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Inter–Agency Space Debris Coordination Committee

Space Debris

IADC Assessment Report for 2010

Issued by the IADC Steering Group

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Acronyms

ADR	Active Debris Removal
ASI	Italian Space Agency
CNES	Centre National d'Etudes Spatiales (France)
CNSA	China National Space Agency
CSA	Canadian Space Agency
COPUOS	Committee on the Peaceful Uses of Outer Space, United Nations
DLR	German Aerospace Center
ESA	European Space Agency
GEO	Geosynchronous Orbit region (region near 35,786 km altitude where the orbital period of a satellite matches that of the rotation rate of the Earth)
IADC	Inter-Agency Space Debris Coordination Committee
ISRO	Indian Space Research Organization
ISS	International Space Station
JAXA	Japan Aerospace Exploration Agency
LEO	Low Earth Orbit region (orbital region below 2000 km altitude)
NASA	U.S. National Aeronautics and Space Administration
ROSCOSMOS	Russian Federal Space Agency
SSAU	State Space Agency of Ukraine
STSC	COPUOS Scientific and Technical Subcommittee
UKSA	UK Space Agency

1. Foreword

The Inter-Agency Space Debris Coordination Committee (IADC) is an international forum of space agencies for the worldwide coordination of activities related to the issues of man-made and natural debris in space.

The IADC was formally established in 1993 (1) to promote the exchange of information on space debris research activities between member space agencies, (2) to facilitate opportunities for cooperation in space debris research, (3) to review the progress of ongoing cooperative activities, and (4) to identify debris mitigation options.

As of January 2011, 12 space agencies were members of the IADC:

- ASI (Agenzia Spaziale Italiana)
- CNES (French Centre National d'Etudes Spatiales)
- CNSA (China National Space Administration)
- CSA (Canadian Space Agency)
- DLR (German Aerospace Center)
- ESA (European Space Agency)
- ISRO (Indian Space Research Organization)
- JAXA (Japan Aerospace Exploration Agency)
- NASA (U.S. National Aeronautics and Space Administration)
- ROSCOSMOS (Russian Federal Space Agency)
- SSAU (State Space Agency of Ukraine)
- UKSA (UK Space Agency)

The IADC conducts its activities through a Steering Group and four Working Groups. The specialized working groups are as follows:

- Working Group 1: Measurements
- Working Group 2: Environment and Data Base
- Working Group 3: Protection
- Working Group 4: Mitigation

The IADC Terms of Reference, public documents, and other valuable information and links can be found at the IADC internet website at www.iadc-online.org.

The purpose of this annual report is to highlight the recent events and activities related to space debris research and to provide a current assessment of the state of the Earth artificial satellite population, along with growth trends.

2. IADC Highlights

The IADC welcomed its twelfth member in 2010 with the approval by the Steering Group of the request for membership by the Canadian Space Agency (CSA). Membership of the IADC has grown significantly since 1993 when ESA, NASA, RKA (now ROSCOSMOS), and the space agencies of Japan established the organization after several years of bilateral coordination. During 1995-1997 the IADC more than doubled its membership with the additions of BNSC (now UKSA), CNES, CNSA, DARA (now DLR), and ISRO. ASI joined in 1998, followed by NSAU (now SSAU) in 2000.

ISRO hosted the 28^{th} meeting of the IADC in Thiruvananthapuram, India, during the period 9-12 March 2010. Approximately 100 specialists from 10 IADC members were in attendance. The CNSA delegation was unable to attend due to a delay in obtaining visas.

During the opening plenary session, four special presentations were delivered:

- First International Conference on Orbital Debris Removal (NASA)
- GEO End of Life Workshop Report (CNES)
- Space Debris Mitigation Through National Space Licensing (BNSC)
- Survey and Tracking as Part of a European SSA System (ESA).

Figure 1. The IADC Steering Group during the opening plenary session at the 28th meeting of the IADC in Thiruvananthapuram, India.

Figure 2. Participants at the 28th meeting of the IADC in Thiruvananthapuram, India.

The 12th IADC Risk Object Reentry Exercise was held from 20 April until 30 April, 2010. On average, once a year the IADC risk object reentry communications network is tested by monitoring the natural reentry of a resident space object. The IADC established and first tested this communications system in 1998. The purpose of the network is to provide a means of sharing both orbital tracking data and reentry predictions among IADC members in the event of the reentry of a satellite which might pose an elevated risk to people and property on Earth due to the mass of the object or due to the presence of specific hazardous materials, e.g., radioactive materials.

The subject of the 2010 exercise was a 30-year Vostok upper stage launched by the former Soviet Union. Ten of the 11 IADC members participated in the exercise by providing reentry predictions; three of the IADC members also provided tracking information. Five IADC members submitted predictions within the last three hours before reentry, and all these predictions were slightly early with an average error of 15 minutes compared with the actual time of reentry.

The Steering Group met for the second of its semi-annual meetings on 30 September in Prague, Czech Republic. The 29th meeting of the IADC was set for 11-14 April 2011 under the leadership of DLR.

3. Space Debris Activities in the United Nations

Space debris has been an agenda item for the Scientific and Technical Subcommittee (STSC) of the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) since 1993. In 1999, after a multi-year effort, the STSC produced the first UN Technical Report on Space Debris. In 2003 the STSC began considering the preparation of a set of space debris mitigation guidelines. This activity was completed in 2007 with subsequent endorsements by the full COPUOS and by the General Assembly.

The IADC is often invited to make a special technical presentation during the annual meeting of the STSC in February of each year. In 2010 the IADC described to the Subcommittee the nature of its Protection Manual. Developed by IADC Working Group 3, this manual provides

- a standard framework to assess meteoroid and orbital debris risk
- validated ballistic limit equations
- benchmark results for cross-calibration of test facilities
- benchmark cases for validation of numerical simulations
- design guidelines for protection of spacecraft.

The IADC presentation also addressed a 2009 request by the STSC to IADC "to develop first ideas on concrete measures with the purpose of making available already existing sources of information as well as data and information on objects in outer space for the promotion of a safe and sustainable development of the peaceful uses of outer space."

In addition to the IADC presentation, eight other national presentations and one presentation by ESA were made under the space debris agenda item:

France:	Recent Space Debris Mitigation Activities in France
Germany:	Cost and Benefit Analysis of Space Debris Mitigation Measures
India:	Space Debris Activities in India
Indonesia:	Space Debris, Near Earth Objects, and Space Weather Research and Observation in Indonesia
Russian Federation:	GEO Protected Region: ISON Capabilities to Provide Informational Support for Tasks of Spacecraft Flight Safety and Space Debris Removal
Switzerland:	Swiss Contributions to a Better Understanding of the Space Debris Environment
USA:	Space Situational Awareness (SSA) Sharing Update
USA:	USA Space Debris Environment and Operational Updates
ESA:	ESA Activities on Space Debris Mitigation

These presentations can be accessed via the internet at http://www.oosa.unvienna.org/oosa/en/COPUOS/stsc/2010/presentations.html.

Under a new multi-year work plan, the STSC established the Working Group on the Long-term Sustainability of Outer Space Activities. Dr. Peter Martinez of South Africa was selected as the Chairman of the new working group. In a draft Terms of Reference for the working group, the objective of the effort was "to examine and propose measures to ensure the safe and sustainable use of outer space for peaceful purposes, for the benefit of all countries."

Topics of consideration for the working group include:

- Sustainable space utilization supporting sustainable development on Earth
- Space debris
- Space weather
- Space operations
- Tools to support collaborative space situational awareness
- Regulatory regimes
- Guidance for new entrants in the space arena.

The working group expected, in 2011, to designate expert groups to examine the aforementioned topics and to propose potential international guidelines or standards for each area.

4. Earth Satellite Population

In its Space Debris Mitigation Guidelines, the IADC has defined two protected regions about the Earth (Figure 3). The first region is the low Earth orbit (LEO) protected region which extends from the lowest maintainable orbital altitude up to a height of 2,000 km above the surface of the Earth. The second region is the geosynchronous orbit (GEO) protected region, which includes the volume of space bounded in altitude by +/- 200 km of the geosynchronous altitude (35,786 km) and in inclination by +/- 15 degrees. Note that the GEO protected region represents only a portion of the entire GEO region.

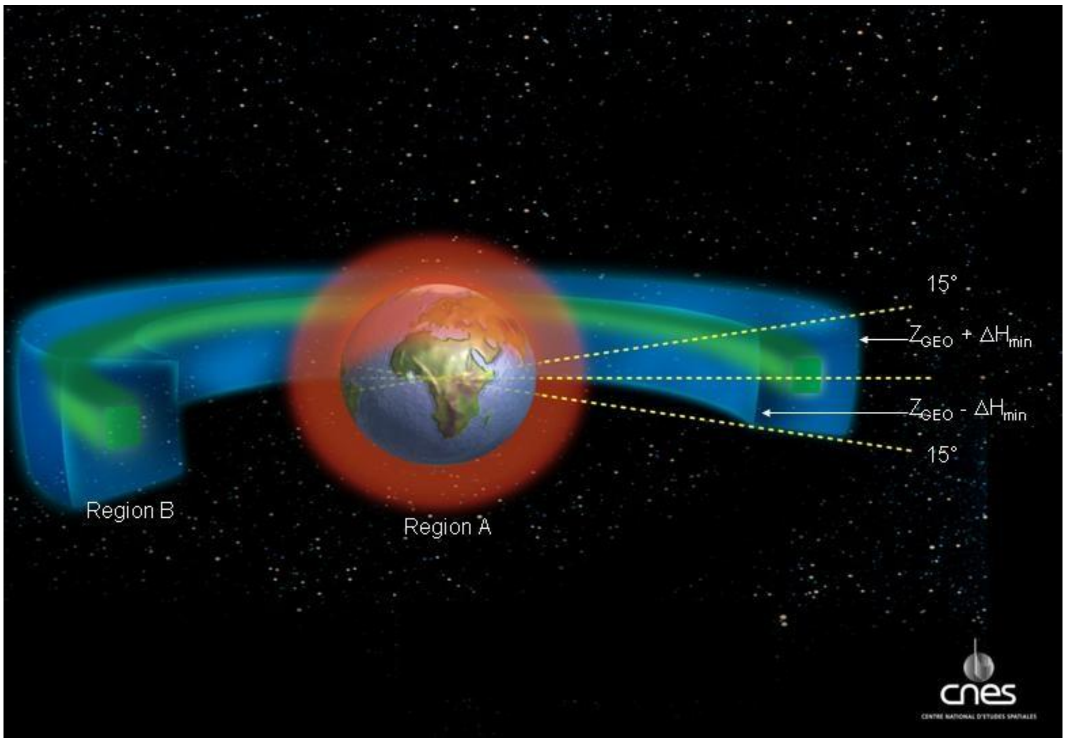

Figure 3. Protected Regions A and B, as defined by the Inter-Agency Space Debris Co-ordination Committee and adopted by the United Nations. (Source: *Support to the IADC Space Debris Mitigation Guidelines*, October 2004)

Knowledge about the population of man-made objects in orbit about the Earth is derived from three main sources as a function of object size:

1. <u>Objects larger than ~10 cm in LEO and larger than ~1 m in GEO</u>: These objects, which include intact spacecraft, launch vehicle stages, mission-related debris, and fragmentation and other debris, are tracked by established space surveillance systems, comprised primarily of terrestrially-based radar and electro-optical sensors, such as the U.S. Space Surveillance Network and the Russian Space Surveillance System. The majority of these objects

have been identified and officially cataloged and are monitored on a frequent basis.

2. <u>Objects between 2 mm and 10 cm in LEO and between 10 cm and 1 m in GEO</u>: These objects typically consist of mission-related or fragmentation debris and are detected by special ground-based sensors. In LEO no attempt is made to maintain discrete orbits for these objects. Instead, data on size, altitude, and inclination are used to develop statistical models of the environment. In GEO some efforts are underway to develop a catalog-like database for these objects.

3. <u>Objects smaller than 2 mm in LEO</u>: The presence of these objects can be inferred by the examination of space vehicle surfaces which have been returned to Earth, *e.g*., solar arrays of the Hubble Space Telescope.

Figure 4 depicts the most recent assessment of the growth of the Earth satellite population at all altitudes since the launch of Sputnik 1 in 1957. Fragmentation debris has clearly been the dominant component of the population since the 1960s. The dramatic increases of fragmentation debris seen in 2007 and 2009 are due to the breakup induced by the collision of the Fengyun-1C spacecraft and the collision of the Cosmos 2251 and Iridium 33 spacecraft, respectively. Many of these debris are expected to fall back to Earth during the next several years when levels of solar activity increase as part of the Sun's natural 11-year cycle.

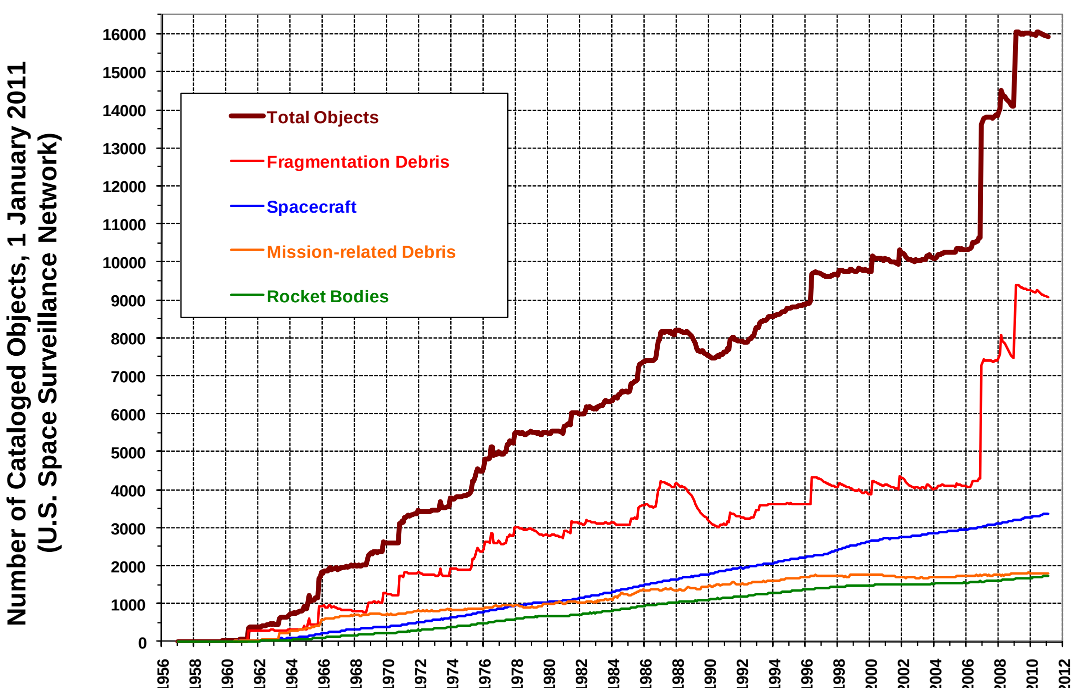

Figure 4. Growth of the cataloged population of objects in Earth orbit.

The growth of the cataloged Earth satellite population in just the LEO region is illustrated in Figure 5. This is the most highly congested region in near-Earth space. For objects too small to catalog, the population levels are much higher. For instance, the number of debris between 1 and 10 cm is assessed to be several hundred thousand, and the number between 1 mm and 1 cm is assessed to be in excess of 100 million.

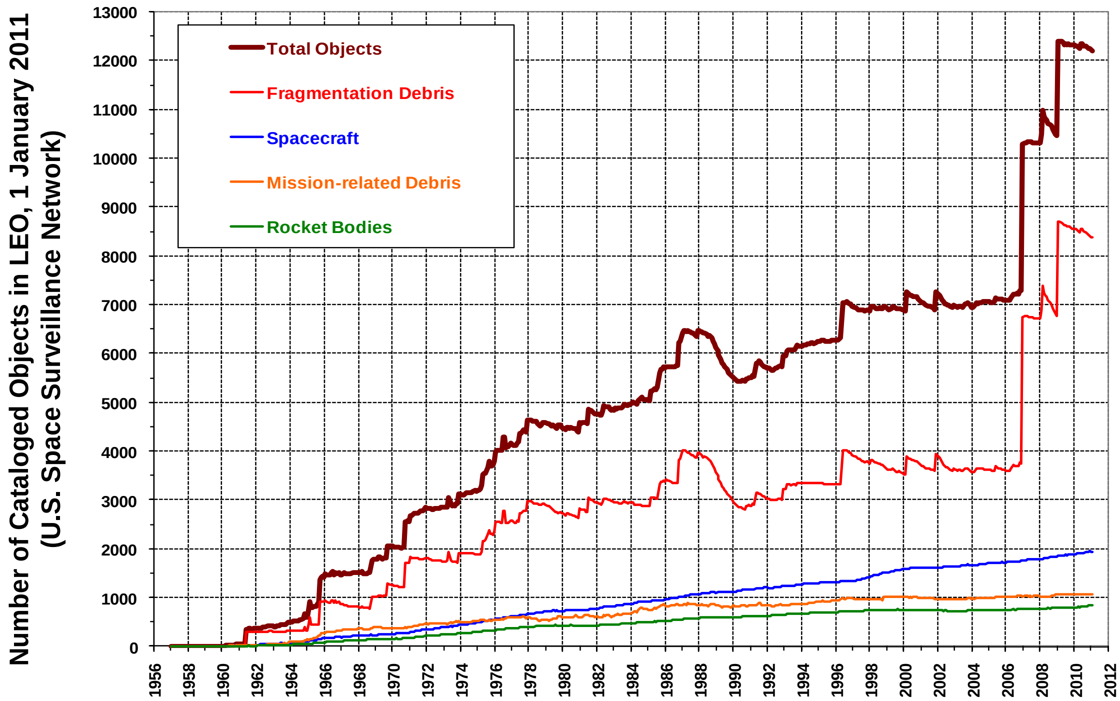

Figure 5. Growth of the cataloged population of objects in low Earth orbit only.

The objects in the GEO region are much less numerous than in LEO and reside in about seven times the volume of LEO, but this unique regime is the home to more than 400 operational communications and other spacecraft which serve vital purposes for all countries of the world. The total number of cataloged objects in or near the GEO region is in excess of 1,100. The current number of estimated objects as small as 10 cm in or near the GEO region is on the order of 3,000. Only rough estimates are available for debris smaller than 10 cm at these high altitudes.

Another important measure of the Earth's satellite population is the total mass which is now in orbit. As Figure 6 clearly illustrates, more than six million kilograms have accumulated during the past half century. As expected, virtually all this mass arises from intact spacecraft (functional and non-functional) and launch vehicle orbital stages. The rate of increase in mass has been surprisingly steady through the years: ~ 145 metric tons annually during the past 40 years.

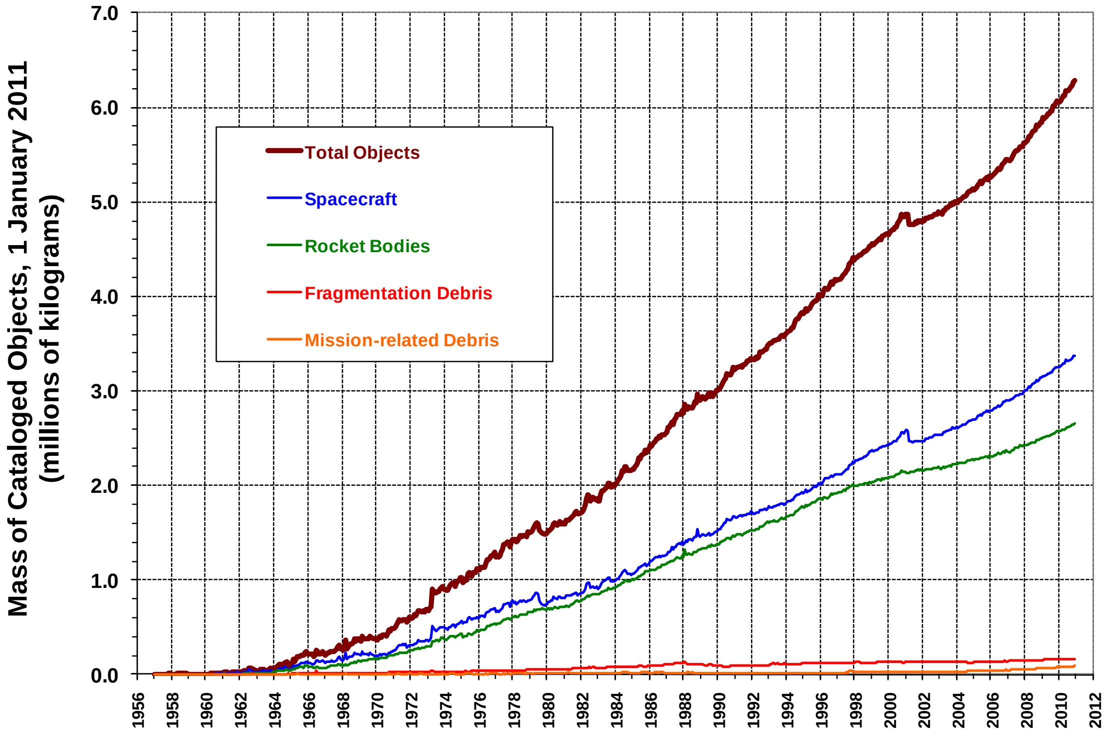

Figure 6. Growth of mass of man-made objects in Earth orbit.

5. Satellite Launches, Reentries, and Retirements

A total of 70 world-wide space launches reached Earth orbit during 2010. This was the second highest launch rate since the year 2000 but well below the annual launch rates of the 1970s and 1980s (Figure 7). Missions were launched by seven countries: China, France, India, Israel, Japan, the Russian Federation, and the United States. Four attempts to reach Earth orbit (two by India and one each by South Korea and the Russian Federation) were unsuccessful.

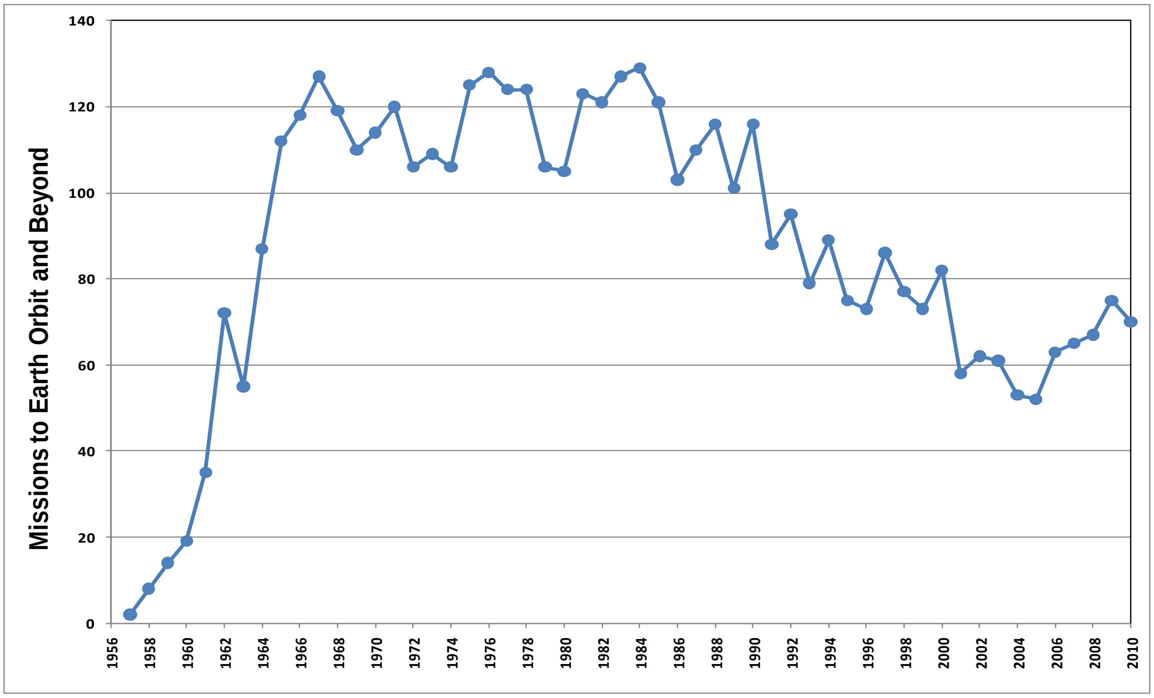

Figure 7. Annual number of space missions to Earth orbit or beyond.

The total amount of mass initially inserted into Earth orbit was more than 370 metric tonnes, not including the empty mass of U.S. Space Shuttles. However, more than 115 metric tonnes from these new launches fell back to Earth in either controlled or uncontrolled reentries.

Overall, nearly 400 cataloged objects reentered during 2010, and of these only 16 did so in a controlled fashion. Eleven of the controlled reentries were associated with logistical flights to the International Space Station. The total amount of reentering mass (excluding U.S. Space Shuttles) was approximately 150 metric tonnes, about half of which returned in an uncontrolled manner. Fortunately, no incidents of injury or significant property damage were reported.

After mission operations have been terminated, the IADC Space Debris Mitigation Guidelines specifically address the need to dispose of spacecraft and launch vehicle orbital stages in a responsible manner, especially when operating in the LEO and GEO regions. Vehicles reaching end of life in the LEO region have the options of (1) controlled reentries, (2) being left in disposal orbits which will lead to natural, uncontrolled reentries within 25 years, (3) direct retrieval, or (4) maneuvering to a disposal orbit above 2,000 km.

Some launch vehicle orbital stages perform substantial maneuvers after delivering the payloads to mid-LEO altitudes. For example, after a U.S. Delta 2 second stage deployed Italy's COSMO-SkyMed #4 spacecraft to an orbit of near 620 km on 6 November 2010, the stage restarted and placed itself into much lower orbit from which it fell back to Earth in only a month, instead of 20 years or more. Three other launch vehicle orbital stages (one from the U.S. and two from China) went even further by conducting controlled reentries.

In December 2004, France launched a constellation of four small satellites, called Essaim, into operational orbits near 660 km. After nearly doubling their design life of three years, the satellites reached their end of mission in late 2010. To passivate the satellites and to reduce their remaining time in orbit, all residual propellants were expended during a series of orbit-lowering maneuvers. At the end of these maneuvers, each Essaim satellite was left in an obit with a lifetime of less than 20 years, as follows:

Satellite	Final Mean Altitude	Estimated Remaining Lifetime
Essaim 11	632 km	17 years
Essaim 12	637 km	18 years
Essaim 23	642 km	19 years
Essaim 24	623 km	15 years

Similarly, NASA's ICESat spacecraft concluded 7 years of environmental monitoring operations in February 2010. From its normal orbit near 600 km, ICESat was maneuvered into a disposal orbit of 200 km by 580 km. Reentry occurred only six weeks later, rather than 15 years later had it been abandoned at its original altitude (Figure 8).

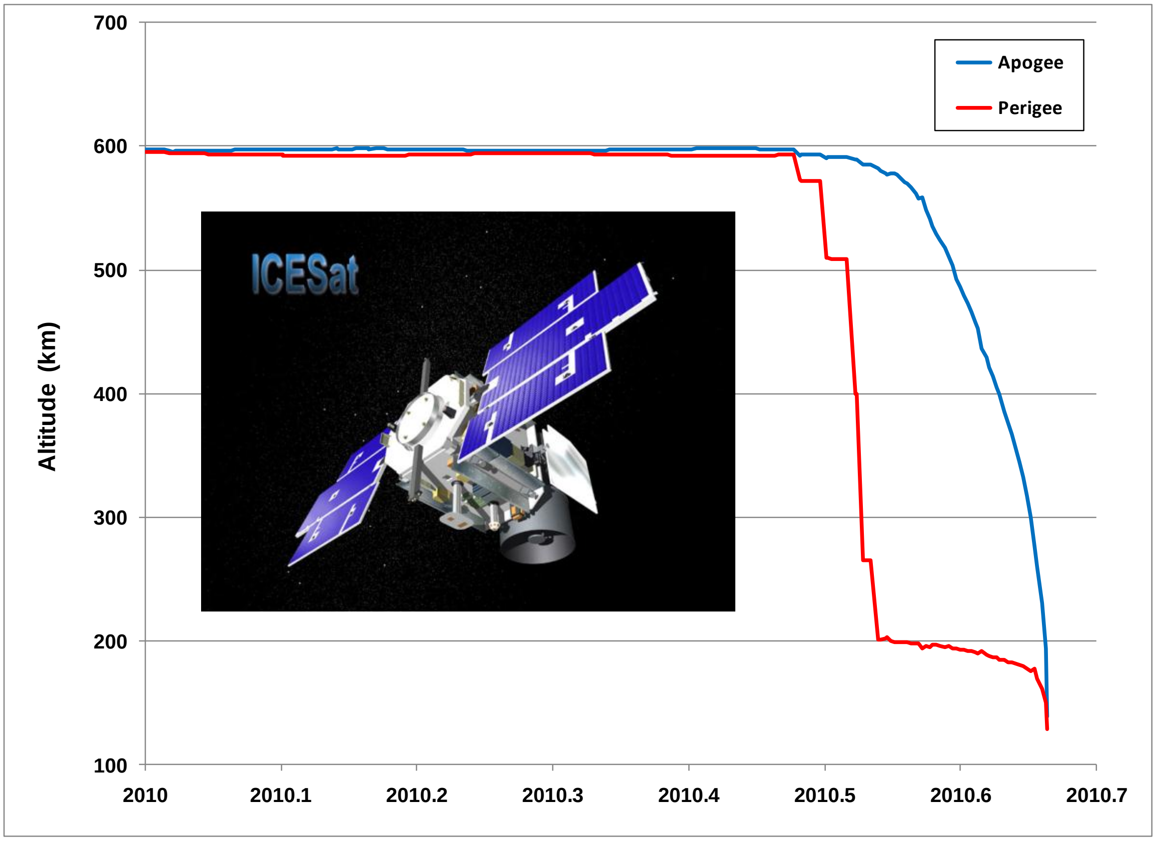

Figure 8. ICESat reentered the atmosphere only 6 weeks after its orbit-lowering maneuvers.

The satellites of the Globalstar communications network operate in the LEO region at an altitude of 1,415 km. From this height, moving into a storage orbit above 2,000 km is more attractive than trying to return to Earth within 25 years. During 2010, four Globalstar satellites reached their end of mission and began the long climb to their disposal orbits (Figure 9). The fourth spacecraft did not reach its goal until early 2011.

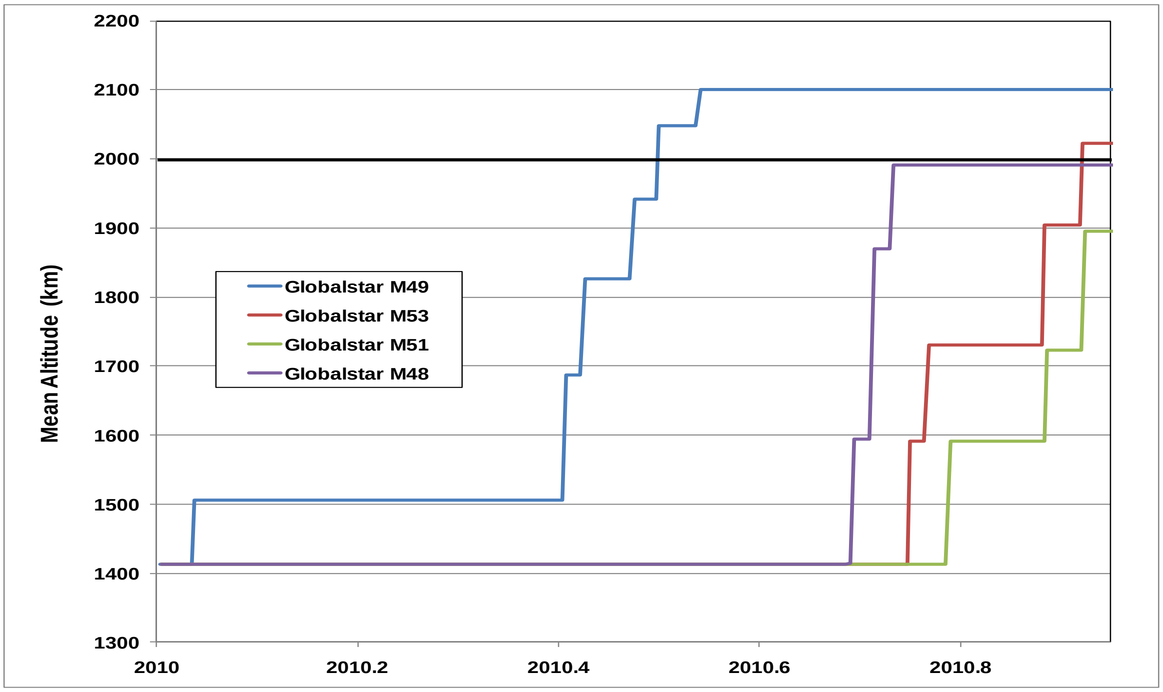

Figure 9. The disposal of four Globalstar satellites during 2010.

For geosynchronous satellites, reentry into the Earth's atmosphere is not a practical option. Recommendations by the IADC, the United Nations, and the International Telecommunications Union call for maneuvering non-operational geosynchronous satellites into disposal orbits, typically 300 km or more above the geosynchronous altitude. By the end of 2010, more than 300 geosynchronous satellites had been maneuvered into higher altitude disposal orbits.

Whereas 32 new geosynchronous satellites were launched in 2010, at least 18 older geosynchronous spacecraft reached their end of mission. All but three of these were maneuvered into higher altitude disposal orbits. However, the disposal orbits of four of the spacecraft were insufficiently high to be compliant with international recommendations, resulting in an overall compliance rate of 61%.

Table 1. GEO Satellites Retired in 2010

NAME	DISPOSAL MANEUVER	APOGEE (km above GEO)	PERIGEE (km above GEO)
BEIDOU G2	No		
BRAZILSAT B1	Yes	300	285
BSAT 1A	Yes	335	320
COSMOS 2440	No		
EUTELSAT W2	Yes	285	250
GALAXY 9	Yes	250	170
GSAT 3	Yes	295	275
INSAT 3B	Yes	210	145
INTELSAT 4 / PAS 4	Yes	985	825
INTELSAT 802	Yes	735	500
NAHUEL 1A	Yes	280	225
RASCOM QAF 1	Yes	365	320
SATCOM C3	Yes	1055	830
TDRS 1	Yes	525	345
THAICOM 1	Yes	310	305
THAICOM 2	Yes	215	200
TURKSAT 1C	No		
YAMAL 102	Yes	90	80

6. Satellite Fragmentations

Since 1961 more than 300 satellite fragmentation events have been identified. They can range from the creation of just one new piece of debris (collision involving the CERISE spacecraft in 1996) to the generation of thousands of debris large enough to be cataloged.

Satellite fragmentations are often categorized as breakups or anomalous events. The former is usually characterized by the destructive disassociation of an orbital spacecraft, rocket body or other structure, often with a wide range of ejecta velocities. The cause of a satellite breakup might be accidental or the result of intentional actions. In contrast, an anomalous event is the unplanned separation, usually at low velocity, of one or more detectable objects from a satellite which remains essentially intact.

Seven resident space objects were involved in satellite fragmentations during 2010: five breakups and two anomalous events. Table 2 summarizes these fragmentations, including the number of debris which had been cataloged by the end of the year and the number of debris which are believed to have been created. The non-functional UARS and NOAA 11 spacecraft experienced the two anomalous events. Fortunately, the vast majority of the generated debris from the 2010 fragmentations were short-lived.

For only two objects has the cause of the fragmentation been deduced. A Briz-M tank (2009-042C) broke-up shortly before reentry due to aerodynamic forces exerted on the object during its very low perigee passages. Debris produced under such circumstances normally fall back to Earth very rapidly and do not affect the long-term orbital environment. The event in 2010 was unusual in the large number of debris which were cataloged and the even larger number of debris which were detected. Any residual propellant in this tank might have contributed to the degree of the breakup. Fortunately, all these debris had fallen back to Earth within 6 months of the breakup.

The Briz-M stage which exploded (2008-011B) had suffered a serious propulsion failure shortly after launch on 14 March 2008, stranding it in a highly elliptical orbit with a large amount of unburned propellants. On 13 October 2010, more than two and one-half years after launch, the stage exploded. The residual propellants in the stage are believed to have been the root cause of the breakup. Due to the nature of the stage's orbit, only a minority of the originally detected debris were later officially cataloged.

Table 2. Satellite Fragmentations in 2010

Common Name	International Designator	Fragmentation Date	Perigee	Apogee	Cataloged / Assessed Debris	Cause
Yaogan 1	2006-015A	4 February	625 km	630 km	8 / 8	Unknown
Briz-M Tank	2009-042C	21 June	90 km	1490 km	89 / 400+	Aerodynamic
UARS	1991-063B	22 September	335 km	415 km	1 / 1	Unknown
Briz-M Stage	2008-011B	13 October	645 km	26565 km	9 / 30+	Propellants
CZ-3C Third Stage	2010-057B	1 November	160 km	35780 km	1 / 50+	Unknown
NOAA 11	1988-089A	24 November	835 km	850 km	2 / 2	Unknown
H-2A Debris	2007-005E	23 December	430 km	440 km	3 / 6	Unknown

+ symbol indicates more than the number to which it is attached

The International Space Station (ISS) is also sometimes the source of short-lived debris, either accidentally or deliberately. On average, five cataloged debris separate from the ISS annually. For example, in 2008 a tool bag was accidentally lost during a space walk, and in 2007 a large assembly of unneeded ammonia tanks was intentionally jettisoned. Over the course of three space walks during 2010, a total of six debris separated from ISS. All had fallen back to Earth by the end of the year.

Table 3 summarizes the ten worst satellite breakups in terms of total debris cataloged. Note that at least eight of the breakups were accidental.

Table 3. Top Ten Worst Satellite Breakups

Common Name	Cataloged Debris*	Debris in Orbit*	Year of Breakup	Altitude of Breakup	Cause of Breakup
Fengyun-1C	3037	2931	2007	850 km	Collision
Cosmos 2251	1347	1272	2009	790 km	Collision with Iridium 33
STEP 2 Rocket Body	710	60	1996	625 km	Accidental Explosion
Iridium 33	528	491	2009	790 km	Collision with Cosmos 2251
Cosmos 2421	509	8	2008	410 km	Unknown
SPOT 1 Rocket Body	492	33	1986	805 km	Accidental Explosion
OV 2-1 / LCS 2 Rocket Body	473	36	1965	740 km	Accidental Explosion
Nimbus 4 Rocket Body	374	248	1970	1075 km	Accidental Explosion
TES Rocket Body	370	115	2001	670 km	Accidental Explosion
CBERS 1 Rocket Body	343	187	2000	740 km	Accidental Explosion
Total	**8183**	**5381**			

* As of January 2011. These data are based upon observations by the U.S. SSN only.

7. Collision Avoidance

The large numbers of objects in orbit about the Earth, traveling in a myriad of directions at high speed, inevitably lead to frequent close approaches, called conjunctions. On rare occasions, collisions can occur. Through the end of 2010, four known accidental collisions between cataloged space objects had occurred. The first three such collisions (in 1991, 1996, and 2005), produced only very small amounts of new debris. However, the collision of the Cosmos 2251 and the Iridium 33 spacecraft in 2009 generated more than 2,000 new large debris spread across nearly the entire LEO region. Following that event, efforts to avoid future collisions were expanded.

On average, 10-30 close approach warning messages are now transmitted daily by the U.S. Joint Space Operations Center to satellite operators around the world. During 2010 an expanded message format, called the Conjunction Summary Message (CSM), was introduced. The CSM contains detailed information on both objects involved in the conjunction, including detailed uncertainty data which can be used to calculate the probability of collision.

In the LEO region, a calculated miss distance of less than 1 km can lead to a collision avoidance maneuver; in the GEO region a miss distance of less than 5 km might also warrant a collision avoidance maneuver. As a direct result of these warnings, more than 100 collision avoidance maneuvers were executed in 2010 alone.

During the year, the ISS conducted its 11th collision avoidance maneuver since 1999, an average of one per year. In this case the object which posed a threat of collision was the fragment unexpectedly released by the dormant NASA UARS spacecraft in late September (see section 6 above). About 4 weeks after its release, the debris was heading toward a very close approach with the ISS, resulting in a probability of collision in excess of 1 in 10,000, the maximum allowable risk level. Following established flight rules, U.S. and Russian specialists worked together to prepare and to execute a collision avoidance maneuver on 26 October, a little more than 2 hours before the close approach. The Progress M-07M logistics vehicle, which was then attached to ISS, performed a small (~ 0.4 m/s), posigrade maneuver that sufficiently increased the miss distance between the two.

8. Orbital Debris Removal

The growing numbers and congestion of objects in low Earth orbit is apparent in Figure 5. Since 2006, studies by researchers across the globe have indicated that portions of low Earth orbit have already reached the point where future accidental collisions will produce new debris faster than the debris will fall naturally from orbit, leading to an ever increasing debris population, the well-known Kessler Syndrome (Figure 10). Although concepts for the removal of derelict spacecraft and launch vehicle orbital stages have been proposed for decades, not until recently has the international community as a whole begun to give serious thought to how such operations might be accomplished.

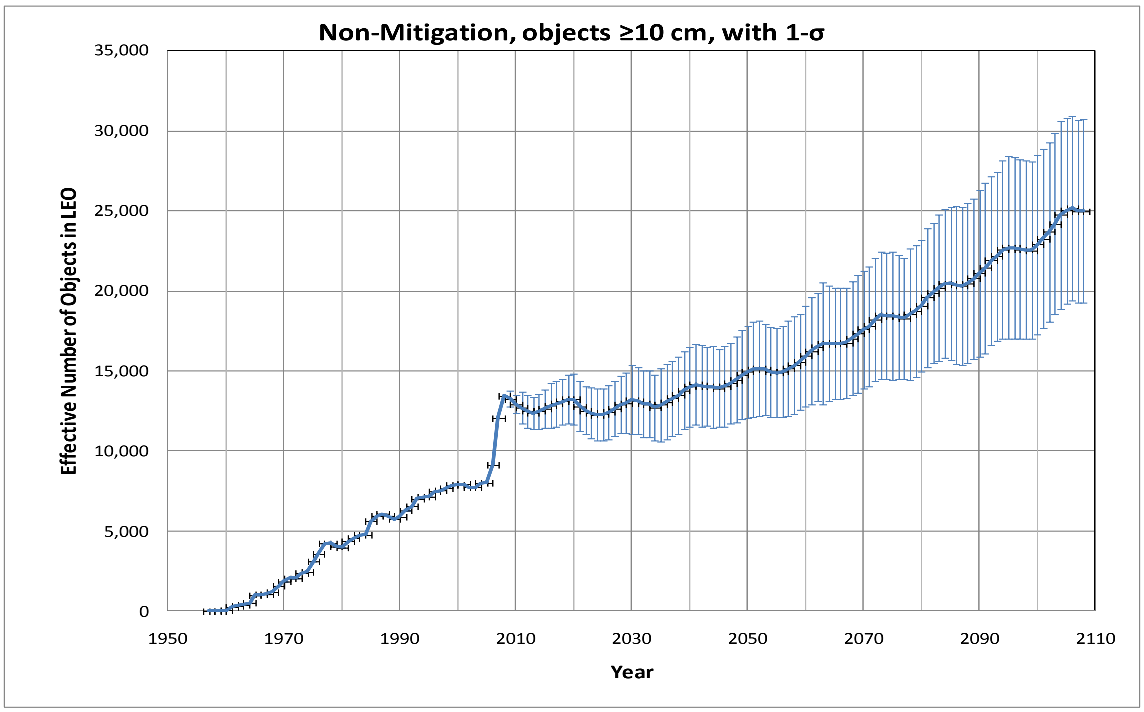

Figure 10. Projected growth of satellite population in low Earth orbit with annual space launches at recent rates and without active debris removal (Source: NASA).

In late 2006 the International Academy of Astronautics initiated a comprehensive survey of techniques, which offered the potential of removing either small or large debris from either low or high altitude orbits. In December 2009, the first International Conference on Orbital Debris Removal was held near Washington, DC, in the United States. The momentum of this conference carried over into 2010 with the 1st European Workshop on Active Debris Removal, held 22 June in Paris, France. Hosted by the French space agency CNES, the one-day meeting was attended by more than 120 specialists from 10 European countries, as well as from Canada, Japan, and the United States.

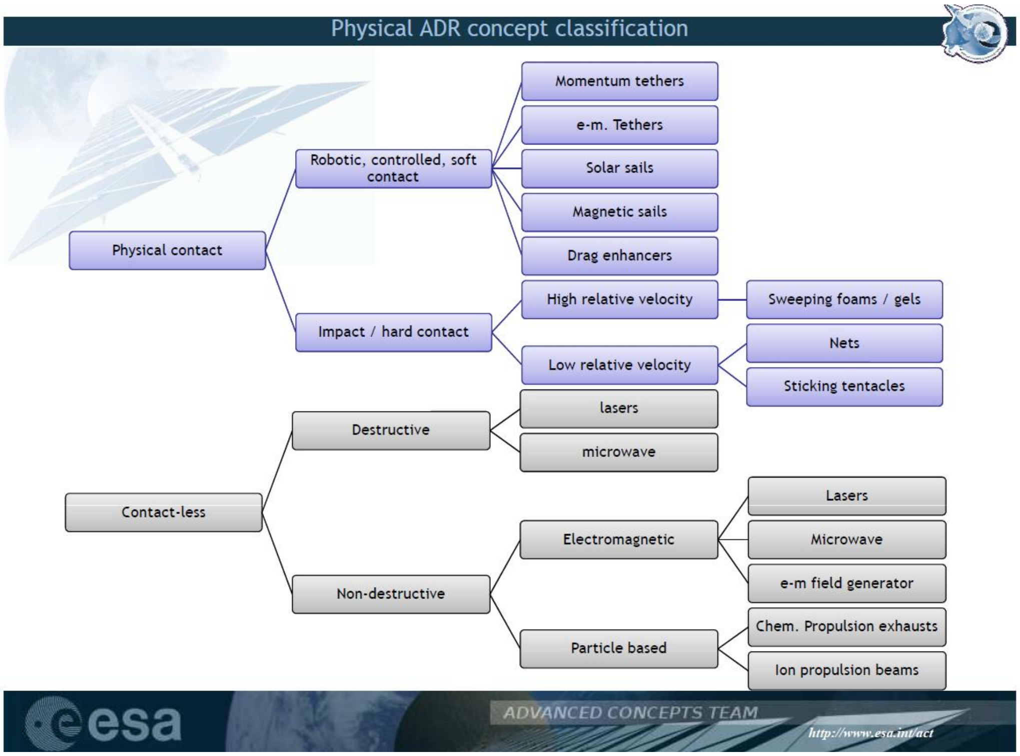

Figure 11. Hierarchy of the principal concepts for active debris removal.

Seventeen technical presentations were delivered at the highly successful meeting. A team from ESA summarized the hierarchy of the principal active debris removal (ADR) techniques (Figure 11). All agreed that in addition to the technical challenges of debris removal, many economic and legal hurdles also existed.

Just a week after the workshop in Paris, U.S. President Barack Obama issued a new National Space Policy. All U.S. national space policies since 1988 had explicitly called for the mitigation of orbital debris, but for the first time, the 2010 policy called upon the NASA Administrator and the U.S. Secretary of Defense to pursue research and development of technologies and techniques to remove orbital debris.

9. Major Meetings Addressing Space Debris

Many scientific and technical conferences around the world devoted special sessions to the topic of orbital debris during 2010. Hundreds of papers were delivered covering the full spectrum of space debris topics, including measurements, modeling, mitigation, protection, and removal.

Some noteworthy meetings included:

- 33rd Guidance and Control Conference, American Astronautical Society, Breckinridge, Colorado, USA, 6-10 February. During a special session on space debris, Don Kessler delivered a paper on the origin and meaning of the Kessler Syndrome.

- 47th Session of the Scientific and Technical Subcommittee, Committee on the Peaceful Uses of Outer Space, United Nations, Vienna, Austria, 8-19 February. See Section 3 for details of this session.

- 28th Meeting of the Inter-Agency Space Debris Coordination Committee, Thiruvananthapuram, India, 9-12 March See Section 2 for details of this meeting.

- 11th Hypervelocity Impact Symposium, Freiburg, Germany, 11-15 April.

- International Science and Technology Center Workshop on Space Debris Mitigation, Moscow, Russian Federation, 26-27 April. A total of 24 techni-al papers were presented.

- 4th International Association for the Advancement of Space Safety, Huntsville, Alabama, USA, 19-21 May. Both on-orbit and reentry risks were addressed by more than 200 participants from government and industry.

- 1st European Workshop on Active Debris Removal, Paris, France, 22 June. See Section 8 for details of this workshop.

- 38th COSPAR Scientific Assembly, Bremen, Germany, 18-25 July. The theme for the Panel on Potentially Environmentally Detrimental Activities in Space (PEDAS) at this biannual event was “Space Debris – A Global Challenge”. A total of 27 presentations were made.

- 11th Advanced Maui Optical and Space Surveillance Technology (AMOS) Conference, Maui, Hawaii, USA, 14-17 September. A special session on space debris and other papers emphasized advances in data collection and processing.

- 61st International Astronautical Congress, Prague, Czech Republic, 27 September – 1 October. This is the preeminent meeting each year for space debris specialists. During five half-day sessions a total of 44 papers were presented on measurements; modeling and risk analysis; hypervelocity impacts and protection; mitigation, standards, removal, and legal issues; and space situational awareness.

Appendix: Satellite Breakups, 2000-2010

SATELLITE NAME	INTERNATIONAL DESIGNATOR	SATELLITE OWNER	LAUNCH DATE	BREAKUP DATE	APOGEE (KM)	PERIGEE (KM)	INCLINATION (DEG)	ASSESSED CAUSE
CBERS 1/SACI 1 R/B	1999-057C	CHINA	14-Oct-99	11-Mar-00	745	725	98.5	PROPULSION
GORIZONT 29 ULLAGE MOTOR	1993-072E	RF	18-Nov-93	6-Sep-00	11215	140	46.7	PROPULSION
COSMOS 2316-18 ULLAGE MOTOR	1995-037K	RF	24-Jul-95	21-Nov-00	18085	150	64.4	PROPULSION
INTELSAT 515 R/B	1989-006B	FRANCE	27-Jan-89	1-Jan-01	35720	510	8.4	PROPULSION
COSMOS 2139-41 ULLAGE MOTOR	1991-025G	RF	4-Apr-91	16-Jun-01	18960	300	64.5	PROPULSION
GORIZONT 27 ULLAGE MOTOR	1992-082F	RF	27-Nov-92	14-Jul-01	5340	145	46.5	PROPULSION
COSMOS 2367	1999-072A	RF	26-Dec-99	21-Nov-01	415	405	65.0	UNKNOWN
TES R/B	2001-049D	INDIA	22-Oct-01	19-Dec-01	675	550	97.9	PROPULSION
INTELSAT 601 R/B	1991-075B	FRANCE	29-Oct-91	24-Dec-01	28505	230	7.2	PROPULSION
INSAT 2A/EUTELSAT 2F4 R/B	1992-041C	FRANCE	9-Jul-92	Feb-02	26550	250	7.0	PROPULSION
INTELSAT 513 R/B	1988-040B	FRANCE	17-May-88	9-Jul-02	35445	535	7.0	PROPULSION
COSMOS 2109-11 ULLAGE MOTOR	1990-110G	RF	8-Dec-90	21-Feb-03	18805	645	65.4	PROPULSION
COSMOS 1883-85 ULLAGE MOTOR	1987-079H	RF	16-Sep-87	23-Apr-03	18540	755	65.2	PROPULSION
COSMOS 1970-72 ULLAGE MOTOR	1988-085F	RF	16-Sep-88	4-Aug-03	18515	720	65.3	PROPULSION
COSMOS 1987-89 ULLAGE MOTOR	1989-001H	RF	10-Jan-89	13-Nov-03	18740	710	65.4	PROPULSION
COSMOS 2399	2003-035A	RF	12-Aug-03	9-Dec-03	250	175	64.9	DELIBERATE
COSMOS 2383	2001-057A	RF	21-Dec-01	28-Feb-04	400	220	65.0	UNKNOWN
USA 73 (DMSP 5D2 F11)	1991-082A	USA	28-Nov-91	15-Apr-04	850	830	98.7	UNKNOWN
COSMOS 2204-06 ULLAGE MOTOR	1992-047G	RF	30-Jul-92	10-Jul-04	18820	415	64.9	PROPULSION
COSMOS 2392 ULLAGE MOTOR	2002-037F	RF	25-Jul-02	29-Oct-04	840	235	63.6	PROPULSION
DMSP 5B F5 R/B	1974-015B	USA	16-Mar-74	17-Jan-05	885	775	99.1	COLLISION
COSMOS 2224 ULLAGE MOTOR	1992-088F	RF	17-Dec-92	~22-Apr-05	21140	200	46.7	PROPULSION
COSMOS 2392 ULLAGE MOTOR	2002-037E	RF	25-Jul-02	1-Jun-05	835	255	63.7	PROPULSION
COSMOS 1703 R/B	1985-108B	RF	22-Nov-85	4-May-06	640	610	82.5	PROPULSION
COSMOS 2022-24 ULLAGE MOTOR	1989-039G	RF	31-May-89	10-Jun-06	18410	655	65.1	PROPULSION

SATELLITE NAME	INTERNATIONAL DESIGNATOR	SATELLITE OWNER	LAUNCH DATE	BREAKUP DATE	APOGEE (KM)	PERIGEE (KM)	INCLINATION (DEG)	ASSESSED CAUSE
ALOS-1 R/B	2006-002B	JAPAN	24-Jan-06	8-Aug-06	700	550	98.2	UNKNOWN
COSMOS 2371 ULLAGE MOTOR	2000-036E	RF	4-Jul-00	~1-Sep-06	21320	220	46.9	PROPULSION
DMSP 5D-3 F17 R/B	2006-050B	USA	4-Nov-06	4-Nov-06	865	830	98.8	UNKNOWN
COSMOS 2423	2006-039A	RF	14-Sep-06	17-Nov-06	285	200	64.9	DELIBERATE
COBE R/B	1989-089B	USA	18-Nov-89	3-Dec-06	790	685	97.1	UNKNOWN
IGS 3A R/B	2006-037B	JAPAN	11-Sep-06	28-Dec-06	490	430	97.2	UNKNOWN
FENGYUN 1C	1999-025A	CHINA	10-May-99	11-Jan-07	865	845	98.6	COLLISION
BEIDOU 1D R/B	2007-003B	CHINA	2-Feb-07	2-Feb-07	41900	235	25.0	UNKNOWN
KUPON ULLAGE MOTOR	1997-070F	RF	12-Nov-97	14-Feb-07	14160	260	46.6	PROPULSION
CBERS 1	1999-057A	CHINA/BRAZIL	14-Oct-99	18-Feb-07	780	770	98.2	UNKNOWN
ARABSAT 4 BRIZ-M R/B	2006-006B	RF	28-Feb-06	19-Feb-07	14705	495	51.5	PROPULSION
USA 197 R/B	2007-054B	USA	11-Nov-07	11-Nov-07	1575	220	29.0	UNKNOWN
USA 193	2006-057A	USA	14-Dec-06	21-Feb-08	255	245	58.5	COLLISION
COSMOS 2421	2006-026A	RF	25-Jun-06	14-Mar-08	420	400	65.0	UNKNOWN
COSMOS 1818	1987-011A	RF	1-Feb-87	4-Jul-08	800	775	65.0	UNKNOWN
IRIDIUM 33	1997-051C	USA	14-Sep-97	10-Feb-09	780	775	86.4	COLLISION WITH COSMOS 2251
COSMOS 2251	1993-036A	RF	16-Jun-93	10-Feb-09	800	775	74.0	COLLISION WITH IRIDIUM 33
COSMOS 2139-41 ULLAGE MOTOR	1991-025F	RF	4-Apr-91	8-Mar-09	18535	465	64.9	PROPULSION
COSMOS 192	1967-116A	RF	23-Nov-67	30-Aug-09	715	710	74.0	UNKNOWN
YAOGAN 1	2006-015A	CHINA	26-Apr-06	4-Feb-10	630	625	97.9	UNKNOWN
AMC 14 BRIZ-M R/B	2008-011B	RF	14-Mar-08	13-Oct-10	26565	645	48.9	PROPULSION
BEIDOU G4 R/B	2010-057B	CHINA	1-Nov-10	1-Nov-10	35780	160	20.5	UNKNOWN
IGS 4A/4B R/B DEBRIS	2007-005E	JAPAN	24-Feb-07	23-Dec-10	440	430	97.3	UNKNOWN

1. Breakup date and orbit are for the first event only if multiple events occurred.
2. Does not include satellite anomalous events or fragmentations caused by aerodynamic forces prior to reentry.
3. Russian Federation (RF) ownership includes space objects launched by the former USSR.
4. R/B = rocket body.