approach would be to apply aviation law during the initial phases of a mission and then to apply space laws when a vehicle no longer behaves like a 'conventional aircraft'. Unfortunately, it is unclear when a space vehicle would ceases to operate in the jurisdiction of aviation law (Masson-Zwaan, 2010).

This paper is particularly timely given recent public and political interest in potential 'Codes of Conduct' to supplement space law (BBC, 2012). The proponents of such an agreement point to the success of the International Civil Aviation Organization (ICAO) in encouraging common standards across the aviation industries. These must be ways to restrain states from taking actions that jeopardize access for everyone. This argument is typically illustrated by the impact of China's missile launch against a weather satellite; creating more than 140,000 items of debris larger than 1cm in diameter. The first steps were taken by the 2010 publication of a draft code backed by the European Union and the US Secretary of State Hillary Clinton. This covered collision avoidance; control of deliberate explosions; traffic management protocols as well as data exchange. It also included confidence building and debris mitigation measures. Unfortunately, the draft agreement arguably did not pay sufficient attention to the military and civil concerns expressed by the BRICs states (Brazil, Russia, India and China). The critics argued that it would be undermined by the mistrust and competition between nations in the absence of a legally binding agreement. In the United States, republican groups also opposed any code on the basis that it would impose unnecessary restraints on the commercial development of domestic space industries. Others pointed to the risks inherent in the disclosure of ephemeris data that can mitigate the risks of collisions but also compromise the position of key national assets.

The following pages look less at the political objections to a Code of Conduct for Space Operations and focus more on the technical issues that arise from the limitation of both aviation and space law. The intention is to establish the urgent need for further initiatives in this area. In particular, subsequent sections argue that we must enhance ICAO Annex 13 to provide a framework for the international investigation of space accidents and incidents *before a mishap occurs.* Without such an initiative, we will continue to suffer from ad hoc investigations that do little to prevent the recurrence of future space-related accidents (Johnson, 2003, 2011).

AN OVERVIEW OF SPACE LAW

The advent of space tourism creates new challenges for the legal and regulatory environment that protects the safety of operators, customers and the general public. These operations fall under different legal frameworks for conventional aviation, for sub-orbital and for orbital operations. The application of these frameworks is complicated because there are no universally accepted distinctions between these terms (Marciacq, Morier, Tomasello, Erdelyi and Gerhard, 2008, Masson-Zwaan, 2010). It is, therefore, difficult to determine when, for instance, a particular mission would move from the provisions of existing aviation law to then be covered by space law.

Commercial Aviation, the Chicago, Warsaw, Montreal and Rome Conventions

The Chicago convention was signed in December 1944 and is now recognised by some 200 nations. Under the provisions of the convention, states have complete sovereignty over the airspace above their territory. However, the convention does not consider the vertical extent of this sovereignty into sub-orbital or orbital operations. The Chicago Convention led to the creation of the International Civil Aviation Organisation (ICAO) with the aim of promoting the safe growth of aviation around the world. Later sections will deal with ICAO Annex 13 to the Chicago Convention; which deals with aircraft accident and incident investigation. For now it is important to emphasise that ICAO recommendations and standards are made to states and not to individuals or groups within those states. They are not legally binding and must, therefore, be transposed by implementing provisions

within each nation's legal system. The convention also ensures the mutual recognition of certificates issued by other signatories.

According to the Chicago convention, aircraft have the nationality of the state in which they are registered. An aircraft is defined in Annex 8 to be "any machine that can derive support in the atmosphere from the reactions of the air other than the reactions of the air against the earth's surface". These concepts are important because they might provide a framework for the regulation of commercial space flight. However, there are considerable technical and theoretical difficulties in determining when a particular machine 'can derive support in the atmosphere'. The problems of using this definition as a basis for legal decisions are compounded because the level of support is influenced both by the design of particular vehicles and also by existing environmental conditions, i.e., pressure, temperature, density and viscosity.

Further problems arise in applying existing agreements to determine liability in space operations. In 'conventional' aviation, companies are liable for injury to passengers and their possessions. Passengers may also make claims for delays following the Montreal and Warsaw Conventions. However, these liability provisions only apply to international flights. They need not, therefore, apply to spaceport operations with a single point of departure and arrival. As we shall see, the ICAO provisions contrast with those in space law. These only consider the rights and liabilities associated with crews; they did not explicitly consider the implications of carrying commercial passengers.

Further differences exist between aviation and space law in relation to third part liability. This affects anyone with whom there was no previous contractual relationship. The 1952 Rome Convention on Damage Caused by Foreign Aircraft to Third Parties on the Surface established principles that have been adopted by some 50 states. This agreement made the operator absolutely liability if damage was caused by an aircraft in flight unless they can show that this was due solely to the negligence, to another wrongful act or to an omission of the person who suffered the damage. The amount of liability is determined by the mass of the aircraft, unless it can be proven that the damage was the result of a deliberate act or omission by the operator. In which case, there are no limits placed on the damages under the Rome Convention.

The 1952 agreement also considers collisions between aircraft; "When two or more aircraft have collided or interfered with each other in flight and damage for which a right to compensation … results, or when two or more aircraft have jointly caused such damage, each of the aircraft concerned shall be considered to have caused the damage and the operator of each aircraft shall be liable, each of them being bound under the provisions and within the limits of liability of this Convention". In other words, a third party can make a claim against both of the operators involved in the collision. As we shall see, space law does not handle third party liability in the same way. As soon as a craft is in outer space, it comes under the Liability Convention. This creates an additional absolute liability for damage on the earth for the states launching or procuring the object or operating its launch facility. Absolute liability does not require that the claimant prove negligence or intent. Space Law also establishes unlimited fault liability if damage occurs to another space object. It remains to be seen how the focus of Space Law on state agencies might influence future litigation – for example, when state agencies only have limited involvement in commercial space missions. In the meantime, it seems likely that third parties will be able to refer to liability under both Space Law and the Rome Convention should an accident occur.

US Space Legislation and Regulation

US space legislation and regulation must be placed within the context of the National Space Policy. Every four years, the President outlines the principles and objectives that their government will promote across the industry. For instance, the 2010 policy document identifies the following goals:

- Energize competitive domestic industries to participate in global markets and advance the development of: satellite manufacturing; satellite-based services; space launch; terrestrial applications; and increased entrepreneurship.
- Expand international cooperation on mutually beneficial space activities to: broaden and extend the benefits of space; further the peaceful use of space; and enhance collection and partnership in sharing of space-derived information.
- Strengthen stability in space through: domestic and international measures to promote safe and responsible operations in space; improved information collection and sharing for space object collision avoidance; protection of critical space systems and supporting infrastructures, with special attention to the critical interdependence of space and information systems; and strengthening measures to mitigate orbital debris.
- Increase assurance and resilience of mission-essential functions enabled by commercial, civil, scientific, and national security spacecraft and supporting infrastructure against disruption, degradation, and destruction, whether from environmental, mechanical, electronic, or hostile causes.
- Pursue human and robotic initiatives to develop innovative technologies, foster new industries, strengthen international partnerships, inspire our Nation and the world, increase humanity's understanding of the Earth, enhance scientific discovery, and explore our solar system and the universe beyond.
- Improve space-based Earth and solar observation capabilities needed to conduct science, forecast terrestrial and near-Earth space weather, monitor climate and global change, manage natural resources, and support disaster response and recovery.

The US 2010 National Space Policy also introduces a number of more detailed objectives that reflect the importance of safety concerns, summarised in the opening sections of this paper. For example, the Obama administration has stressed the need to "Foster the Development of Space Collision Warning Measures". The Secretary of Defense is tasked with the Director of National Intelligence, the Administrator of NASA, and other departments and agencies to draw on industry and foreign nations to improve space object databases. They are also encouraged to pursue common 'international data standards and data integrity measures' that might support the dissemination of orbital tracking information.

The Federal agencies referred to in the National Space Policy, include the FAA's Office of Commercial Space Transportation (AST). This was established within the Office of the Secretary of Transportation within the Department of Transportation (DOT) following the 1984 Space Launch Act. In 1995, it became the only area of business within the FAA that is explicitly concerned with space. Its aims are to regulate U.S. commercial space transportation and ensure compliance with international obligations. AST must protect the public health and safety, the safety of property and national security. However, they are also charged to promote commercial space launches and re-entries by the private sector. In order to achieve these different objectives, AST can recommend changes in Federal statutes, regulations and policies.

The development of AST is supported by the 2011 Commercial Space Launch Amendment Act (51 U.S.C. Ch. 509, §§ 50901-21, 2011) that provides the FAA with the legal basis for the regulation of human, commercial space flight with a particular concern for public safety during launch and re-entry. Since 1989, they have licensed approximately 200 launches and have subsequently issued operator licenses for eight commercial spaceports. The amended Commercial Space Launch Act makes it clear that the Department of Transportation and the Federal Aviation Administration are jointly responsible for regulating private human space flight under 49 U.S.C. Subtitle IX, Ch. 701. The Act creates a regulatory framework based on experimental permits for suborbital operations. Before the 2004 amendments, FAA licenses were issued for launch and re-entry. These changes were intended to encourage the development of commercial space operations by providing a faster response to any application and by supporting the development of reusable suborbital rockets (US FAA, 2005). US Space Legislation also includes Public Law 108-428, H.R. 3257 Congressional Report (108-429), Commercial Space Transportation Competitiveness Act of 2000 and the Commercial Space Act of 1998. As might be expected from these national provisions, they provide little explicit guidance on the regulation of space missions that involve other nations. In particular, later sections will explain how there is an urgent need to extend the domestic provisions for mishap investigation to provide an international framework for the exchange of safety-related information in the aftermath of orbital and sub-orbital accidents.

European Space Legislation

The Treaty of Rome (1957) gave the European Commission the right to create common policy and regulations across the transportation industries in member states. The same treaty also created a requirement for unanimous agreement in the European Council before these common requirements could be enacted. In the hiatus, Joint Aviation Authorities were created to encourage technical consensus. In 1986, the development of qualified majority voting under the Single European Act increased the pace of harmonisation (Marciacq et al, 2008). One consequence of this is that member states of the European Union have begun to act in a collective manner to transpose ICAO standards into national law following the Chicago Convention. It is important to note that the Single European Act has led to the development of a Single European Skies initiative; reinforcing the importance of consistent and harmonised action. This applies to safety related concerns but also to market access. Hence the regulations that are adopted across member states cannot be supplemented by national provisions in situations that might restrict the internal market – for example by introducing additional provisions that restrict the operation of companies from other member states. This has important implications for the future of space safety where it is common for national agencies to prevent the dissemination of lessons from previous mishaps if they are perceived to have strategic importance. In some cases, this has prevented overseas companies from entering markets because they have been denied access to safety-related information identified during previous incidents and accidents (Johnson, 2003).

The European Aviation Safety Agency (EASA) was established in 2002, with changes made to their role in EC 216/2008. They provide opinions that explicitly guide the European Commission in drafting implementing rules. EASA publishes certification specifications and applicable means of compliance which are not legally binding. They may also issue special conditions that adapt existing airworthiness codes for new systems. This framework supports the development of type certificates that may also be extended to sub-orbital aeroplanes if they derive support from the atmosphere during some stages of their flight (Marciacq et al, 2008, Masson-Zwaan, 2010).

Recent years have seen significant differences in the ways in which Europe and the United States have sought to regulate commercial space flight. In particular, the FAA's Commercial Space Transportation Advisory Committee (COMSTAC) has argued that EASA's potential extension of aircraft-like certification for winged space vehicles is 'premature'. The costs associated with existing certification processes could damage the nascent suborbital space transportation industry. In contrast, the FAA issue launch licenses to commercial operators but do not certify their vehicles. The intention is to build up experience of commercial operations before any regulations are published. The consequences of any long term disagreement between the US and Europe would have significant consequences. For instance, companies such as Virgin Galactic, operate under the FAA in New Mexico and under EASA regulations in Kiruna, Sweden. Other operators, such as XCOR Aerospace would be in a more complex situation using launch sites in Curacao. Curacao is a 'constituent country' of the Netherlands but outside the immediate scope of EASA. Given the difficulties in achieving harmonisation across the different approaches advocated by EASA and the FAA, there have been moves to support 'interoperability'; this implies that sub-orbital space flights will be permitted with 'minimal changes' between two or more regulatory regimes. A memorandum of understanding might then be created between EASA and the FAA to simplify the application process for commercial operators. Such an agreement would build on existing space law.

Space Law

Previous sections have argued that there are no clear distinctions between conventional, sub-orbital and orbital operations. For example, the ICAO definition of an aircraft relates to the support that it receives in the "atmosphere from the reactions of the air". It can, therefore, be argued that extra-atmospheric space begins where the reaction with the air cannot support any machine. This Kárman line has variously been interpreted to exist between 84 and 100 kilometres (53-60 miles) above sea level. As has been mentioned, however, any distinction tends to arbitrarily depend upon the design of particular vehicles and also by interactions between different environmental conditions including pressure, temperature, density and viscosity.

The provisions of space law above the Kárman line are quite different from those described in previous paragraphs. These differences are equally important for both orbital and sub-orbital operations given that the provisions of space law apply even if a sub-orbital flight temporarily crosses into orbital space but does not enter a sustained orbit. The origins of space law date back to bilateral discussions between the United States and the USSR following the launch of Sputnik 1 in 1957. These meetings led to the establishment of the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) during 1959. They subsequently formed a legal subcommittee that helped to draft the following five treaties:

1. Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies;
2. Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space;
3. Convention on International Liability for Damage Caused by Space Objects;
4. Convention on Registration of Objects Launched into Outer Space;
5. Agreement Governing the Activities of States on the Moon and Other Celestial Bodies.

The first of these is the most widely adopted and has become known as the 'Outer Space Treaty'. In terms of commercial space operations, the treaty resembles some of the provisions within the Chicago Convention; "the activities of non-governmental entities in outer space, including the Moon and other

celestial bodies, shall require authorization and continuing supervision by the appropriate State Party to the Treaty" (Article VI). There are also provisions that enable states to request consultation rights if they believe that the activities of another nation "would cause potentially harmful interference with activities in the peaceful exploration and use of outer space".

The Agreement on the Rescue of Astronauts enumerates the rights and obligations of states concerning the crew. If any state party becomes aware that the personnel of a spacecraft are in distress then they must notify the launching authority and the Secretary General of the United Nations. All possible assistance must be provided to rescue the personnel of a spacecraft who have landed within a state's territory, through an accident, distress or emergency. Search and rescue support must be provided by any state that is in a position to make such an offer. The Rescue Agreement refers to "personnel of the spacecraft". It does not define precisely what is meant be the term 'spacecraft'; which has also been interpreted to include sub-orbital platforms (Marciacq et al, 2008). The basis for this argument is that spacecraft are still covered by the provisions of the agreement when they are operating in the sub-orbital phase of flight. Conversely, it might therefore be argued that the obligation to assist personnel might equally exist for sub-orbital missions when they are not relying on reactions with the air, following the ICAO definition. Similar ambiguity relates to the 'personnel'; whether the rescue agreement includes passengers as well as crew. This compounds ambiguity in the Outer Space Treaty which refers to 'astronauts' without further clarification. Further problems relate to the practicality of rescue missions; the agreement does not explain who must meet the costs of any operation.

The third of the treaties developed by COPUOS focuses on compensation agreements for the recovery of space objects. The state responsible for the launch of an object can request the state where it lands to recover and return it providing that any costs incurred in these operations are reimbursed. At the time of writing this paper there are no known deaths, injuries or significant ground damage attributed to the space objects covered by the treaty. The 'Space Liability Treaty' asserts that states are responsible for all space objects that are launched within their territory. If two states cooperate to launch a space object then they are jointly and severally liable for any damage that it causes. From this it follows that a state will be liable if it operated a satellite that subsequently caused damage, even though it was launched from the territory of another state. In the same way that the Chicago Convention holds between signatory states, claims under the liability convention must be brought by a state against another state. No claims can be brought by or against individuals under the treaty; they must solicit the assistance of their state in order to make such a claim.

The fourth treaty focuses on the registration of objects that are launched into space. States must provide the United Nations with ephemeris data for each object that they are responsible for under the terms of the compensation treaty, described above. The treaty also provides for the maintenance of a launch register that documents the name of the launching state, a registration number, the location of the launch and orbital trajectory. Additional details may also be provided about the purpose of the object and whether or not it is active. In the future, it is likely that the register will be extended to explicitly document the conditions under which any object will be moved into a disposal orbit. This extension of the register illustrates further tensions between existing space law and the rise of commercial space operations. Space law focusses on state responsibilities; hence, governments must ensure that corporate bodies act responsibly if they are to meet their national obligations under these various treaties. States that wish to encourage nascent, domestic space industries may, therefore, choose not to ratify the COPOUS agreements.

The final 'Moon treaty' is less directly relevant for the purposes of this paper and focuses on jurisdiction over celestial bodies. The intention is to ensure that all nations abide by international law, however, the treaty has not been widely adopted by nations with the capability to launch mission.

It remains to be seen whether the legislative framework developed in the 1970s is sufficient to support the rapidly expanding space industry. In particular, there are significant questions about the degree to which these treaties and agreements encourage the *sustainability* of space operations. Space-based infrastructures play a central role across many industries. Any disruption to these services would have a direct impact on economic and social well-being. For instance, satellite based navigation and timing systems support aviation, rail and maritime transportation as well as electricity distribution, food deliveries etc. 'Good behaviour' is required to ensure continued access to increasingly congested orbits and to sustain the space situation awareness that is necessary to avoid multiple collisions. Companies should avoid collisions and minimise the chances that their operations will create additional debris. They might also observe additional procedures that reflect a higher level of caution around other satellites. If these behavioural norms are not followed then it is likely that space will become an increasing area of conflict. Another prerequisite for sustainable space operations is the exchange of data. Such practices increase confidence and cooperation, not only between states but also between commercial organisations. In particular, lessons learned from accident and incident investigations must be shared if we are to prevent any recurrence of future adverse events in space-based operations.

SPACE-BASED ACCIDENT AND INCIDENT INVESTIGATION

Previous sections have summarised the legal and regulatory context for commercial space flight. In particular, we have focused on the responsibilities that exist both for sub-orbital flight and also under space law for operations that go beyond the 100km nominal demarcation. The following pages extend this analysis to consider the requirements for accident and incident investigation.

Commercial Aviation, Annex 13 of the Chicago Convention and Liability Issues

The Chicago convention has played a strong role in shaping accident investigation policy for space based systems, just as it forms a corner-stone for the wider legislative environment. In particular, Annex 13 of the Chicago Convention establishes a framework for aviation accident investigations. The intention is to ensure that a degree of consistency is achieved in the analysis and recommendations that might be derived from adverse events that can occur in many different states. The Annex describes the types of events that should be investigated; when there is a serious injury; when an aircraft is damaged or sustains a structural failure or when an aircraft goes missing. An attachment to the main Annex provides a longer list; including near collisions requiring an avoidance manoeuvre and controlled flight into terrain, landings and aborted take-offs on a closed runway, fires or smoke in passenger compartments or engines etc.

Annex 13 also establishes the rights of different parties to participate in an investigation. The state in which an accident occurs will normally lead the investigation. In practice, however, states may assign this responsibility to another state, for instance with more expertise in aviation accident investigations. In this case, the delegated state becomes responsible for publishing the results of an investigation. Other parties to an investigation include the states where an aircraft is registered, states where the airline is based, states where the aircraft is designed and manufactured. Participation is typically through an accredited representative. These individuals acquires certain rights under the

provisions of the agreement, for instance, they must be sent copies of draft reports to provide feedback prior to the final publication. If the accident occurs in the territory of a signatory state then they are responsible for notifying interested parties, including the ICAO. In contrast, if an incident occurs in a state, which has not signed the Chicago convention, then the notification obligations fall on the state of registration. Similar provisions might be extended to orbital and sub-orbital flights. However, additional provisions would have to consider the rights and responsibilities of launch states and of states in which any debris was recovered etc.

A founding principle of Annex 13 is that "the sole objective of the investigation of an accident or incident shall be the prevention of accidents and incidents. It is not the purpose of this activity to apportion blame or liability". This implies that accident investigation authorities must retain a high degree of independence. In particular, they should have the ability to gather evidence, such as witness statements and wreckage, identify causes, issue recommendations and publish final reports without undue influence from judicial agencies; "The investigator-in-charge shall have unhampered access to the wreckage and all relevant material, including flight recorders and ATS records, and shall have unrestricted control over it to ensure that a detailed examination can be made without delay by authorized personnel participating in the investigation". Annex 13 also protects witness statements, communications involved in the operation of an aircraft, medical records, cockpit voice recorders, intermediate findings etc. from disclosure outside the investigation team unless judicial authorities determine that such disclosure outweighs the adverse domestic and international impact such an action would have on that or any future investigations.

Some of the provisions mirror those in the Liability Convention within COPUOS Space Law, described in previous sections. ICAO Annex 13 stipulates that the state in which an accident occurs must take all *reasonable* measures to protect the evidence and maintain safe custody of an aircraft as well as its contents to enable an investigation to be completed. For example, any flight recorder should only be handled by qualified personnel. Such provisions might be extended to the recovery of space objects – however, for many states it may be difficult to determine appropriate measures to secure and safeguard these objects without significant support from the states involved in the launch and operation of the satellite/vehicle. The state of registry/design/operation and manufacture can also request that the aircraft is not disturbed until an inspection can be made by one of their accredited representatives. The state of occurrence must also release the aircraft back to the state of registration or operation as soon as the investigation is finished.

Annex 13 to the Chicago convention also contains provisions that deal with accidents or incidents outside the territory of any state. In these circumstances, the state of registration must coordinate the investigation. Again there is the possibility of delegating this responsibility to another State through mutual agreement. In addition, it is assumed that the nearest state to an accident in international waters will provide all necessary assistance. Although this is intended to deal with mishaps over the 'high seas', some of the clauses could also be re-interpreted in the context of orbital and sub-orbital missions. Further provisions within the Annex deal with the participation of states whose citizens may have been killed or injured in an accident. They can make a request to the coordinating State so that an appointed expert can visit the scene of the accident, access factual information, participate in victim identification, question any survivors from their own state, receive copies of the final report etc. The annex to the Chicago convention also makes it clear that States shall not publish any part of a draft report or other documents relating to an investigation with the consent of the coordinating state. This provision is important because, as we have seen, several other nations may request access to interim findings and reports for comment prior to the release of a final document.

At any stage during an investigation, the coordinating state can make recommendations to appropriate authorities *in any other State* in order to prevent the recurrence of an accident or incident. When necessary, recommendations may also be addressed to ICAO so that international agreements can be updated to reflect the lessons learned from an adverse event. Annex 13 also goes on to describe the protocol by which states must respond to a recommendation either by describing corrective actions or explaining why no actions were appropriate. Such provisions could usefully be extended into Space Law so that lessons will not simply be learned by a small number of leading nations. A key issue here is to sustain the confidence of international investors who play a key role in determining the success or failure of the commercial space industries. In aviation, Annex 13 helps to increase the transparency that is a cornerstone of US space policy. States can trace the ways in which investigatory agencies direct recommendations to all stakeholders; they can also read the formal response to those recommendations describing the interventions that are intended to preserve the safety of future flights.

ICAO Annex 13 requires that States "establish a mandatory incident reporting system to facilitate collection of information on actual or potential safety deficiencies". In addition, voluntary reporting systems should also be used to capture non-mandatory incidents. States are advised to alter their judicial systems to ensure that these systems are non-punitive. However, one potential criticism of the annex is that it provides little detailed guidance on how to satisfy such recommendations. More details are provided within associated accident prevention manuals (e,g, ICAO Doc 9422). Such publications illustrate that the development of space-based accident investigation frameworks must be augmented with guidance on implementation. Annex 13 also recommends the development of databases to facilitate the storage and retrieval of information about safety-related incidents. States should use 'standardised formats to facilitate data exchange'. In practice, however, there remain considerable difficulties in coordinating the electronic exchange of incident data between signatory states. This is a significant limitation because Annex 13 also recommends that states should analyse information from diverse sources, including data on international incidents, to identify safety innovations. ICAO seeks to promote "safety information sharing networks among all users of the aviation system and should facilitate the free exchange of information on actual and potential safety deficiencies". It may be some time before similar systems might be developed across the commercial and state-sponsored space industries.

US Space Investigation Framework

In keeping with the broader legislative frameworks introduced in previous sections, the United States has enacted a number of national provisions (US FAA, 1995). In particular, the Commercial Space Launch Act of 1984, amended in 2004, authorizes the Secretary of Transportation to oversee commercial launch activities. The Act places a number of responsibilities on the Secretary including both the regulation and promotion of a 'competitive US commercial space transportation industry'. It is important to note that previous accidents, including the loss of the Piper Alpha oil production platform and the Linate runway collision, have caused other States and other industries to ensure that these two duties are not shared. There can be significant conflicts in ensuring both the regulation and promotion of an industry.

The Secretary of Transport must also oversee any investigations that are required to enforce the provisions of the Commercial Space Launch Act. This led to the drafting of a 1989 Memorandum of Agreement between the US Department of Transportation Office of Commercial Space Transportation (OCST) and the National Transportation Safety Board. This summarises the roles for the two agencies in the investigation of accidents involving commercial space transportation. The

NTSB retains its role as the US government's *independent* accident investigation agency under P.L. 93-633 (Independent Safety Board Act of 1974, Title III). The NTSB must investigate accidents that occur "in connection with the transportation of people or property which, in the judgment of the Board, is catastrophic, involves problems of a recurring character, or would otherwise carry out the policy of this title" (Section 304(a)(1)(F)). This is interpreted to include some commercial space transportation accidents. The Reimbursable Memorandum of Agreement between the Department of Transportation and the National Transportation Safety Board from 5th June 1989 states that the

> "The NTSB will investigate all commercial space launch accidents resulting in:
>
> a) Known impact of a commercial launch vehicle, its payload or any component thereof outside the impact limit lines designated by the launch range facility; or
> b) A fatality or serious injury (as defined in 49 CFR 830.2) to any person who is not associated with commercial space launch activities and who is not located on the launch range facility; or
> c) Any damage estimated to exceed $25,000 to property which is not associated with commercial space launch activities and which is not located on the launch facility.
>
> NTSB may investigate any other commercial space launch accident which, in the judgement of the Board, is subject to Section 304(a)(1)(F) of the Independent Safety Board Act of 1974."

Under the mutual agreement with the NTSB, the OCST retains authority to conduct investigations of commercial space launch accidents and to obtain evidence to support this task. As we shall see, the OCST has a particular concern to determine whether an accident was the result of a violation of licenses (and eventually any subsequent regulations) or whether a mishap indicates a deeper need to reform the licensing system for commercial space operations. This agreement between the NTSB and OCST governs the investigation of accidents and incidents across all forms of space operations. For example, launch vehicles are defined to include any platform constructed for "the purpose of operating in, or placing a payload in, outer space, and any suborbital rocket".

As with Annex 13, the memorandum of understanding between the NTSB and the OCST is supported by both a high level definition of an accident and further enumerations. Accidents refer to an unexpected or undesirable event following the criteria laid out for NTSB investigations, given above. Incidents refer to malfunctions of flight safety systems or failures of a licensee's safety operations plan that might affect public safety but that do not lead to an accident. The agreements also refer to 'other occurrences' including unexpected events that are neither incidents or accidents that lead to property damage of value more than $25,000 to the payload, launch vehicle, support facility etc. or which results in injury to personnel or that leads to mission failure. As might be expected, the definition of terms, such as 'fatal injury', is related to the wider Code of Federal Regulations (e.g., 49 CFR sec. 830.2).

Again, following the pattern established by the provisions of the Chicago convention, the US investigatory framework defines an Investigator In Charge (IIC) to be an individual appointed by the investigatory agency to coordinate and control all phases of the investigatory process. The IIC may be drawn from the OCST or from the NTSB. At the heart of the US framework is a division of responsibilities between the two agencies. The OCST investigates all commercial space launch accidents that are not investigated by the NTSB. The incidents for which NTSB has responsibility are enumerated in an appendix to the memorandum. In addition the OCST may undertake separate investigations from those conducted by the NTSB where there are specific concerns over the violation

of an OCST license that could have undermined public safety. The OCST may also participate in, or request documentary input from investigations conducted by commercial space operators. Both the NTSB and the OCST recognise the significant role that must be played by consultants and others forms of 'expert witness' within their investigatory systems. This builds on the 'Go Team' concept that supports the wider work of the NTSB; a small core of trained investigators is supplemented by external experts that are recruited in response to particular incidents and accidents. In particular, the OCST agreement recognises the need to recruit particular expertise in range safety, reliability engineering and quality control, launch vehicle operations and risk analysis.

Commercial operators must create accident investigation plans for reporting incidents to OCST. These plans must describe how companies will secure wreckage and other material evidence. As we have seen, these plans must be in accordance with the Space Liability Treaty that amongst other things provides for the return of wreckage from other States. Operators must also identify the necessary staff and procedures for cooperating with the NTSB during any subsequent investigation; this includes the provision of documentary evidence as well as other forms of mission relevant data. If commercial operators choose to hold their own independent investigation then this must not conflict with those of the OCST or NTSB. The agreements between the NTSB and the US Department of Transport also consider interactions with other third party investigations, such as the launch range operators that may either be Federal or commercial entities.

In cases where the OCST supports an NTSB investigation, OCST staff has been directed to focus their attention on failures relating to Launch Vehicle Flight Safety or to ground command systems. They have also been directed towards failures in range safety tracking or data acquisition systems, especially where they play a role in ensuring public safety. OCST staff should also investigate failures in the planning and approvals processes that might also have contributed to an increased level of public risk. Other areas of concern include re-entry and failures in vehicle guidance that might endanger other spacecraft or result in a significant amount of debris.

There are significant differences between the purpose of an investigation under Annex 13 of the Chicago convention and the aims of an OCST investigation involving commercial space operations. Annex 13 explicitly states that the intention is not to allocate blame. However, the OCST guidance states that their aim is "to determine the probable cause of an incident or other occurrence as accurately as possible and/or determine if there was a *violation* and make recommendations…, which, if implemented, will limit or significantly reduce the reoccurrence of such event" (US FAA, 1995). Even if violations have been identified then this information may not only be used to implement 'corrective recommendations' for commercial operators but will also be used to refine existing licensing practices and regulations. The difference of emphasis between OCST investigations and Annex 13 is significant because the NTSB implement the US requirements under the Chicago convention. Hence if the NSTB and OCST work together on a commercial space accident investigation there may be situations in which the ICAO's 'no blame' approach is in conflict with the OCST requirements under the Commercial Space Launch Act to identify potential violations. In such cases, the OCST Coordinator must notify the NTSB investigator in charge of any OCST enforcement actions, if the NTSB investigation is not yet completed.

European Space Investigation Legislation

EC Regulation (EU) No 996/2010 implements the provisions of Annex 13 to the Chicago Convention across member states. A key aim of this regulation is to establish a consistent framework for aviation investigations across Europe. Following the ICAO requirements, it places obligations on the State of Occurrence or the State of Registry to conduct an investigation. In contrast to the OCST requirement to identify violations in the US Commercial Space Flight permit regime, EU 996/2010 is solely intended to promote aviation safety. Following the NTSB approach, the intention is not to assign blame or to determine liability.

Previous sections have described how the European Aviation Safety Agency (EASA) was established under EC Regulation 216/2008. EASA ensures the prompt implementation of corrective actions following the publication of an accident report in order both to sustain public confidence and maintain public safety. It is entitled to participate in investigations across member states. As we have seen, Annex 13 provides for the inclusion of representatives from the State of Registry, the State of Design and the State of Manufacture. EASA now coordinates many of these airworthiness responsibilities on behalf of the Member States through the approval process within Regulation (EU) No 996/2010. Inside the European Union, EASA acts as an adviser to the national investigator in charge. In other countries, EASA acts as an advisor to the European Accredited Representative who is appointed by the State in which the manufacturer of the aircraft is located.

A number of recent documents have clarified the position of EASA with respect to the investigation of space related incidents (Marciacq et al, 2008). As might be expected, these continued the general argument in favour of the extension of existing legislation covering aviation operations to also apply for orbital and sub-orbital commercial space flight. For instance, Directive 94/56/EC establishes the Independence of Investigators. This includes a requirement on member states not only to investigate major accidents but also to investigate incidents 'when the investigating body may expect to draw air safety lessons from it' and the investigators shall 'in no case be concerned with apportioning blame or liability'. Directive 56 goes on to assert that the investigators shall be 'be functionally independent in particular of the national aviation authorities responsible for airworthiness, certification, flight operation, maintenance, licensing, air traffic control or airport operation and, in general, of any other party whose interests could conflict with the task entrusted to the investigating body or entity'. An annex to the directive lists examples of serious incidents that should be investigated, such as Controlled Flight Into Terrain (CFIT) and aborted take-offs. However, this list does not consider the specific concerns associated with orbital and sub-orbital operations that have been considered in the first half of this paper.

The European approach to space accident investigation is also informed by Directive 2003/42/EC on Safety Occurrence Reporting. This applies to occurrences which "endanger or which, if not corrected, would endanger an aircraft, its occupants or any other person". The directive requires member states to create mandatory reporting systems for safety occurrences and also encourages the use of voluntary reporting systems for wider concerns shared by anyone in a position of responsibility across the aviation industries. Article 6 also requires that "Member States shall participate in an exchange of information by making all relevant safety-related information stored in the databases mentioned in Article 5(2) available to the competent authorities of the other Member States and the Commission… The competent authority designated in accordance with Article 5(1) receiving an occurrence report shall enter it into the databases and notify, whenever necessary, the competent authority of the Member State where the occurrence took place, where the aircraft is registered, where the aircraft is manufactured and/or where the operator is certificated." These requirements and their possible extension to sub-orbital operations reinforce the differences that we have seen in previous sections.

The requirements for disclosure in 2003/42/EC would be hard to sustain outside member states, when strategic commercial or security interests might be threatened.

The European Space Agency published a position paper on space tourism in 2008 which recognised that most of these activities would take place within national air space, hence national agencies and European organisations including EASA, should lead the development of a regulatory framework. Masson-Zwaan (2010) has interpreted this to imply that "ESA sees the currently foreseen sub-orbital slights as an aviation activity to which air law must be applied and would at a later stage look at the possible application of space law for the regulation of orbital space tourism". In part, this stance may reflect the legal status of ESA as technical and advisory organisation; which does not have the power to enact regulations or enforce harmonised approaches to accident investigation.

CONCLUSIONS AND FURTHER WORK

Previous sections have identified three different approaches to the regulation and legislation of sub-orbital and orbital commercial space flight. The first approach is to extend the existing frameworks that govern commercial aviation. This creates problems because there are many areas of technical development, for instance in environment and life support systems, which are only partially covered by existing requirements. Further problems arise because many states do not have regulators with sufficient experience and expertise to be able to extend airworthiness processes into space operations. A second approach is to extend the existing provisions of Space Law to govern commercial space operations. This creates difficulties because existing provisions focus on the safety of the crew and do not directly address commercial passengers. Further problems arise because there are no provisions to encourage the exchange of safety-related information, as there are under ICAO Annex 13. The final approach would be to use a hybrid system in which aviation law applies only to those portions of a flight in which any vehicle functioned as an aircraft and to apply Space law to the orbital and sub-orbital segments of a mission. This would suffer from all of the problems mentioned above, with the added complexity of determining when the transition between aviation and space law might be applied.

In practice, many of these concerns are being addressed in a piecemeal but pragmatic manner through memorandums of understanding. The FAA has done much to promote these agreements by moving from an immediate aim of harmonisation in regulation to support interoperability. Previous sections have explained this difference in philosophy; sub-orbital space flights will be permitted with 'minimal changes' between two or more regulatory regimes. Letters of understanding between different states outline the processes that commercial operators must follow in order to meet the requirements of each signatory.

The piecemeal approach, described above, is sufficient to support the short term regulation of a dynamic and emerging market. However, it arguably provides a dangerous basis for the investigation of incidents and accidents. It is for this reason that previous sections have argued for the creation of an international agreement – either extending ICAO Annex 13 with explicit provisions for commercial space flight or developing an entirely new basis that ensures the exchange of safety lessons from any future mishaps. The following list summarises our concerns that motivate international agreements over space accident investigation:

- *Confidence in the recommendations.* There is a danger that other nations will not trust the findings of investigations launched by other states if appropriate tools and techniques are not used in a transparent manner. The provisions of international agreements, such as ICAO

Annex 13 and the EU directives introduced earlier, increase confidence in the recommendations from aviation investigations because other nations can review the methods used to reach those findings and can participate in stages of an inquiry;

- *Defences against bias.* There is a temptation to use experts drawn from national space programmes to lead the investigation of mishaps involving commercial space operations. This creates a number of problems. In some states, there exists a degree of rivalry between public and private organisations. In other nations, government agencies have a financial stake in the development and promotion of commercial space enterprises. In both cases, it is difficult to protect investigators from the subtle organisational pressures that might bias recommendations;

- *Separation of responsibilities.* It is very difficult, arguably impossible, for the same organisation to be responsible both for the preservation of safety and the economic promotion of an industry. In such situations, it is very difficult for individuals not to feel compromised by these twin objectives. For instance, production pressures may encourage regulators to approve high-risk operations that would not otherwise have been allowed. There are further cogent arguments in favour of the separation of investigators from regulators; this is important when the causes of an accident might stem from a failure to apply existing legislation or from deeper problems in the regulatory infrastructures. At present, too many space mishaps are investigated by individuals drawn from the same organisations that were responsible for those mishaps. While this is appropriate for scientific endeavours, it is clearly inappropriate as a basis for the investigation of accidents in which the lives of passengers might be placed at risk;

- *Ensuring sufficient technical expertise.* Some state-sponsored space agencies have argued that they are the only bodies with sufficient technical expertise to investigate space-related accidents. This creates concerns when successive mishap boards have identified very similar recommendations over more than a decade; in such cases there is an argument for greater external input in the investigatory processes (Johnson 2003, 2011). It is also difficult to sustain this stance when commercial agencies are playing an increasingly prominent role in the provision of service to national space agencies. These inter-dependencies make it essential that international agreements promote the creation of independent bodies with sufficient technical expertise to investigate the root causes of potential mishaps, for instance involving space tourism. In practice, this involves specialist investigators who coordinate teams of specialist engineers formed to meet the needs of each new investigation; following the US NTSB's go-team model. This approach is particularly appropriate given the multi-agency nature of many commercial operations – where the assembly, launch and operation of a vehicle may all involve organisations based in different states. However, the success of go-team investigations is determined by a range of non-technical skills and investigatory competencies;

- *Ensuring investigatory competence.* We argue that the growth of commercial space operations creates a need for independent accident and incident investigation agencies, supported by international agreements similar to ICAO Annex 13. The development of professional investigatory agencies also implies the need for specialist training to ensure competency – not just in the technical issues at the heart of space missions but also in

investigator techniques – including the collection of witness statements as well as physical evidence. Investigators must also be trained to collate primary materials prior to more detailed causal analysis and also to identify recommendations that are intended to avoid any recurrence of previous incidents (Johnson, 2011a). These skills cannot be gathered on an ad hoc basis in the immediate aftermath of an accident.

- *Balancing appropriate disclosure and commercial sensitivity.* A further reason for the development of international agreements over the investigation of sub-orbital accidents is a concern to balance the dissemination of lessons learned while at the same time not violating commercial confidence. International agreements in other domains have established a priority for the dissemination of safety-related information. This makes it difficult for any investigator to subsequently be prosecuted for the inadvertent disclosure of intellectual property. Similar guidance and protection will be needed in the future to ensure that public safety is protected through the dissemination and publication of both the root causes and recommendations from space-related mishap investigations.

- *Recognition of national security.* In the past, some nations have used the recommendations of accident investigations for strategic purposes. Overseas companies cannot view the findings of some enquiries because those lessons have been classified under national security legislation. In the future, there is a risk that this will prevent the exchange of safety-related information. National security concerns might be used to preserve commercial advantages, for example by blocking market access. While this might be sustainable in the short to medium term, the lack of information exchange will place lives at risk and discourage the cooperation that has been a significant strength of many recent space missions.

- *Encouraging transparency and trust.* At the heart of incident and accident investigation is the assumption that the recipients of recommendations will act in good faith to take the remedial actions necessary to prevent the recurrence of previous mishaps. This will only happen if the different parties involved in commercial space missions trust the processes and procedures employed by investigatory agencies. Too often in the past, recommendations have been made in the aftermath of space mishaps that have little direct connection to the particular events that led to the causes of an incident. International agreements are required to ensure, for example, that a company based in one state will accept and act upon the findings of an investigation coordinated by another nation.

This is a partial list – additional justifications include the need to create international agreements that preserve ‘no blame’ investigations so that all parties are encouraged to participate in identifying the root causes of an adverse event without fear that their cooperation will inform subsequent prosecutions. The bottom line here is that urgent action is required to ensure international agreement *before an accident occurs* so that we can better support the safety of commercial space flight.

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