IMPLEMENTING SPACE DEBRIS MITIGATION WITHIN THE UNITED KINGDOM'S OUTER SPACE ACT

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ABSTRACT

The Outer Space Act 1986 (OSA) is the legal basis for the regulation of activities in outer space (including the launch and operation of space objects) carried out by persons connected with the United Kingdom. The Act confers licensing and other powers on the Secretary of State acting through the British National Space Centre (BNSC). The Act ensures compliance with UK obligations under the international conventions covering the use of outer space. Under the legislation of the OSA, the Secretary of State shall not grant a licence unless he is satisfied that the activities authorised by the licence will not jeopardise public health or the safety of persons or property, will be consistent with the international obligations of the United Kingdom, and will not impair the national security of the United Kingdom. Further the Secretary of State requires the licensee to conduct his operations in such a way as to prevent the contamination of outer space or adverse changes in the environment of the Earth, and to avoid interference with activities of others in the peaceful exploration and use of outer space. In the context of space debris mitigation, we consider the physical contamination of the orbital environment and potential physical interference with operational spacecraft. This paper outlines both the philosophical approach adopted in interpreting the requirements of the outer space treaties and translating these into evaluation criteria, and practical experience of assessing compliance of licence applicants with the emerging standards, guidelines and codes for space debris mitigation. The documentation and software tools developed to assist in performing these assessments are introduced, and the modelling and data approaches explained.

1. INTRODUCTION

Historically, meteoroids were the background particulate environment against which artificial satellites were designed. Towards the end of the third decade of the space age, it became apparent that another population of debris was having an impact on artificial satellites, but unlike the naturally occurring meteoroids, it is man-made in origin. This orbital debris population is growing rapidly, dominating the meteoroid environment in all but the micro-metre size range. This new particulate environment, posing a significantly increased collision hazard to the artificial satellites, is a direct consequence of launching and operating similar systems. As we become more dependent upon space-based systems for remote sensing, communications, and navigation, it is important that we understand the nature of the threat that orbital debris poses to operational satellites and take appropriate steps to ensure the sustainable development of near-Earth space.

A number of standards and guidelines for minimising debris production and protecting spacecraft now exist at both national and international level. The importance of such mitigation measures is recognised by all space-faring nations. The issue of man-made debris has been a priority agenda item for the Technical Subcommittee of the United Nations Committee for the Peaceful Uses of Outer Space (UNCOPUOS) since 1994. In 1999, UNCOPUOS published its report following a thorough review of the technical issues. In 2001 UNCOPUOS endorsed the action undertaken by the Inter-Agency Debris Coordination (IADC) Group to reach an international consensus on mitigation practices. This is a key step in managing the future evolution of the orbital environment in a fair and equitable manner, as there is a cost associated with many mitigation practices. To ensure that their application will not penalise operational competitiveness, such mitigation measures must be recognised and applied by all users of space in a co-ordinated manner. To be effective, mitigation practices will need to become an intrinsic and consistent element of in-orbit operations rather than a piecemeal, ad hoc practice. If these practices can be embodied within national legislation, then operators will be obliged to consider space debris mitigation during all phases of a mission, from initial definition and feasibility through to final disposal. The UK's Outer Space Act is the basis for licensing the activities of UK nationals in space and technical assessments have recently been adapted to include consideration of space debris mitigation practices when deciding whether to issue a licence to an applicant.

2. UK OUTER SPACE ACT

The Outer Space Act 1986 (OSA) is the legal basis for the regulation of activities in outer space (including the

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launch and operation of space objects) carried out by persons connected with the United Kingdom. The Act confers licensing and other powers on the Secretary of State acting through the British National Space Centre (BNSC). The Act ensures compliance with UK obligations under the international conventions covering the use of outer space to which the UK is a signatory. These conventions are:

- Treaty on principles governing the activities of states in the exploration and use of outer space, including the moon and other celestial bodies, 27 January 1967 (The Outer Space Treaty)
- Agreement on the rescue of astronauts, the return of astronauts and the return of objects launched into outer space, 22 April 1968 (The Rescue Agreement)
- Convention on international liability for damage caused by space objects, 29 March 1972 (The Liability Convention)
- Convention of registration of objects launched into outer space, 14 January 1975 (The Registration Convention)

Under the legislation of the OSA, the Secretary of State for the Department of Trade and Industry (DTI) shall not grant a licence unless he is satisfied that the activities authorised by the licence will not jeopardise public health or the safety of persons or property, will be consistent with the international obligations of the United Kingdom, and will not impair the national security of the United Kingdom. Further the Secretary of State requires the licensee to conduct his operations in such a way as to prevent the contamination of outer space or adverse changes in the environment of the Earth, and to avoid interference with activities of others in the peaceful exploration and use of outer space.

The Secretary of State requires the licensee to insure himself against liability incurred in respect of damage or loss suffered by third parties, in the United Kingdom or elsewhere, as a result of the activities authorised by the licence. Further the licensee shall indemnify Her Majesty's government in the United Kingdom against any claims brought against the government in respect of damage or loss arising out of activities carried on by him to which this Act applies.

The OSA provides the necessary regulatory oversight to: consider public health and safety, and the safety of property; to evaluate the environmental impact of proposed activities; to assess the implications for national security and foreign policy interests; and to determine financial responsibilities and international obligations.

3. THE LICENSING PROCESS AND TECHNICAL EVALUATION

Safety evaluation aims to determine whether an applicant can safely conduct the launch of the proposed launch vehicle(s) and any payload. Because the licensee is responsible for public safety, it is important that the applicant demonstrate an understanding of the hazards involved and discuss how the operations will be performed safely. There are a number of technical analyses, some quantitative and some qualitative, that the applicant must perform in order to demonstrate that their commercial launch operations will pose no unacceptable threat to the public. The quantitative analyses tend to focus on the reliability and functions of critical safety systems, and the hazards associated with the hardware, and the risk those hazards pose to public property and individuals near the launch site and along the flight path, to satellites and other on-orbit spacecraft. The qualitative analyses focus on the organisational attributes of the applicant such as launch safety policies and procedures, communications, qualifications of key individuals, and critical internal and external interfaces.

The launch of a payload into orbit and the hazards associated with such an operation, can be categorised by the general mission phases of:

- Pre-launch
- Launch
- Orbit acquisition
- Re-entry

In the technical submissions for a licence under the Outer Space Act 1986, an applicant must provide an assessment of the risk to public safety and property, covering each phase of the mission relevant to the proposed operations and licensed activity. This assessment should include:

- discussion of possible vehicle and payload failures which could affect safety (including the safety of other active spacecraft);
- estimation of the likelihood of their occurrence, supported by vehicle reliability data, both theoretical and historical;
- consideration of the effects of such failures.

As appropriate the assessment should address:

- launch range risks
- risk to downrange areas due to the impact of discarded mission hardware
- over-flight risks
- orbital risks, including the risk of collision and/or debris generation, due to intermediate and final orbits of vehicle upper stages and payloads

- re-entry risks of vehicle upper stages and payloads.

This risk assessment is then used as a basis for the review conducted by assessors to determine if the applicant's proposed activities are compliant with the requirements of the Outer Space Act. The qualitative and quantitative criteria used for this evaluation are based on standards and practices employed by a variety of formal bodies. In each case, the assessor seeks to understand the approach proposed by the licence applicant, to judge the quality of this process, to check the degree of consistency within the project, to consider the effectiveness of the proposed technology or process, and to establish its conformance with industry or Agency norms, and the requirements of the OSA. The document hierarchy employed within the OSA is presented in Figure 1. Level 0 documents are those which outline the UK's international obligations, Level 1 documents are those which present the specific requirements placed on the applicant, Level 2 documents are those generated by the applicant to demonstrate their compliance (or otherwise), Level 3 documents are those generated by the assessors in their evaluation of the application, and Level 4 documents are the licences themselves.

4. SPACE DEBRIS MITIGATION AND INTERPRETATION WITHIN THE OSA

In developing the technical evaluation framework to reflect space debris mitigation issues, the particular issues of physical interference and contamination referred to in the Outer Space Act are employed. Although the problem of space debris was not recognised when the OSA was enacted in 1986, the Act is flexible enough to allow interpretation to cover this aspect in the technical evaluation. Thus "physical interference" is used to address probability of collision with other objects in orbit and "contamination" to address safe disposal at end of life. As regards the actual measures that are used to evaluate a licence application, use is made of the growing number of guidelines, codes and standards that are being developed to deal with space debris mitigation. The IADC Mitigation Guidelines and the European Code of Conduct provide qualitative and quantitative measures that are used to assess compliance of licence applicants' proposed activities and measures with recognised "best practice" within the community. These documents are considered Level 1 documents in the structure discussed in the previous section. The most common licence that BNSC processes is a payload licence. In the case of a payload licence, the safety assessors check the satellite platform's specification (e.g. attitude control system, orbit, power storage mechanism, launcher interface and separation mechanism) and the safety processes (plans and procedures) to assess their effectiveness at space debris mitigation. Examples are given below:

Attitude control system: Initial determination of nature of system and whether fit for purpose. Is the technology cold gas thrusters, reaction/momentum wheels, is there a potential for stored energy at end of life, if so consider likelihood of fragmentation occurring and if so, recommend passivation measures at end of life

Orbit: Basic understanding of the orbital elements of the proposed trajectory. Consider natural lifetime, stability of orbit under the influence of natural perturbations, degree of crowding at particular altitude, any unique aspects of orbit configuration

Power Storage Mechanism: General review of technology and suitability. Is it physical (flywheel) or electric, are fuel cells standard technology, are there any unique/exotic elements (e.g. radioisotope thermal generator), is system scaled for platform power requirements and charge cycles (account for eclipse characteristics) is there a potential overcharge problem at end of life, passivation consideration.

Launcher Interface and Separation Mechanism: Understand nature of coupling and ejection process. Is the interface dictated by the launcher or payload, is the launch environment very demanding, is launch environment well understand/specified and payload qualified, how many objects are introduced into orbit in addition to upper stage and payload, does separation process minimise debris production?

Safety processes and procedures: Determine existence and consideration of safety issues. Where relevant to the launch phase, consider safety implications of payload for launcher, are there unique risks associated with payload, if multiple payload launch, does payload deployment pose risk to others? In orbit phase see below:

With regard to contamination of the environment, the impact on both the debris and radiation environment is assessed (for example, frequency interference with other operators).

Impact on the debris environment: Safety assessors consider likelihood of collision of payload with other operational payloads and general debris environment. This is determined by orbital configuration, orbital lifetime, physical size, and spatial density of objects at proposed altitude

De-orbit-re-orbit plans: Regarding the operator's ability to comply with safety requirements, the applicant is asked about his de-orbit/re-orbit plans, whether plans exist to remove the satellite from the operational orbit should an irrecoverable failure occur, whether such capability is available, etc.. Safety assessors need to understand if plans exist and if so are they effective. Has the issue been considered, at what altitude is operational orbit, is disposal necessary, is re-orbit to higher altitude or de-orbit to lower altitude planned, are disposal orbits effective, do they comply with existing standards/guidelines (e.g. use of IADC re-orbiting formula for GEO satellites, 25 year maximum disposal orbit lifetime below 2000 km), what is feasible with platform technology, extent of autonomy on-board to conduct de/re-orbit without ground intervention, what criteria are used to determine End Of Life. Are operational procedures agreed or will they be put in place prior to regular operations?

5. MODELS AND TOOLS

When considering the impact on the debris environment, the safety assessor can use a tool known as SCALP (Satellite Collision Assessment for the UK Licensing Process). SCALP enables investigations into the effect of proposed satellite operations on the low Earth orbit (LEO) and geosynchronous orbit (GEO) regions. It does this by considering the operational orbit of the payload; it does not include the launch phase or the effect of any proposed de-orbit or re-orbit manoeuvre. SCALP enables an overall assessment of the collision risk the licence applicant's payload poses to the on-orbit population, as well as identifying individual satellites that may be involved in close approaches with the new satellite. The risk assessment can be carried out for the entire lifetime of the payload so the long-term risk over many years can be calculated.

The LEO and GEO regions present very different challenges when modelling collision risk. To meet these challenges the SCALP model has two branches — one for LEO and one for GEO. Each branch consists of three main components, which combine to provide the assessor with the required outputs:

- Current population
- Orbit propagation
- Collision risk assessment.

Current Population. The current population of objects in SCALP is limited to the tracked population. The information for these objects is obtained from ESA's Database and Information System Characterising Objects in Space (DISCOS). Physical and orbital parameters are obtained for both the currently controlled, operational population and the uncontrolled population of defunct satellites, rocket bodies and other large debris objects. The criteria for including objects in SCALP are given in Table 1. The assessor may include the population information for objects in geostationary transfer orbits (GTO) in collision risk assessments for LEO or GEO payloads.

Table 1. The object populations included in SCALP.

	GEO	LEO	GTO
Perigee (km)	> 37,048	< 8,378	< 7,378
Apogee (km)	< 45,280	N/A	42,164 ± 1,000
Inclination (°)	< 20	N/A	< 56
Eccentricity	< 0.1	< 0.1	N/A

Orbit Propagation. Objects in the geosynchronous region are evolved in SCALP using a high precision, fast numerical propagator, which includes all of the orbit perturbations known to be important at GEO altitudes. Thus, perturbation effects due to solar radiation pressure, luni-solar gravity, Earth potential (to 5th order) and Earth axes precession are all included. Of particular importance when modelling the evolution of objects in the GEO region is the consideration of their operational status. The station-keeping strategy of an operational satellite, maintaining the satellite within a given longitude slot, is simulated using an algorithm that performs generic manoeuvres typical of GEO satellites.

In LEO a fast, analytical propagator is used in preference to the numerical model. This is done to ensure efficient processing speeds whilst maintaining the orbit accuracy required for the collision risk assessment. The propagator includes atmospheric drag, gravitational perturbations due to the Earth, Sun and Moon, and solar radiation pressure (including Earth's shadow effects).

Collision Risk Assessment. The collision risk assessment method used for GEO payloads makes full use of the deterministic population data and high precision orbit propagation. It is a purely geometric method, which assess the close approach between the licence applicant's payload and another object, and subsequently the possibility of a collision. A collision 'encounter' is defined as the intersection of the orbit of one object with the uncertainty volume of another, where the uncertainty volume is defined by the positional uncertainty of the object due to tracking errors.

In contrast, the dynamics of the LEO region mean that a time-averaged statistical method for collision risk assessments is appropriate. It is based on a spherical control volume defined in terms of radius, right ascension and declination. A collision 'encounter' is determined by analysing the path of each object in LEO through this control volume and determining the intersections of this path with that of the licence applicant's payload. Each intersection has an associated collision probability.

The results generated by the SCALP tool for a proposed satellite include the total collision risk to the population as well as identifying individual objects with particular events. These outputs allow the safety assessor to evaluate the environmental impact of the activities proposed within the licence application.
The safety assessor may also make use of the orbit propagators as stand-alone tools, in order to assess the de-orbit / re-orbit plans of the applicant.

6. SUMMARY

The United Kingdom has implemented space debris mitigation measures in its evaluation of licence applications under the UK's Outer Space Act 1986 to ensure compliance with the established outer space treaties and conventions and the emerging set of guidelines, codes and standards. In addition to including space debris mitigation within its set of evaluation criteria, the British National Space Centre has sponsored the development of a series of tools such as SCALP to support the evaluation process.

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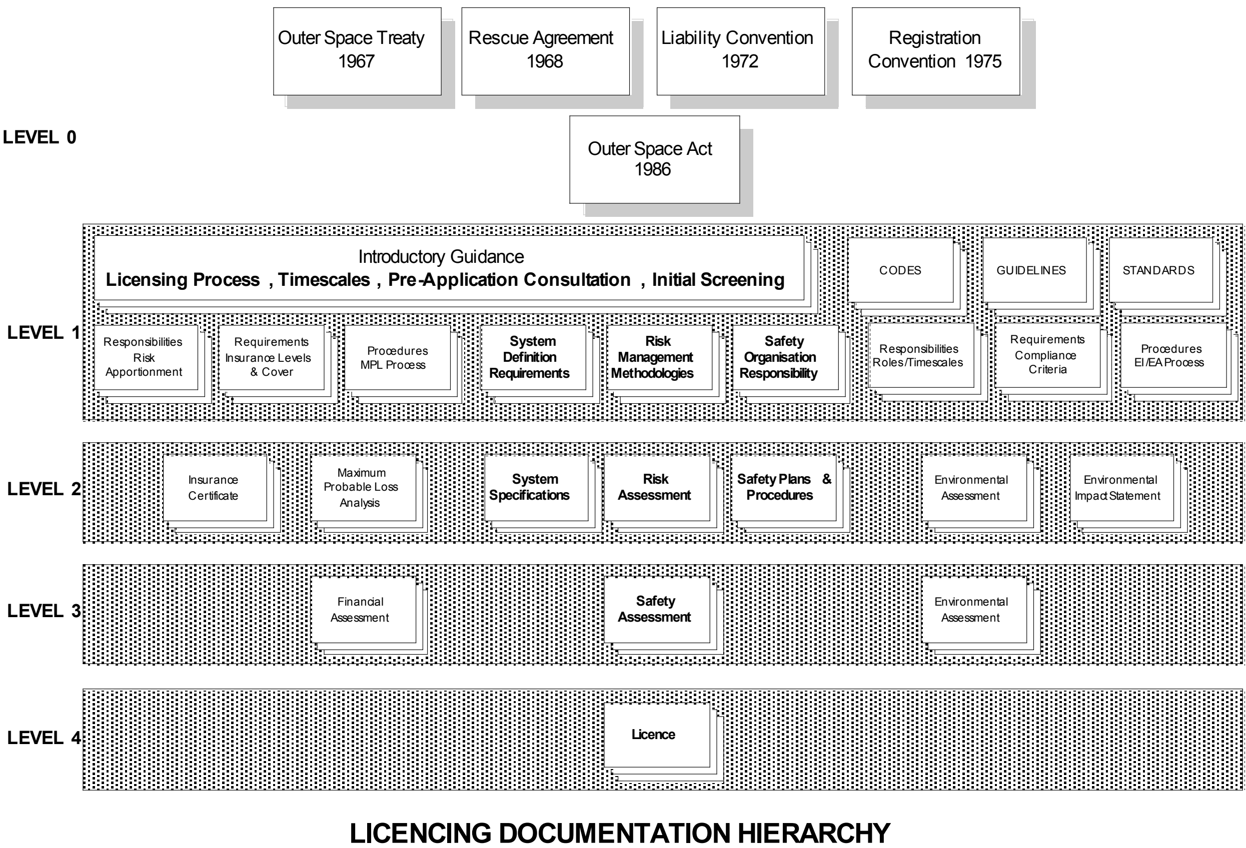

Figure 1 OSA Licencing Document Hierarchy