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Working report of expert group B: Space Debris, Space Operations and Tools to Support Collaborative Space Situational Awareness

I. General

A. Composition of the expert group

The expert group was co-chaired by one expert from Italy and one from the United States. The expert group included approximately 70 technical experts from 23 Member States of the United Nations, and from three international organizations.

B. Summary method of work for expert group B

In accordance with the method of work adopted on February 14, 2012, expert group B met formally in 2012, 2013 and 2014 on the margins of sessions of the Scientific and Technical Subcommittee and the Committee on the Peaceful Uses of Outer Space in Vienna, Austria. The expert group also held informal consultation meetings on the margins of the International Astronautical Congress held in Cape Town, South Africa, in 2011; in Naples, Italy, in 2012; and in Beijing, China, in 2013. These formal and informal meetings were supplemented by electronic exchanges of information, including through the dedicated web page established by the Working Group on the Long-term Sustainability of Outer Space Activities (hereafter “Working Group”) on the website of the Office for Outer Space Affairs.

Expert group B considered the inputs received from States and consulted with other expert groups on cross-cutting issues, including gaps between expert group findings and recommendations on best practice guidelines, and the relevant findings and recommendations of other expert groups. Expert group B also participated in the workshop organized by the Working Group during the fiftieth session of the Scientific and Technical Subcommittee, where representatives of national non-governmental organizations and private sector entities, having experience in space activities, provided information on their experiences and practices in the conduct of sustainable space activities.

C. Methodology

The aspects of the long-term sustainability of outer space activities in the context of expert group B are summarized as background discussions in the subsequent sections.

Criteria for the development of new best practice guidelines

In accordance with the Terms of Reference for the Working Group, expert group B considered three criteria in assessing potential guidelines in the areas of space debris, space operations and tools for collaborative space situational awareness:

- Improvement of the safety of space operations and the protection of the space environment, giving consideration to acceptable and reasonable financial and other connotations, and taking into account the needs and interests of developing countries;

- Consistency with the existing international legal framework for outer space activities, including existing United Nations treaties and principles governing the activities of States in the exploration and use of outer space;

- Relationship to current work being done within the Committee on the Peaceful Uses of Outer Space and its Subcommittees, other United Nations intergovernmental bodies, international intergovernmental organizations, and other international organizations and bodies.

D. References

Ref.1: A/AC.105/C.1/L.307.

Ref.2: A/AC.105/1001, Annex IV, para. 16.

Ref.3: “Stability of the future LEO Environment” - Technical Presentation made by the Inter-Agency Space Debris Coordination Committee (IADC) to the 50th session of the Scientific and Technical Subcommittee, 13 February, 2013.

Ref.4: Donald J. Kessler, “The Kessler Syndrome,” March 8, 2009, http://webpages.charter.net/dkessler/files/KesSym.html (accessed on 16 June 2014).

Ref.5: Compendium of space debris mitigation standards adopted by States and international organizations, Document submitted by Canada, the Czech Republic and Germany, A/AC.105/2014/CRP.13, 10 June 2014.

Ref.6: “The Realities of Re-entry Disposal”, Dr. Russell Patera and Dr. William Ailor, (Los Angeles: The Aerospace Corporation, Center for Orbital and Re-entry Debris Studies).

Ref.7: V. Lukiyashchenko, M. Yakovlev, et al., “The Problem of Space Environment Radioactive Pollution”, Space Forum, Vol. 1, pp. 103-107, (Amsterdam: Gordon and Breach Science Publishers), 1996.

Ref.8: Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space Official Records of the General Assembly, Sixty-second Session, Supplement No. 20 (A/62/20), paras. 117 and 118 and annex, endorsed by the General Assembly resolution 62/217 of 21 December, 2007.

Ref.9: Tiffany Chow, “Space Situational Awareness Sharing Program: An SWF Issue Brief,” (Washington: Secure World Foundation), September 22, 2011.

Ref.9: The Space Data Association, “SDA General Information,” July 2012, http://www.space-data.org/sda/wp-content/uploads/downloads/2013/08/SDA-Flyer-26Jul2012.pdf (accessed on 16 June 2014).

Ref.10: Long-term sustainability of activities in outer space, Working paper submitted by the Russian Federation A/AC.105/L.285, 31 July 2012.

E. Abbreviations and definitions

ADR: Active Debris Removal
IADC: Inter-Agency Space Debris Coordination Committee
MMOD: Micro Meteoroid and Orbital Debris
NOTAM: Notice to Airmen
SSA : Space Situational Awareness
WWNWS: World-Wide Navigational Warning Service

II. Guidelines

Guideline B.1

Promote the collection, sharing and dissemination of space debris monitoring information

States and international organizations should encourage the development and use of relevant technologies for the measurement, monitoring and characterization of the orbital and physical properties of space debris and should promote the sharing and dissemination of derived data products and methodologies for their use.

Rationale

Regular monitoring of space debris located on the Earth orbit is necessary for obtaining objective and up-to-date information in order to address the following key tasks, both at the international and national levels:

- to elaborate and improve the models that describe the current state of man-made debris objects in the near-Earth space and the dynamics of changes of this environment enabling quantitative assessments of risks related to the constantly changing number of space debris objects in different regions of near-Earth space;

- to elaborate substantiated engineering solutions for the protection of spacecraft from possible collisions with small-sized space debris fragments that cannot be traced individually;

- to formulate scientifically substantiated recommendations regarding measures aimed at reducing the amount of space debris in the near-Earth space (including through providing sufficient information to assess necessary improvements in order to comply with requirements of national and international standards and guidelines on space debris mitigation in near-Earth space).

Regular monitoring of qualitative and quantitative changes that the space debris population undergoes can be achieved solely through routine measurements, the provision of information on orbital and physical properties of space debris and the comparison of the results obtained at various time periods. In the given context, this helps to fulfil a number of dedicated tasks, including the following ones:

- to obtain a reliable estimation of the amount of debris objects, including, *inter alia*, small-sized (from fractions of a millimetre to centimetres in cross section), of their orbital and physical properties, and to build, based on the data obtained, statistical functions representing the distribution of the values of the relevant parameters;

- to identify the potential sources of debris objects and to classify them;

- to assess the effect of each type of space debris source on the changes in the space debris population in short-, mid- and long-term perspectives;

- to identify events that generate new space debris (including fragmentations due to explosion and collision);

- to design and regularly verify models describing the physics of the generation and orbital evolution of the observed debris objects in short-, mid- and long-term perspectives;

- to carry out statistical risk analysis with respect to particular near-Earth space regions for a given time interval;

- to identify the areas in near-Earth space environment with the highest space debris spatial density;

- to maintain a regularly updated database on orbital properties (with certain precision level) of the tracked objects in order to facilitate the identification and analysis of dangerous conjunctions, and to enable the use of special measurement devices (sensors) to study the physical properties of space debris.

The accomplishment of the above tasks contributes to improved understanding of space debris population in the near-Earth space environment and of the present and future effect of space debris on the safety of on-orbit space activities. In particular, the information obtained (after its necessary processing and integration into the models developed) can be used by spacecraft designers to account for the required characteristics and design features of spacecraft protection elements, including the identification of spacecraft construction elements most exposed to small-sized man-made objects during the spacecraft's estimated lifetime in the target orbit. In addition, objective information on the sources of small-sized debris particles and their generation processes is necessary in order to obtain qualitative and quantitative estimates related to the practicability and cost-effectiveness of the proposed space debris mitigation measures designed to prevent the generation of new debris objects.

Existing practices for space debris monitoring

Currently, ground-based radars as well as electro-optical sensors placed both on Earth and on board of spacecraft are used to acquire information on space debris objects larger than 0.5-1.0 centimetres (cm), whereby orbital data is obtained for object typically larger than 10 cm. The small-size space debris population (objects less than 1 millimetre in size) is best measured in situ by using special detectors on board of spacecraft and by analysing impact features and residues on spacecraft surfaces returned from space. Moreover, laboratory experiments can help modelling some stages of the orbital debris generation and allow studying physical properties of materials exposed to space environment in order to better understand changes in physical properties of materials (e.g. reflectivity characteristics) as well as the processes of their deterioration and subsequent destruction. The amount of information that can be obtained on certain space debris objects largely depends on the physical properties of the observed objects (in particular, the reflectivity characteristics of objects in the spectrum ranges used for radar and optical observations), the orbital parameters, and the instruments and the methods of observation.

Observations carried out by radar and optical sensors can be based on different methodological approaches and be aimed at both deterministic study of individual objects, and the acquisition of statistical data about the total population of space debris objects in certain regions of space. The results of deterministic observations can be used to estimate the following characteristics of each particular object:

- parameters of centre of mass motion and their evolution over time;

- parameters of attitude and their evolution over time;

- reflectivity and spectral properties (for example, the change in the intensity of the reflected signal in different regions of the electromagnetic spectrum and under different viewing conditions which allows estimating the average value of the effective area of the reflecting surface which in turn can be used to estimate the geometric dimensions);

- effective area-to-mass ratio.

Thus, by using radar and electro-optical sensors, it is possible to obtain trajectory information, direction and velocity of the observed object in space relative to the observation facility, information about the reflectivity characteristics of the object in optical and/or radar bands, and their changes in throughout the observation.

With sufficient amount of trajectory information it is possible to estimate the parameters of the orbital motion of each particular object with a certain degree of accuracy, as well as the ratio of the effective surface area of the object to its mass (ratio of the area normal to the vector of acceleration due to atmosphere drag or the area normal to the vector of acceleration due to solar radiation pressure to the mass of the object). The results of statistical surveys can be used to assess the following characteristics:

- object flux (per unit of observed space and per unit of time);

- spatial density of objects;

- estimations for basic parameters of orbit for each individual object which has been observed during the survey based on the simplified assumption on orbital motion (e.g. on the assumption of having ideal circular orbits for all objects in the flow);

- reflective characteristics of each individual object which has been observed during the survey (and, therefore, the average value of the effective area of the reflecting surface permitting to infer geometric dimensions).

Periodic statistical measurements can detect changes in the distribution of space debris fragments in a particular area of the near-Earth space, which may be caused by an orbital event not yet identified at the time of such measurements (e.g. the fragmentation of an orbiting object that was not detected by means of deterministic research).

Existing practices for international cooperation

Given the large number of potentially dangerous space debris and the complex evolution of both individual objects and their population as a whole, as well as the vast volume of the near-Earth space where the objects are scattered, regular monitoring of the situation in the near-Earth space is extremely challenging and requires significant financial, technical and human resources.

Meanwhile, the emergence and development of new technologies makes it possible to engage an increasing number of researchers from different countries in monitoring of the near-Earth space. No State in the world is currently able to provide a complete and constantly updated picture of the situation in orbit on its own. Thus, there is an objective need to combine capabilities in this area. The tools and technologies of optical observations of objects in the near-Earth space are no longer financially costly and are available to all interested states, which make it quite feasible to ensure the widest possible participation to study the man-made debris in the near-Earth space, especially in the high orbits (geostationary and highly elliptical orbits), where the space debris population is less characterized.

Examples of existing international practices in the areas of joint measurements, monitoring, and determination of orbital and physical characteristics of debris objects in the near-Earth space and the provision for public use and dissemination of derived products and methodologies for their use include:

- dedicated test measurement campaigns (beam-park radar experiments and dedicated optical campaigns) for statistical studies of the population of small space debris in various regions of the near-Earth space under the auspices of the Inter-Agency Space Debris Coordination Committee (IADC), which brings together experts from 12 major space agencies of the world;

- regular monitoring of high orbit debris within the international research project entitled International Scientific Optical Network (ISON), which brings together researchers from 14 countries.

The monitoring data cannot be correctly interpreted and used without understanding of the methodology behind them. It is obvious that this fact must be taken into account during planning, sharing and collaborative use of data. Therefore, a key aspect of international cooperation in the investigation of the man-made space debris environment in near-Earth space (besides the data exchange) is the development and harmonisation of common approaches to evaluate the quality of the data, to interpret them and to assess their potential use for specific tasks.

Cross-cutting issues and existing gaps

Different kinds of failures and anomalies may occur during the operation of the on-board systems of spacecraft in orbit. In some cases, these failures and anomalies can indeed be caused by collisions with small-sized space debris. Nevertheless, these failures are often due to other causes – the effects of space weather, failure of electronic and mechanical components of the on-board equipment and impacts of natural objects (meteoroids and micrometeoroids).

For a better understanding of the true causes of such incidents, especially in the event of failure of a spacecraft and the inability to obtain the necessary telemetry data to analyse the situation, one needs the fullest possible picture of the real state of the space environment outside the spacecraft at the time of its failure. To this end, the study of the near-Earth space environment where spacecraft operate should be comprehensive and evaluate the possible effect of each component of this environment on the spacecraft.

The existing approaches to the study of the near-Earth space debris suffer from a number of gaps. These gaps make it difficult to obtain a comprehensive understanding of the phenomenon of space debris and limit the participation of many countries in the analysis and solution of this complex and multifaceted issue. The most serious gaps are briefly described below.

Currently, only a few states carry out regular observation of space debris in near-Earth space. The development of common, mutually agreed approaches to verify the information received from other parties and to fuse data from different sources in a qualified way has been and remains a relevant issue. This fact inevitably limits practical capabilities and efficiency of collaboration. Furthermore, there is no international mechanism for exchanging verified information that, using the same methodological approach, might be used by different countries which do not carry out observation themselves, but have qualified scientific personnel, including specialists in physics, mathematics and material engineering.

Another aspect of the problem which is equally important in the studies of space debris environment in near-Earth space is the lack of standard approaches to represent measurement data (which is primary in nature), as well as to represent derived products on space debris which includes orbital information (centre-of-mass motion parameters), estimation of mass, size, attitude motion parameters relative to the centre of mass, as well as reflection characteristics. Despite the large amount of work carried out by different states at national and international levels, there are no scientifically and practically well-funded common formats that would define the structure and content of various types of information, the models for obtaining and processing information, as well as the methods of correct interpretation and practical use of information, which have yet to be completely agreed upon.

Comprehensive implementation of the proposed guideline, if it is appropriately institutionalized, could greatly contribute to international cooperation in the field of space debris environment research.

Guideline B.2

Implement space debris mitigation measures

In accordance with the Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space, States and intergovernmental organizations should address, establish and implement space debris mitigation measures through applicable mechanisms.

Rationale

The current space debris environment is deteriorating due to an increasing number of orbital objects, despite worldwide efforts to reduce growth rates through the implementation of internationally agreed debris mitigation standards and guidelines. Figure 1 shows the number of objects in Earth orbit that have been identified and linked to an object associated with a specific launch according to the U.S. Space Surveillance Network (SSN).

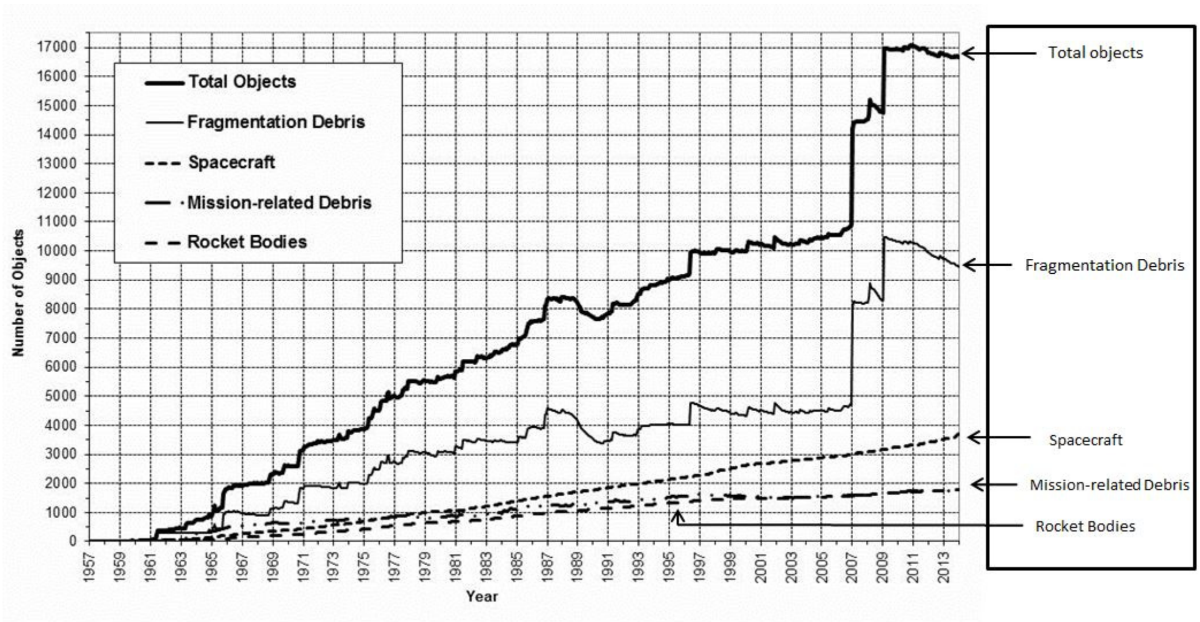

Fig-1 Monthly Number of Catalogued Objects in Earth Orbit by Object Type (Source: U.S. National Aeronautics and Space Administration, Orbital Debris Programme Office, *Orbital Debris Quarterly News*, Volume 18, Issue 1, January 2014, page 10)

As of March 2014, this number has reached approximately 17,000 objects. Not all the objects the SSN actively tracks, however, have been formally identified and placed in the public catalogue. Many objects are tracked regularly and their orbits are known, but they are not “catalogued” because they have not been correlated with a known launch or parent body. The total number of objects for which the SSN maintains accurate orbit fluctuates over time due a variety of reasons, including decays and launches of objects, and variations of sensor capabilities for different orbits. There are approximately 19,000 objects with orbits tracked and maintained by the SSN. The majority of these trackable objects are larger than about 10 cm in low Earth orbits (LEO) and larger than about 1 metre in the geostationary ring (GEO). These size ranges are limited due to the sensitivity of radar sensors as primary surveillance and tracking devices for LEO and telescopes as preferred sensors for altitudes above the LEO up to the GEO regime. The number of objects which are too small to detect from the ground but pose a significant risk to operational space missions is by far larger. Even tiny debris or meteoroids smaller than 1 mm can pose a risk to exposed electric harnesses or other vulnerable components, possibly resulting in the loss of functions or even in a break-up.

For debris hazard analyses one must distinguish two major risk categories: (1) risk of deterioration or termination of an operational space mission, mainly by the impact of a sub-cm debris, and (2) risk of a catastrophic break-up due a collision of a large, intact object with a catalogue-size object (debris or intact). Events of the first category are more frequent, due to the larger abundance of small debris particles, but they normally only affect the space mission. Events of the second category are predicted to occur in certain sub-regions of LEO every five to ten years (mostly among non-operational objects), with a lasting effect on the debris environment. During the operational phase of a space mission the effects of category one events can be reduced through shielding measures, and the probability of category two events can be reduced through collision avoidance. However, operational space objects comprise just 5% of the overall catalogue population. The remainder of catalogued space objects has the potential to cause catastrophic collisions, yielding further large-size fragments that could lead to further catastrophic collisions (see Ref.3 on p. 2). In some orbit regions this may cause an unstable run-away situation often denoted as the "Kessler Syndrome", where increases of debris objects from collisions exceed the reduction of debris objects due to orbital decay (Ref. 4).

Historically, on-orbit explosions were the primary source of space debris that could be catalogued. Since 2007, some major collision events (accidental and intentional) have increased the share of collision-induced catalogue objects significantly and increased the catalogue size by approximately 50 percent. The collision rate between such catalogued objects may increase progressively in the future, and, in such case, it is expected that collision fragments will continue to increase in the LEO debris environment in the coming decades.

Existing Practices

The Scientific and Technical Subcommittee officially adopted space debris as an agenda item in 1994. As the result of the study based on the work plan to develop a Technical Report on the Space Debris during 1996-1998, the Report was adopted in 1999. The Report was a significant milestone for establishing a common understanding of the importance of space debris issues.

In 2007, the General Assembly, in its resolution 62/217, endorsed the Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space, drafted in the Scientific and Technical Subcommittee after the multi-year study from 2004 to 2006. The Guidelines represent the first international consensus to reduce space debris and are an important step in providing all spacefaring nations with guidance on how to mitigate the problem of space debris. These qualitative guidelines are based on the technical content and the basic definitions of the Inter-Agency Space Debris Coordination Committee (IADC) Space Debris Mitigation Guidelines. In applying the Space Debris Mitigation Guidelines of the Committee, it is recommended to refer the latest version of the IADC Guidelines in order to know the detail of the recommended practices and latest recommendations.

Since 2007, some States have implemented space debris mitigation measures consistent with the Space Debris Mitigation Guidelines of the Committee and/or the IADC Guidelines. These and other States had developed their own space debris mitigation regulations and/or standards based on those guidelines (Ref. 5).

A number of States are also using as a reference the IADC Space Debris Mitigation Guidelines, the European Code of Conduct for Space Debris Mitigation, and International Organization for Standardization (ISO) standard 24113 (Space systems:

space debris mitigation requirements) in their regulatory frameworks for national space activities. In this regard, some States have taken measures to incorporate internationally recognized guidelines and standards related to space debris through relevant provisions in their national legislation. In addition, some States have strengthened their national mechanisms governing space debris mitigation through the nomination of governmental supervisory authorities, the involvement of academia and industry and the development of new legislative norms, instructions, standards and frameworks.

At a technical level, States that have implemented national mechanisms for space debris mitigation use a range of approaches and concrete actions to mitigate space debris, including the improvement of the design of launch vehicles and spacecraft, end-of-life operations (including passivation and placing satellites into disposal orbits), and the development of specific software and models for space debris mitigation.

States and intergovernmental organizations are encouraged voluntarily to implement debris mitigation measures, through national mechanisms or their own applicable mechanisms to the great extent feasible.

Gaps

Not all States have fully implemented Space Debris Mitigation Guidelines of the Committee applicable to their space activities. As a result, the Committee has annually recommended that urged those countries that had not yet done so to consider voluntary implementation of the Space Debris Mitigation Guidelines of the Committee and/or the IADC Space Debris Mitigation Guidelines.

Guideline B.3

Limit the risk to people and property from controlled re-entries

In cases of controlled re-entries of spacecraft or launch vehicle orbital and/or suborbital stages, States and international organizations should consider furnishing notices to aviators and mariners using already established procedures.

Rationale

During launches of space objects or controlled de-orbit of space objects it is possible to provide prior notices in areas where surviving fragments of launch vehicle stages or spacecraft might fall. The projected ground impact area and time of fall can be estimated during the planning of the launch or while planning of the object de-orbit program.

The value of furnishing such information in the context of the long-term sustainability of outer space activities is two-fold:

- prior notice of controlled re-entries of large spacecraft is a safety issue. Notices enable the reduction of risks of possible injuries or damage to assets on the Earth's surface and airspace;

- such notices are one of the measures to enhance transparency and trust between States, demonstrate responsible behaviour, and enable appropriate awareness of such events.

Current practices

A well-developed practice of providing special notices used in aviation and maritime navigation has been adopted for current use. These notices contain, *inter alia,* information on danger zones – air and maritime areas that at a certain period of time can constitute a danger for aircraft and ships.

Provision of notices of dangerous areas for aviation is stipulated by the Convention on International Civil Aviation (the 1944 Chicago Convention). Accordingly, a Notice to Airmen (NOTAM) is transmitted through designated communication channels. NOTAMs contain information on the state of air-navigation equipment, elements of air space structure, early warning of what is of significant importance to the staff involved in aircraft flights, and other air-navigation information as well.

Instructions on the procedure for drawing up and distributing NOTAM are described in the "Annex 15 to the Convention on International Civil Aviation. Aeronautical Information Services".

Danger zones are established over the high seas and land in the interests of the following activities inclusively:

- support of launch and landing of space objects;
- flights for aeronautical and rocket engineering tests and studies;
- support of launches and falls of rockets and fall of their separating parts.

Danger zones for the listed activities are established for the use by the Air Traffic Management (ATM) centre of the appropriate State for a particular period of time (temporary danger zones). The information on these zones is provided by means of NOTAM.

The Notices to Mariners notify mariners of information on changes in sailing conditions and regime of navigation in maritime and ocean waters, and provide information on corrections to the nautical charts and sailing directions. The information contained in the Notices to Mariners is binding.

The warning to mariners of operational changes in sailing conditions and regime of navigation is broadcasted on radio by the World-Wide Navigational Warning Service (WWNWS), founded in compliance with the International Maritime Organization (IMO) Assembly resolution A.419 (XI) on 15 November 1979. The guidance paper, under which the WWNWS runs, was approved by the IMO Assembly resolution A.706 (17) on 6 November 1991, subsequently revised and approved by the

Maritime Safety Committee and published in the circular MSC.1/Circ.1288 on 9 December 2008.

The WWNWS shall broadcast on radio the following information:

- navigational warnings;
- meteorological information;
- the alarm signals and other data necessary for search and rescue.

The WWNWS has divided the World's Oceans into 16 geographical sea areas, or NAVAREA. Every area has its own regional coordinator, namely, a country tasked with area navigation data collection, analysis and broadcasting on radio in the form of the NAVAREA warnings. A list of NAVAREA coordinators with their contact details, prepared in consultation with the International Hydrographic Organization (IHO), may be found in circular COMSAR.1/Circ.51/Rev.4 of 22 July 2013.

The warnings are broadcast at least two times a day.

The WWNWS guidance paper indicates as one of the grounds for the publication of warnings the "special operations which might affect the safety of shipping, e.g., naval exercises, missile firings, space missions, nuclear tests, etc." The guidance paper also indicates in the text of the relevant warning the hazard level information, if any, as an important component. It was recommended that the warnings should be formulated no less than five days before the planned event.

The numbers of current navigational warnings and the texts of the new ones are published in bulletins to the corresponding Notices to Mariners.

Though the procedures for the issuing of the relevant notifications are generally established, the members of expert group B take the view that more work is needed to apply these procedures to objects associated with space launches and re-entries.

Gaps

The members of expert group B were unable to reach a consensus on the procedure for issuing notifications for uncontrolled re-entries of space objects and orbital launch vehicles. In principle, the desirability of such warnings was supported. However, only a few States currently have the technical capability to monitor the uncontrolled re-entry of objects into the Earth's atmosphere, and no State has the technical capability to predict the location and time of an uncontrolled re-entry with sufficient accuracy to issue actionable warnings. This issue will require further study and outreach before any guideline for cooperation can be identified.

Guideline B.4

Promote techniques and investigation of new methods to improve the accuracy of orbital data for spaceflight safety

Recognizing that spaceflight safety depends strongly upon the accuracy of orbital and other relevant data, States are encouraged to promote techniques and the investigation of new methods to improve knowledge regarding orbits of space objects.

These methods could include national and international activities to: improve the capabilities and geographical distribution of existing and new sensors; use passive and active on-orbit tracking aids; and combine and validate data from different sources.

Rationale

The accuracy of orbital data depends on a variety of factors, such as the amount and accuracy of the measurements used, the distribution of measurements over the orbit determination arc, the geographical distribution of tracking sensors, and the suitability of the orbit determination and propagation techniques. In this context, orbital data on functional and non-functional space objects may come from different sources. For functional objects, orbital data is usually obtained by traditional means, such as processing of ground control station trajectory measurements derived from telemetry. An increasing number of functional objects use on-board navigation techniques, but the required accuracy of the orbital data is mainly dictated by mission or operational requirements, and these may not necessarily meet the spaceflight safety requirements. Therefore, even for functional objects it is also required to establish common approaches to achieve and maintain the required accuracy of the orbital data. For objects with no functioning on-board equipment, the only direct sources of orbital information are entities processing measurements acquired by radar and active, as well as passive optical instruments. Radars constitute the primary source of information for large objects in LEO, while passive electro-optical sensors provide the majority of data for objects in high-altitude orbits. The current geographical distribution and capabilities of these sensors are limited and in many cases do not permit the derivation of orbits of suitable quality for conjunction analysis and subsequent decisions on avoidance manoeuvres. The problem becomes even more pronounced for the increasing number of small-size intact objects such as CubeSats. Some possible solutions are listed in the following table.

Space object	Small	Medium-to-Large
functional	• consider design modifications to increase the radar cross section, e.g., by the deployment of dipole structures, and to increase the optical visibility, e.g., by the use of highly reflective surface materials • consider the possible implementation of on-board GNSS techniques	• consider design options to improve the accuracy of trajectory measurements derived from telemetry • consider design modifications to allow for the installation of cooperative tracking aids e.g., corner cube retroreflectors to be used in particular after decommissioning
non-functional	• increase the number and sensitivity of sensors and optimize their geographical distribution • develop and implement improved data fusion organizational and technical procedures	• for orbital stages consider design modifications to allow for the installation of passive tracking aids, e.g. corner cube retroreflectors.

The current geographical distribution of the various sensors capable to provide high-accuracy trajectory measurements is not optimum and has limited capabilities to timely react, if possible at all, on urgent requests to acquire the required measurements in support conjunction analysis, in particular for objects in certain orbital regions.

In order to make best use of high accuracy measurement data, it is also important for data processing entities to implement standard orbit dynamic models to permit proper exploitation of accurate measurements. Furthermore, all measurement data providers should consider regular calibration of the measurement accuracy. Calibration methods may include, but are not limited to, the comparison of measurement data with independently derived orbital data (which should include the corresponding accuracy) or cross-calibrations with other sensors.

While some of these suggested methods could help in certain circumstances, they are not universal solutions.

Current practice

An increasing number of functioning space objects are equipped with on-board navigation devices making use of GNSS signals to determine the precise position and velocity of a space object, and the use of increasingly stable on-board oscillators facilitates high-accuracy Doppler and range measurements derived from telemetry. On specific missions additional on-board devices can be used to provide high-accuracy measurements, such as laser retroreflectors, altimeters, and active Doppler systems in order to increase the accuracy of orbit knowledge of such objects. However, the number of objects equipped with such devices is very limited. In order to improve the orbit information of individual objects which are not equipped with such devices, especially in case of potential conjunctions, special high accuracy ground tracking facilities are used.

Gaps

One currently unsolved problem for objects performing nearly continuous intentional changes of their trajectory, for example, by means of electric propulsion engines, is the determination and prediction of the trajectory parameters and the estimation of their accuracy (position and velocity uncertainties). Another problem exists for non-functional objects for which no accurate dynamical model of the orbital motion can be established due to unknown accelerations caused by outgassing, varying effective cross-section, uncertain surface reflection properties and other factors.

Guideline B.5

Perform conjunction assessment during orbital phases of controlled flight

Conjunction assessment with other space objects should be performed for all spacecraft capable of adjusting trajectories during orbital phases of controlled flight for current and planned spacecraft trajectories.

Appropriate steps of the conjunction assessment process include improving the orbit determination of relevant space objects, screening current and planned trajectories of relevant space objects for potential collisions, and determining whether an adjustment of trajectory is required to reduce the risk of collision, in coordination with other operators and/or organizations responsible for conjunction assessment, as appropriate.

States and international intergovernmental organizations are encouraged to develop and implement common approaches to conjunction assessment.

Spacecraft operators, including those of the private sector, who are unable to perform conjunction assessments, should be encouraged to seek support, via State authorities as necessary and in accordance with relevant applicable regulations, from appropriate around-the-clock conjunction assessment entities.

Rationale

Various information and services delivered by satellites in space are indispensable to our daily life. But the approximately 1,000 functional spacecraft in orbit today are joined by tens of thousands of pieces of space debris. The orbital collision of the functional Iridium 33 and non-functional Cosmos 2251 in February 2009 proved that a catastrophic satellite collision is a realistic possibility.

Practice has shown that the implementation of Guideline 3 of the Space Debris Mitigation Guidelines of the Committee (Ref. 8), containing a recommendation to avoid accidental collisions in orbit, requires additional elaboration.

- Firstly, the guideline refers to “known objects”. However, to date there is no universally recognized international database of all objects in orbit (functional and non-functional space objects, including fragments of space debris) that contains regularly updated orbital data and estimations of the accuracy of that information. It is precisely such an international database that could serve as a tool in the implementation of the guideline under consideration. Otherwise, a specific participant in space activities may interpret “known objects” as referring to the population of objects known precisely to that participant. In such a case, a situation might arise in which a space object manoeuvres to avoid a possible collision with a “known object” only to enter the trajectory of likely collision with another object not known to the said participant in space activities but quite possibly known to another participant in space activities. Unifying a database of tracked objects is not a trivial matter;

- Secondly, the term “available orbital data” used in the guideline is, as practice has shown, understood by some participants in space activities as essentially any orbital data from any source. However, not all such data is suitable to assess the risk of conjunction of objects. Orbital data that are not accompanied by any estimation of their accuracy should not, in principle, be used in making the relevant calculations, and especially not for taking decisions as to whether it is necessary to carry out avoidance manoeuvres. Likewise, orbital data calculated using simplified motion models that introduce a significant margin of error into the assessment of the predicted centre-of-mass position of the approaching object should not be used in analysis. If a spacecraft that is adjusting its orbit poses a threat to another spacecraft (i.e., a conjunction is expected), then data on the first spacecraft’s movement trajectory should be used as orbital data for the purposes of analysis of conjunction risk; these data should take into account all future (planned) orbit change operations during the time interval the analysis is carried out. Thus, the requirement of effective and practical implementation of the guideline under consideration inevitably necessitates sharing of reliable and regularly updated orbital data in an internationally recognized standard format on objects in near-Earth space;

- Thirdly, there is currently no uniform, universally accepted standard for calculating the probability (risk) of collisions on the basis of which it would be possible to decide whether or not a spacecraft should carry out an avoidance manoeuvre. Consequently, every operator of spacecraft, when calculating such probability, is forced to rely solely on its own methodology.

Implementation of this guideline supports the long-term sustainability of the space environment and safe spacecraft operations by avoiding debris-generating collisions. Currently not all spacecraft operators perform conjunction assessment and there is no common method for weighing overall risk posed by the conjunctions against the risk of spacecraft trajectory adjustments. Appropriate assessment and action can reduce the risk of collision between two functional spacecraft or between a functional spacecraft and space debris (including non-functional spacecraft).

Additionally, some spacecraft operators do not have sufficient flight dynamics expertise, access to precise orbital data, the capability to improve knowledge of orbits, appropriate software tools, or around-the-clock operational teams to conduct collision avoidance analysis following the identification of potential conjunction. This guideline encourages all operators to develop relevant expertise and capabilities to perform conjunction assessment and/or to request support, when necessary, from other appropriate organizations. When requesting support, operators should work with the government of their supervising State, consistent with Article VI of the Outer Space Treaty and in accordance with relevant regulations.

While it is prudent to conduct collision avoidance activities, these activities cannot prevent collisions between space objects that cannot adjust their trajectories (both functional and non-functional). Unfortunately, these currently comprise the vast majority of space objects.

Current practices

Conjunction assessment practices can be divided into two areas: pre-launch screening and orbital conjunction assessment.

Pre-launch screening

Guideline 3 of the Space Debris Mitigation Guidelines of the Committee encourages operators to avoid collisions during the system's launch phase. In implementing this guideline, launch vehicle operators are expected to plan launch windows to avoid potential conjunctions with orbital objects. Some launch vehicle operators adjust launch times by screening for collisions with the International Space Station; a few of them also screen for collisions with functioning spacecraft. Some conjunction assessment organizations offer pre-launch collision avoidance screening services to assist launch vehicle operators in performing screenings and adjusting launch times. However, there are several gaps in this process, which are described below.

Orbital phases

Today, an increasing number of spacecraft operators have given greater importance to avoiding collisions. To attain this goal, some operators perform conjunction assessments. Other operators without sufficient flight dynamics expertise, access to precise orbital data, appropriate software tools, and/or around-the-clock operational teams work with appropriate organizations capable of performing conjunction assessments to screen the orbital parameters of functioning spacecraft against other space objects and identify if a potential conjunction exists. Some operators interact directly with other operators to perform conjunction assessments and collision avoidance for spacecraft for which they are responsible.

The conjunction assessment process for orbital phases include the following key steps:

- Screening current and planned trajectories of relevant space objects for potential collisions. Conjunction assessment involves periodic screening of current and planned trajectories for potential conjunctions between a functioning satellite and all other catalogued orbiting objects, including space debris. Ephemeris data for functioning satellites are compared to ephemeris data on other catalogued space objects to determine if any two objects are predicted to approach each other in ways that violate pre-defined safety thresholds. Currently there is no common method for establishing safety thresholds and levels of risks;

- Improving the orbit determination of relevant space objects (i.e., both objects involved in the conjunction event). When a potential conjunction is predicted, it is important to refine the estimate of orbits and potential collision risks. Satellite operators can use orbital information derived from measurements obtained using on-board equipment (if available and sufficient), which may be supplemented by data from other sources (e.g., ground sensors). Some operators work with organizations capable of providing improved orbital information. This collaborative process is repeated until the uncertainties of orbital parameters are reduced to a level adequate to support decision making;

- Determining whether an adjustment of trajectory is required to reduce the risk of collision, in coordination with other operators and/or organizations responsible for conjunction assessment, as appropriate. Once a potential conjunction is identified and a satellite operator is aware of the risk, the satellite operator weighs the overall risk posed by the conjunction against the risk of manoeuvring the spacecraft. In cases where a collision avoidance manoeuvre is decided, operators should screen the planned trajectory (in accordance with the steps described above), to ensure the trajectory adjustment does not result in new conjunctions within the screening time window. In cases where a conjunction involves two functioning satellites capable of adjusting their trajectories, the relevant operators sometimes coordinate any trajectory adjustments. Currently there is no common method for weighing overall risk posed by the conjunctions against the risk of manoeuvring spacecraft. Evaluation of risks could be complicated when operators use different data and processes as the basis for their conjunction assessments.

Gaps

The expert group identified the following gaps:

Pre-launch screening

Guideline 3 of the Space Debris Mitigation Guidelines of the Committee encourages operators to avoid collisions on launch, the most relevant aspect of pre-launch notification in support of long-term sustainability. However, there are no common standards to represent planned orbital insertion phase trajectories (i.e., before injection of all payloads into final orbits) and associated uncertainties for use in conjunction assessment analysis described above. So the ability to assess risks is limited at this stage.

Launch phase

There is no common practice to perform conjunction assessment analysis during the actual orbital insertion phase (until initial orbital insertion of all payloads). Even with the capability to perform conjunction assessment, the ability to adjust launch trajectories is limited by launch vehicle design and technology and cannot be addressed by a guideline. Precise orbital insertion is often limited by fundamental technical constraints. Further technical research and development would be required to address this gap.

Orbital phases

A critical phase of on-orbit flight occurs after orbital insertion until the completion of spacecraft bus commissioning, which can last from hours to months. During this phase, the accuracy of estimates of spacecraft trajectories varies and the spacecraft is not fully operational. This makes it difficult to perform conjunction assessments and to perform necessary trajectory adjustments. Further technical research and development would be required to address this gap.

Guideline B.6

Provide appropriate contact information

States and international organizations are encouraged to exchange contact information for appropriate entities responsible for spacecraft operations and conjunction assessment. States and international organizations are also encouraged to establish appropriate procedures to enable timely coordination to reduce the probability of, and facilitate effective responses to, orbital collisions, orbital break-ups and other events that might increase the probability of accidental collisions.

Rationale

When an orbital close approach is predicted after conjunction assessment or a trajectory adjustment is performed for orbital collision avoidance, timely notifications are important. It is also important to have timely coordination between relevant entities responsible for spacecraft operations and conjunction assessment.

Contact information can facilitate coordination between relevant entities to make appropriate trajectory adjustment decisions. This contact information can also allow for States with space monitoring capabilities to provide close approach notifications to potentially affected spacecraft operations entities, allowing them to make timely decisions on trajectory adjustments for collision avoidance.

Governmental agencies and non-governmental entities with information on debris producing events can also use contact information to share this information with relevant entities responsible for launch operations, spacecraft operations, or conjunction assessment.

Current practices

Some government and private sector operators of spacecraft currently maintain internal directories of contact information for other entities responsible for the operation of other spacecraft. Some entities performing conjunction assessment also maintain internal directories of contact information in order to provide close approach notifications in all orbital regions. Some space operators use contact information to coordinate collision avoidance and other operational activities, e.g., minimization of radio frequency interference. Some entities might coordinate mutually, as necessary, in accordance with relevant regulations, under their supervising State's authorization.

Pursuant to General Assembly resolution 62/101 entitled "Recommendations on enhancing the practice of States and international intergovernmental organizations in registering space objects", the United Nations Office for Outer Space Affairs has established a Registration Information Submission Form (http://www.unoosa.org/pdf/misc/reg/regformE.pdf). This form allows States to provide additional voluntary information regarding registered space objects. Using this form, some States currently identify satellite operators and also provide web links to official information on space objects.

Gaps

Informal and internal directories of contact information for and submissions to the register of space objects of the Office for Outer Space Affairs are not the most complete with regard to current identities of spacecraft operators, owners, supervising States or web links to official information on space objects. When contact information for entities responsible for spacecraft operations is provided, it may not reflect the supervising State and may not be updated in a timely fashion.

Resolution 62/101 recommends that the Office for Outer Space Affairs should make public through its website the contact details of the focal points, however such information has not yet been posted. In addition, submissions to the register of space objects are not always readily available in all six official languages of the United Nations.

Although the domestic regulations of some States require private sector satellite operators to provide contact information for spacecraft control entities, there is no commonly agreed practice for States to compile and share this contact information with other States for the purposes of timely coordination for collision avoidance. Current registration procedures for space objects also do not provide for exchanges of contact information for entities responsible for conjunction assessment.

Guideline B.7

Promote use of standards when sharing orbital information on space objects

When sharing orbital information on space objects, operators and other appropriate entities should be encouraged to use common, internationally recognized standards to enable collaboration and information exchange. Facilitating greater shared awareness of the current and predicted location of space objects would enable timely prediction and prevention of potential collisions.

Rationale

Receiving, accumulating, sharing and distributing orbital information is necessary for detecting potentially dangerous conjunctions and ensuring the security of orbital operations (in situations where at least one of the objects is operational and can adjust its trajectory in order to avoid possible collision), as well as for the determination and analysis of physical characteristics of space debris objects.

Orbital information not accompanied by an assessment of its precision and/or calculated with the help of simplified motion models (that introduce a significant margin of error into the assessment of the predicted centre-of-mass position of the approaching object), strictly speaking, should not be used when a decision about a potential collision avoidance manoeuvre is being made. For the analysis of the conjunction risk of two controlled spacecraft, data on the motion trajectories of both spacecraft that takes into account all future (planned) orbit change operations during the time interval considered by the analysis should be taken into account. Thus, the effective practical implementation of Guideline 3 of the Space Debris Mitigation Guidelines of the Committee inevitably necessitates the creation of unified approaches for the generation and distribution of reliable and regularly updated orbital information on objects in near-Earth space using unified and internationally recognized standards.

Current practice

In terms of applied standards for the international exchange of orbital information, the recommended standard of the Consultative Committee for Space Data Systems (CCSDS) 502.0-B-2 "Orbit Data Message (ODM)" suggests various ways in which orbital information can be provided. Taking into account the diversity and complexity of mathematical models describing the motion of orbital objects, it seems reasonable to primarily use approaches that eliminate the need to introduce and agree upon complex procedures for a guaranteed and methodically correct interpretation and application of orbital information and its accuracy assessment. Thus, it seems that the most practically suitable approach is to use ephemerides as defined in section 5 (Orbit Ephemeris Message) of the ODM standard. Ephemerides are parameters represented in the form of tables of values given for specific epochs; they describe the position and velocity of the centre of mass of an object and their error assessment in a certain coordinate system using kinematic parameters (position vector and velocity vector components) or classical osculating orbital parameters. The parameter values at a given moment of time that are different from those given in the table may be calculated with simple and well-known methods of interpolation.

The publication by CCSDS in June 2013 of Recommended International Standard 508.0-B-1 “Conjunction Data Message (CDM)” establishes a common framework and provides a common basis for the format of conjunction information exchange between originators of conjunction assessment data and satellite owner/operators. It allows implementing organizations within each conjunction assessment originator to proceed coherently with the development of compatible derived standards for the flight and ground systems that are within their cognizance.

Cross-cutting issues and existing gaps

The existing internationally recognized orbital information standards involve a considerable degree of flexibility for the description of both, data, and models for obtaining such data. However, the formal use of the information provided following those standards does not necessarily result in a correct conclusion because of possibly different models (and their implementation in appropriate software) used to process the basic measurement data including models for accuracy estimation.

Obtaining the required high-quality orbital information involves a two-step process:

- processing of measurements and compiling of a set of parameters that determine the orbital movement of an object, along with the estimation of uncertainties of the determined orbit in the form of a covariance matrix; additional information required to forecast the orbital movement (e.g., units of all quantities, time scale, parameters of physical models for perturbations used, sets of fundamental constants, and other entries) should be included in the above information; and

- transformation of the orbital information (including estimation of accuracy) to an agreed format to be shared.

Therefore, in addition to sharing such information using common standards, the following should be considered when preparing orbital information to be shared:

- the data should be verified in terms of authentication and their conformity to any information provided at earlier epochs;

- the period of time for which the information is valid should be specified;

- the information should be provided with accurate reference to a known time scale;

- the information should be updated frequently enough as required to identify potentially dangerous close approaches; and

- the information category (i.e. up-to-date, forecasting, model) shall be defined and relevant guidance notes be included.

Another important issue concerns the procedures to share and to use orbital information. There are two fundamental models for the implementation of the collection and distribution of the information, either by using a centralized data archive or by distributed information storage. Each option allows for information sharing upon request and by electronic mail.

Common scientific and generally recognized practices should be developed on how orbital information and its accuracy characteristics related to the same object but obtained from different sources should be best used. Mechanisms to update or improve such information upon user's request may be needed.

Guideline B.8

Provide registration information to assist in the identification of space objects

States and international intergovernmental organizations should provide registration information on space objects in accordance with the Convention on Registration of Objects Launched into Outer Space and consider furnishing enhanced registration information, as recommended by the General Assembly in its resolution 62/101. States should provide this registration information to the Secretary-General of the United Nations as soon as practicable to assist in the identification of space objects and to contribute to the peaceful exploration and use of outer space.

Rationale

One of the goals of the Convention on Registration of Objects Launched into Outer Space, as it is stated in its introductory part, is to provide for States Parties additional means and procedures to assist in the identification of space objects believing “that a mandatory system of registering objects launched into outer space would, in particular, assist in their identification and would contribute to the application and development of international law governing the exploration and use of outer space”. It states that “when a space object is launched into Earth orbit or beyond, the launching State shall register the space object by means of an entry in an appropriate registry which it shall maintain”. Article IV of the Convention specifies information which each State of registry shall furnish to the Secretary-General of the United Nations, as soon as practicable, on each space object carried on its registry.

The Secretary-General of the United Nations, in turn, maintains a register containing all information received by Member States. The ability to identify space objects and the sharing of information within the international community, through the publication of the registries, are elements of particular importance and, among others, mitigation of space debris and supporting spaceflight safety.

In this context, the term “identification” means the process of establishing the likely source of origin of a space object and thus the State (or States) who supervises “owner” or “operator” of the object.

Resolution 62/101 recommends enhancing the practice of States and international intergovernmental organizations in registering space objects and also recommends, with regard to the harmonization of practices, that consideration should be given to the furnishing of additional appropriate information to the Secretary-General of the United Nations on any change of status in operations (inter alia, when a space object is no longer functional).

Finally resolution 62/101 recommends that, following the change in supervision of a space object in orbit the State of registry, in cooperation with the appropriate State according to article VI of the Outer Space Treaty, could furnish to the Secretary-General additional information, such as

- the date of change in supervision;
- the identification of the new owner or operator;
- any change of orbital position;
- any change of function of the space object.

The expert group underlines the importance of the link between supervision and registration. Providing appropriate and accurate information about space objects as recommended by General Assembly resolution 62/101 requires a close link between the operator of the space object and the supervising state. It is desirable that the registration state should also be the state initially in charge of supervision of space operations.

Current practice

A number of countries, as part of their national licensing regime, maintain a national register of objects launched into space which are under their jurisdiction, and make this publicly available. However, the majority of States Parties to the Registration Convention do not maintain national registers and provide such information to the United Nations.

Under the Registration Convention, every space object launched into Earth orbit or beyond must be entered in a registry maintained by its "launching State". The convention defines "launching State" to mean either the State from whose territory the object was launched or the State which procured its launch (or whose nationals did).

In the case of States that do not have launch capability or facilities on their territory, there is still a requirement to provide registration information under the Convention. A consequence of the definition of launching State is that when a satellite supplier arranges for the launch of a satellite it has built for a foreign satellite operator under a "delivery in-orbit" arrangement from a launch service provider launching from the territory of third State, there are three potential "launching States" if one is of the opinion that the satellite operator falls into the category of "procurers of the launch". In such a situation the joint "launching States" must agree who is to register it. As a result, there are circumstances where a satellite supplier has procured the launch of a space object but where that space object appears on the registry of another State party to the Registration Convention. There will also be situations where title and control of a space object has been transferred to a satellite operator after launch and the regulatory authority has licensed that company to operate the satellite. For these reasons, the supervisory state may produce a supplementary registry of such space objects.

Gaps

A number of space-faring nations are not parties to the Registration Convention. This can result in a situation where the State from which a launch occurs is obliged to register the object with the United Nations even though it may not have control or jurisdiction over its operation on orbit. Furthermore, many countries do not maintain national registers or if they do, they do not make the information publicly available. The practice of maintaining supplementary registers is also limited to a small number of States. A consequence of the limited adherence to the Registration Convention by many States is that implementation of reporting obligations is compromised and the information available to the United Nations and ultimately to the wider international community is piecemeal. The lack of comprehensive information on objects injected into orbit results in a patchy and incomplete picture of what is in orbit and where, and therefore impacts space situational awareness and ultimately safety if a potentially hazardous event occurs and inadequate information is available to identify the object or its operators, or under whose control and jurisdiction the satellite comes under. Resolution 62/101 in its paragraph 2(a)(i) recommends that among types of information to be provided to the Secretary-General on the registration of space objects, the Committee on Space Research (COSPAR) international designator could be included, where appropriate. In fact, this recommendation is very hard (if possible at all) to fulfil at present in view of absence of internationally established and maintained system of registration of orbital launches (launches in which at least one object was placed into Earth orbit or beyond).

Prior to July 2011 the World Warning Agency for Satellites (WWAS), as part of the World Data Center of International Council for Science, was responsible for assignment of the designators on behalf of COSPAR. This service is no longer available due to changes in organization of the WWAS.

Moreover, the WWAS procedure did not provide a guarantee that some orbital launches were not missed and was not free of miss-assignments that subsequently were changing thus creating some confusion in registration process.

The Registration Information Submission Form of the Office for Outer Space Affairs states that the designator can also be obtained from the Office's Online Index of Objects Launched into Outer Space. Currently, this form recommends use of the discontinued WWAS service. Therefore, it is not clear how the Online Index is maintained because currently there are no internationally established rules on how the launch designation system should be maintained.

Resolution 62/101 in its paragraph 2(b)(ii) also recommends that consideration should be given to the furnishing of additional appropriate information to the Secretary-General on any change of status in operations. However, this concept has not been elaborated.

III. Issues for further consideration by the Scientific and Technical Subcommittee

During its examination of topics within the scope of expert group B, there were new issues raised that were not previously addressed by the Scientific and Technical Subcommittee or its related Working Groups. Expert group B recommends that the Working Group on the Long-term Sustainability of Outer Space Activities raise these issues to the Scientific and Technical Subcommittee for further consideration.

A. Technical developments and possibilities regarding space debris removal

Concepts for removing large debris from low earth orbit have been proposed since the early 1980s. Early ideas for reusable crewed space vehicles, either directly or in conjunction with an orbital transfer vehicle, were found unattractive due to safety, availability, cost, and policy issues. Numerous independent robotic concepts, ranging from classical space-based propulsive tugs to momentum and electrodynamic tethers, drag augmentation devices, solar and magnetic sails, and ground- and space-based lasers have also been considered. However, reviews by panels of international experts have repeatedly failed to identify a single plan which is both technically feasible in the near-term and economically viable.

These studies have also highlighted the need for additional studies of technical concepts to help identify appropriate architectures and technological shortfalls. These issues may be addressed in several planned technology demonstrations of orbital servicing capabilities. However, there is currently no established practice for space debris removal that can serve as the basis for a recommended guideline.

The actual implementation of any environment remediation measures to remove objects from space is very complicated. The cost and technical challenges are the two major obstacles that will not be resolved in the near future. Policy and legal issues, such as ensuring that active debris removal activities are compliant with the provisions of the Outer Space Treaty, the Liability Convention and other applicable international law, also will need to be addressed, and some States have made proposals in this area. However, space debris mitigation measures such as those endorsed by the Committee on the Peaceful Uses of Outer Space in 2007 may be insufficient to limit the growth of the future debris population. Therefore States may choose to move forward with concepts for active debris removal. In this event, the Scientific and Technical Subcommittee can serve as a key forum for exchanges of information on emerging practices and standards that could prompt a re-examination of this matter.

B. On-orbit servicing

On-orbit satellite servicing and associated close proximity operations offer the promise of extending satellite operational life-times, and as such, could enhance the long-term sustainability of space. It could allow greater use of existing on-orbit assets, and potentially slow the growth of non-functional satellites and other debris.

However, other than NASA's Hubble Space Telescope, experience with on-orbit servicing (OOS) is very limited, and if done incorrectly, OOS could create debris instead of reducing it. OOS would entail actual physical contact between two satellites (the servicer and the satellite to be serviced), which is problematic and could lead to collisions between the two satellites, and hence the possible generation of debris.

OOS bears watching by the Working Group on the Long-term Sustainability of Outer Space Activities, but at this time the expert group can propose no guidelines or best practices for this activity, similar to the situation for active debris removal.

C. Ensuring information consistency and transfer reliability

A whole range of States and other legal entities are joining efforts on a multilateral and/or bilateral basis to analyze and exchange specific information. Any of the possible scenarios involves a particular level of technical or political feasibility. One possible idea could be the creation of a single monitoring centre to collect orbital information and assessments of its accuracy, and then to conduct a dedicated process for data fusion in order to create more reliable orbital information and support decision making in case of collision avoidance trajectory adjustments, as well as procedures for conducting subsequent analysis of incidents that have occurred. To provide an institutional basis which would support implementation of this idea would require a considerable focusing of minds.

Some challenges relating to reliability of information transfer are being addressed in the commercial sector using methods that do not specifically apply to space. For example, common secure internet protocols, data encryption algorithms, and other features utilized in internet commerce could be applicable to the reliable transfer of information related to collaborative space monitoring processes and activities.

However, issues with duplicate and potentially conflicting information in a multiplicity of databases are a potential issue with respect to monitoring of space. The fact that there is no common database of space objects (spacecraft plus debris) virtually guarantees that there will be duplication of space objects across the several databases now maintained by different nations, differing degrees of information on objects that are registered in multiple databases, uncertainties of information on objects that are registered in multiple databases, different identifying names for the same object in multiple databases, and an assortment of other data quality and completeness issues with which actors in the space arena must reckon.

Some experts expressed the view that the development and maintenance of a single trusted database of space objects, perhaps under the auspices of the Office for Outer Space Affairs in accordance with guidance provided by the Committee on the Peaceful Uses of Outer Space, could represent a significant advancement in the state of the art even if merely to improve the completeness of the aggregate data set. Such a unified database would need to provide secure and robust update processes, as well as field-level data access controls in order to protect data deemed sensitive by the launching State (if applicable). The principal issues associated with such a database are likely to be in the realm of policy rather than technology given that in many cases the sensors associated with space surveillance networks are under the control of military organizations. Although the creation of a comprehensive, authoritative database of space objects represents a significant international challenge, the benefits of such a resource to the long-term sustainability of human space activities would be substantial.