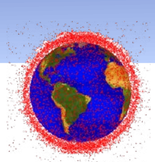
National Aeronautics and Space Administration

Orbital Debris Quarterly News

Volume 20, Issues 1 & 2
April 2016

Inside...



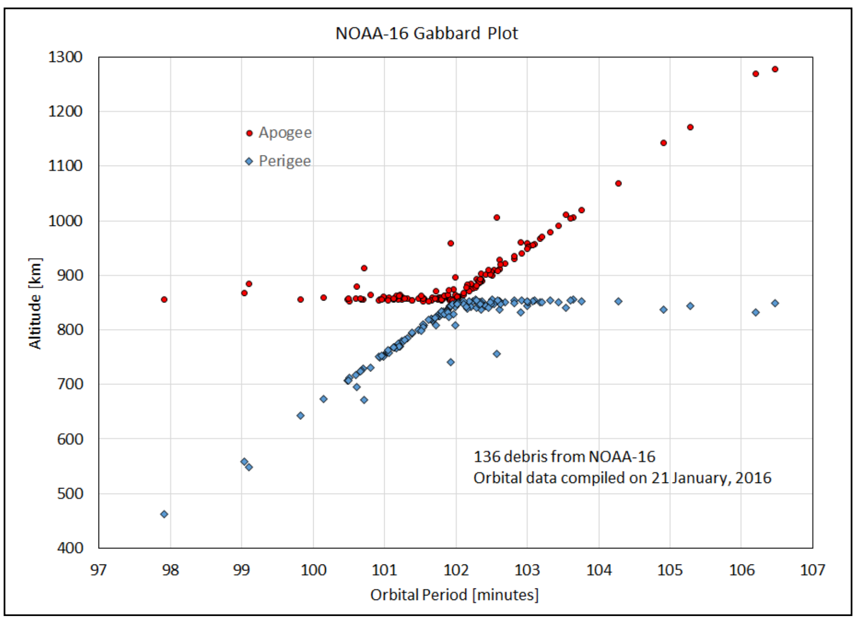
A publication of the NASA Orbital Debris Program Office

Recent NOAA-16 Satellite Breakup

In late November 2015, the decommissioned U.S. weather satellite NOAA-16 (International Designator 2000-055A, U.S. Strategic Command [USSTRATCOM] Space Surveillance Network [SSN] catalog number 26536) experienced a breakup event, resulting in a substantial debris cloud. The 1475 kg dry mass satellite was launched 21 September 2000, as part of the Polar Operational Environmental Satellite (POES) series of U.S. weather satellites. It was placed into a 98.9° sun-synchronous orbit, where it operated until replaced and transferred to backup status in 2005. An anomaly abruptly ended communication with the satellite on 6 June 2014, and it was decommissioned on 9 June 2014.

The breakup occurred at approximately 0950 GMT on 25 November 2015. At the time, the spacecraft was in an 841 x 857 km orbit. The Joint Space Operations Center (JSpOC) has now catalogued 136 objects, making it a rather large breakup. The figure below is a composite Gabbard plot, which shows a classic pattern. As with previous NOAA breakups, much of the debris will remain in orbit for many decades in what is already a very crowded altitude.

There is no indication that the breakup was anything other than an explosion, possibly due to a battery failure. ♦



Dispersion of debris from the NOAA-16 breakup of 136 tracked debris (including the parent body). The Gabbard plot shows the classic "X" pattern indicative of an explosive breakup from a circular orbit.

Note: All requests for information on the recent Astro H (Hitomi) event are being directed to JAXA, the Japan Aerospace eXploration Agency.

A Debris History of the NOAA-Series Spacecraft

The U.S. National Oceanographic and Atmospheric Administration (NOAA) eponymous spacecraft have provided global weather data as the low Earth orbit (LEO) component of the integrated weather data service. As a follow-on to the first two generations of Television InfraRed Observation Satellites (TIROS), the three generations of NOAA spacecraft have provided regular weather data since the launch of NOAA 1 in 1970. NOAA's third generation spacecraft, NOAA 1-5, were succeeded in service by the more sophisticated fourth and fifth generations built around the TIROS-N and Advanced TIROS-N (ATN) busses. Whereas the third generation vehicles resided in sun-synchronous orbits around 1500 km altitude, later vehicles were launched into lower-inclination orbits around 833 and 870 km altitude. The table provides the flight log for these spacecraft.

International Designator	SSN #	Common Name	Launch Date	NOAA Spacecraft Generation	Bus Type	ISS Solid Rocket Motor
1970-106	4793	NOAA 1 (ITOS-A)	DEC 70	3	TIROS-M	x
1972-082	6235	NOAA 2 (ITOS-D)	OCT 72	3	TIROS-M	x
1973-086	6920	NOAA 3 (ITOS F)	NOV 73	3	TIROS-M	x
1974-089	7529	NOAA 4 (ITOS G)	NOV 74	3	TIROS-M	x
1976-077	9057	NOAA 5 (ITOS H)	JUL 76	3	TIROS-M	x
1979-057	11416	NOAA 6 (NOAA A)	JUN 79	4	TIROS-N	STAR-37S
1980-043	11819	NOAA B	MAY 80	4	TIROS-N	STAR-37S
1981-059	12553	NOAA 7 (NOAA C)	JUN 81	4	TIROS-N	STAR-37S
1983-022	13923	NOAA 8 (NOAA E)	MAR 83	4	ATN	STAR-37S
1984-123	15427	NOAA 9 (NOAA F)	DEC 84	4	ATN	STAR-37S
1986-073	16969	NOAA 10 (NOAA G)	SEP 86	4	ATN	STAR-37S
1988-089	19531	NOAA 11 (NOAA H)	SEP 88	4	ATN	STAR-37S
1991-032	21263	NOAA 12 (NOAA D)	MAY 91	4	TIROS-N	STAR-37S
1993-050	22739	NOAA 13 (NOAA I)	AUG 93	4	ATN	STAR-37S
1994-089	23455	NOAA 14 (NOAA J)	DEC 94	4	ATN	STAR-37S
1998-030	25338	NOAA 15 (NOAA K)	MAY 98	5	ATN	STAR-37XFP
2000-055	26536	NOAA 16 (NOAA L)	SEP 00	5	ATN	STAR-37XFP
2002-032	27453	NOAA 17 (NOAA M)	JUN 02	5	ATN	STAR-37XFP
2005-018	28654	NOAA 18 (NOAA N)	MAY 05	5	ATN	x
2009-005	33591	NOAA 19 (NOAA N')	FEB 09	5	ATN	x

TIROS: Television IR Observation Satellite
ITOS: Improved TIROS Operational System
ATN: Advanced TIROS-N
ISS: Integrated Stage System

The NASA Orbital Debris Program Office (ODPO) recognizes several types of debris-generating events. These include standard breakups and anomalous events. Breakups are the usually destructive disassociation of an orbital object, typically characterized by large separation velocities for the resulting fragments. Anomalous events are the unplanned separation of one or more objects from an essentially intact body, usually at a low velocity; these events may reflect the effects of the space environment on the parent object.

NOAA 6, 7, 8, 10, 11, 12, and 14 have experienced anomalous events over their operational and post-mission lifetimes. NOAA 8 also experienced a breakup event on 30 December 1985, believed to have been caused by a battery explosion. None of these events, however, were as dramatic as the November 2015 explosion of NOAA 16. ♦

Fragmentation of *Fregat* Upper Stage Debris

A debris object associated with the launch of Russia's *Spektr-R* radio astronomy satellite fragmented on 3-4 August 2015. The object (International Designator 2011-037B, U.S. Strategic Command [USSTRATCOM] Space Surveillance Network [SSN] catalog number 37756) is described in the SSN catalog as SL-23 DEB, one of five debris objects cataloged with this launch. Four of the debris objects, piece tags C, E, F, and G, are likely the launch vehicle second stage's solid rocket motor separation caps, and are typically observed with launches of the SL-23/*Zenit*-3SLBF variant launch vehicle. Circumstances of this mission's launch profile imply that the upper stage, a *Fregat-SB*, may reside in an elliptical deep space orbit similar to the payload and is apparently uncataloged. The fragmented object is most likely the separable fuel/oxidizer tank discarded by the *Fregat* upper stage between its early and later burns.

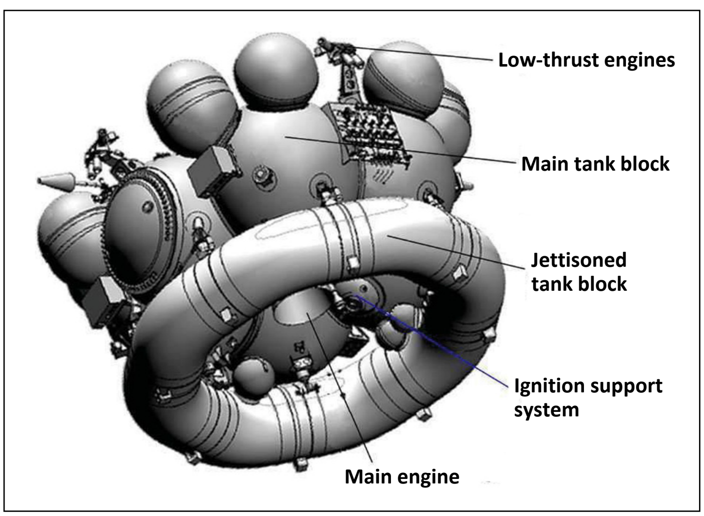


Figure 1. A perspective view of the Fregat-SB upper stage. The suffix "SB" indicates the Fregat sbrasyvaemye baki *or "jettisonable tanks" variant. Source: Ref. 1.*

The Lavochkin *Fregat-SB* is based on the *Fregat* upper stage but adds a toroidal hypergolic fuel/oxidizer tank, the *sbrasyvaemye blok bakov* (SBB) and is variously referred to as the jettisoned tanks unit (JTU) or block (JTB), as shown in Fig. 1. The tank accommodates two fuel and two oxidizer tanks, isolated by spherical bulkheads; unfortunately, at this writing, it is not clear if these are common bulkheads, as employed in the design of the similar *Briz-M* upper stage's auxiliary propellant tank. The JTU uses high pressure helium bottles to pressurize the tanks and devices to sever attachment and cabling to the *Fregat* upper stage body, perhaps indicative of failure modes.

Figure 2 provides another view of the

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Fragmentation

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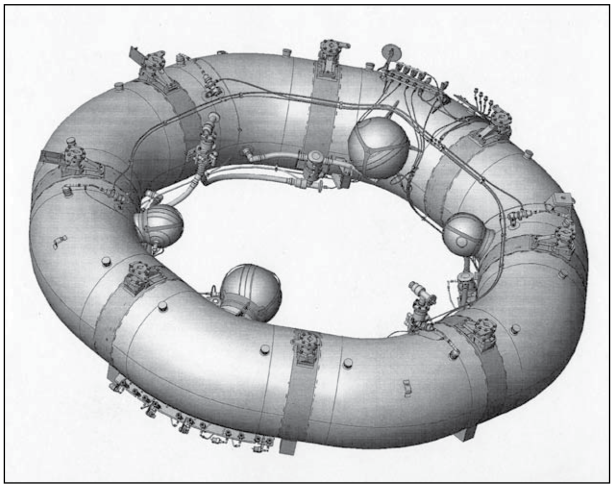

Figure 2. The separated JTU. This unit, used by the Phobos-Grunt spacecraft, is assumed identical to the standard JTU. The actual JTU was likely covered with insulation blankets. Source: Ref. 2.

separated tank, revealing the *He* pressure spheres and stage equipment and systems more clearly.

The JTU structure is welded aluminum alloy *AMg6* [2] while bulkheads are constructed of *AD1* and *AMg6* alloys. Overall dimensions of the toroid are 0.821-m height (tank diameter) and an overall diameter of 3.440 m. Dry mass is quoted as 340-375 kg [3, 4, 5]. The fuel is unsymmetrical dimethylhydrazine (*UDMH*) while the oxidizer is nitrogen tetroxide (N_2O_4). These hypergolic components can explode on contact, indicating a possible failure mode.

The event, of unknown cause, produced a total of 24 debris. As of 3 April 2016 none had entered the SSN catalog. Three *Fregat-SB* upper stages have been launched, and a fourth, modified, provided the basis of the *Phobos-Grunt* propulsion module/cruise stage.

References

1. Land Launch User's Guide/Rev. B, Space International Services, (1 October 2014).

2. Anon. "Propulsion System for Delivering "Phobos-Grunt" Spacecraft on Phobos Surface", p. 186. Accessed from ftp://naif.jpl.nasa.gov February 2016.

3. Zenit-3SLBV ILV/Zenit-M SRC User's Guide, Center for Ground Space Infrastructure Operations (TsENKI), (June 2011).

4. Asyuchkin, V.A. and S.V. Ishin. "Multipurpose Upper Stage "Fregat-SB" with Enhanced Power Capacity", Solar System Research **46**, no. 7, pp. 519-22 (December 2012). Russian-language manuscript originally published in *Vestnik,* no. 1, pp. 9-12, (2011).

5. Ilin, A. "Fobos-Grunt", *Novosti Kosmonavtiki*, vol. **22**, no. 1, p. 35, (January 2012). ♦

Briz-M Core Stage Fragments Near Geosynchronous Orbit

The *Briz-M* upper stage associated with the launch of Russia's Cosmos 2513 satellite fragmented on 16 January 2016 at approximately 03:50 GMT. The object (International Designator 2015-075B, U.S. Strategic Command [USSTRATCOM] Space Surveillance Network [SSN] catalog number 41122) consists of the core body of the *Briz-M* upper stage, the separable Auxiliary Propellant Tank having been jettisoned in the elliptical transfer orbit. At the time of the event the object had been on-orbit about 33 days and was at an altitude of approximately 34866 km over a subsatellite point of 0.17°S, 223°E.

The general layout is depicted in lateral cross-section by Fig. 1. The cylindrical core is 2.49 m in diameter and 2.654 m in overall length, excluding the payload adapter, and is estimated to have a dry mass of 1220 kg.

Up to 10 pieces have been observed. However, as of 3 April 2016, no debris had officially entered the SSN catalog. Debris in deep space orbits are difficult for the SSN to track and catalog. Potentially there could be hundreds of additional fragments.

As new GEO fragmentations present a rare opportunity, the Orbital Debris Program

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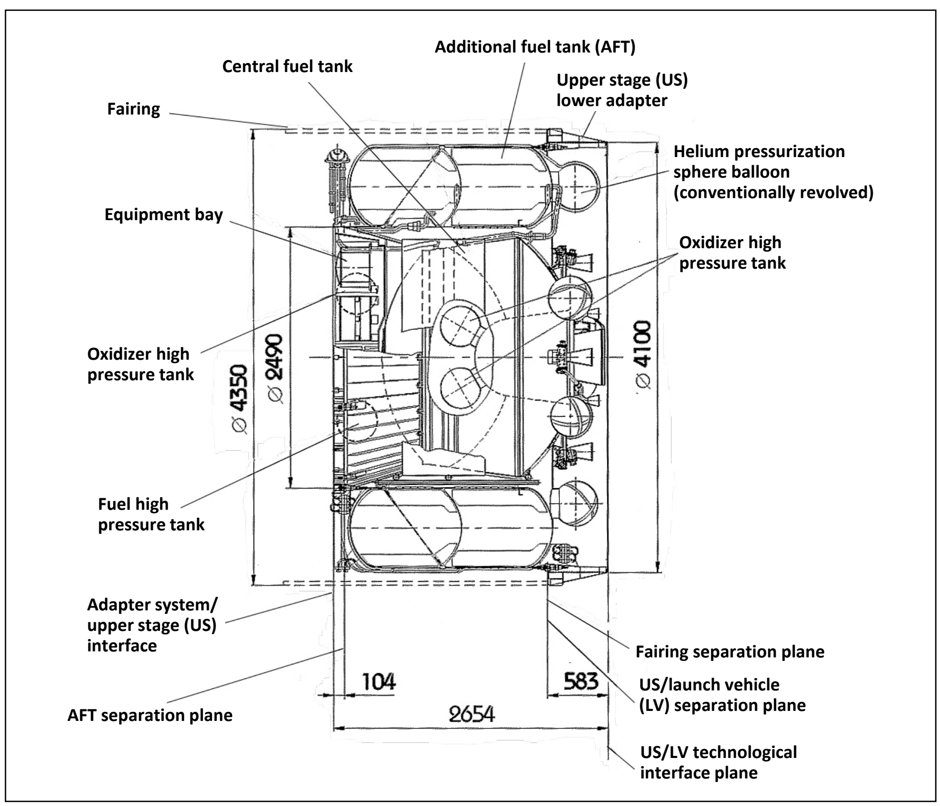

Figure 1. A lateral cross section of the Briz-M stage, including the jettisonable Auxiliary Propellant Tank. Source: Ref. 1. All dimensions are in millimeters.

Briz-M Explosion

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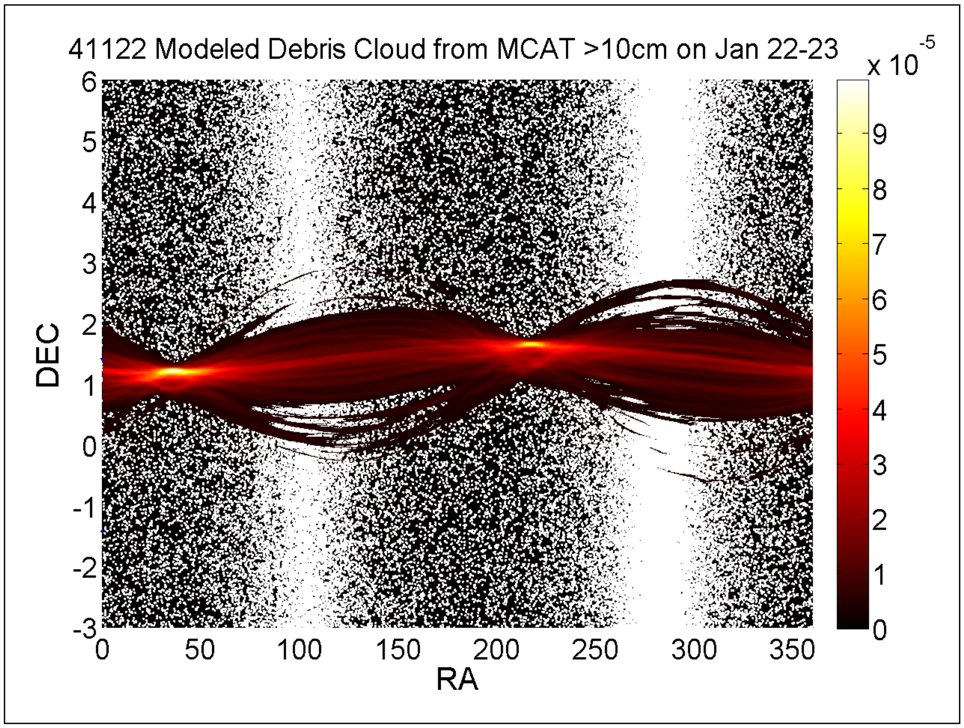

A plot of the density of debris produced by the NASA modeled debris cloud against the celestial sphere as the cloud orbits during 2 days during January 2016. Yellow areas represent the regions of greatest spatial density, the so-called "pinch point" and its antipodal "pinch line." The white dots are the background stars with the two vertical bands being the galactic plane.

Office staff mobilized its assets in an attempt to observe the new debris cloud at an early stage of its evolution. NASA's Standard Satellite Breakup Model was used to create a model debris cloud of fragments ≥ 10 cm in characteristic length. The resulting cloud was then propagated forward in time and projected against the celestial sphere, as shown in Fig. 2. The NASA/Air Force Research Lab Meter-Class Autonomous Telescope (MCAT) has successfully observed objects in the high density areas predicted by the model. A confirmation that the observed objects are indeed correlated with this debris cloud, either by statistical inference or the propagation of SSN cataloged debris (when available), remains to be done.

Reference

1. International Launch Services. Proton Launch System Mission Planner's Guide/Rev. 7 (July 2009): A-6. ♦

Briz-M Core Stage Fragments in Elliptical Orbit

The Briz-M upper stage associated with the launch of Canada's Nimiq 6 communications satellite fragmented on 23 December 2015 at approximately 16:00 GMT. The object (International Designator 2012-026B, U.S. Strategic Command [USSTRATCOM] Space Surveillance Network [SSN] catalog number 38343) consists of the core body of the Briz-M upper stage, the separable Auxiliary Propellant Tank having been jettisoned earlier in the launch sequence. At the time of the event the object had been on-orbit 3.6 years and was in a 12° inclination, 34592 by 10408 km orbit. Based on the nominal breakup time, the event occurred at an altitude of approximately 24310 km over a subsatellite point of 11.9°N, 178°E.

Readers are referred to this issue's article "Briz-M Core Stage Fragments Near Geosynchronous Orbit" for the general layout and physical characteristics of the stage.

As of 3 April 2016, eight debris had officially entered the SSN catalog in addition to the parent object. All debris are in orbits similar to the parent object, with a maximum change in period of 13.9 minutes and change in inclination of 0.09°. Debris in deep space orbits are difficult for the SSN to track and catalog. Hundreds of additional fragments could be on-orbit. ♦

Russian SOZ Unit Breaks Up in March

A *Sistema Obespecheniya Zapuska* (SOZ) ullage motor from a Proton Block DM fourth stage broke up at approximately 12:12 GMT on 26 March 2016. These motors have a long history of fragmentations. This event is the 44th breakup of this class of object over its history and the first since 2014 (ODQN, vol. 18, issue 4, October 2014, pp. 1-2). Ullage motors, used to settle propellants prior to an engine restart, are routinely ejected after the Block DM stage ignites for the final time; they also provide three-axis control to the Block DM during coast. This SOZ unit (International Designator 2008-067G, SSN# 33472) is associated with the launch of the Cosmos 2447-2449, members of the Russian global positioning navigation system, GLONASS, constellation.

The unit, also commonly referred to as an SL-12 Auxiliary motor, fragmented into at least 21 pieces. The motor was in a highly elliptical 18840 x 682 km orbit at an inclination of 65.36° at the time of the breakup. Given difficulties in tracking objects in elliptical and deep space orbits, there could be many more fragments on orbit. ♦

The 2016 UN COPUOS STSC Meeting

The United Nations (UN) Committee on the Peaceful Uses of Outer Space (COPUOS) Scientific and Technical Subcommittee (STSC) held its annual meeting (the 53rd session) at the Vienna International Center during February 15-26, 2016. Seventy of the 83 Member States were represented at the 53rd session, and 38 other nations or organizations attended the session as observers. Among other topics, the session's agenda items included Space Debris, Space Weather, Global Navigation Satellite Systems, Near-Earth Objects, and the Long-Term Sustainability of Outer Space Activities (LTS).

Many Member States expressed concern at the challenges presented by space debris. The U.S. statement on Space Debris emphasized the importance of the UN Space Debris Mitigation Guidelines and called on all space-faring nations and organizations to implement these UN Guidelines to limit the generation of space debris. Several technical presentations were provided during the session, including "United States Space Debris Environment, Operations, and Research Updates;" "The IADC: An Overview of the IADC Annual Activities;" "OneWeb;" "Overview of Space Debris-Related Activities in France in 2015;" "Recent Developments of the International Scientific Optical Network (ISON) Project;" "China Practices on Satellites Post Mission Disposals Toward Space Long Term Sustainability;" and "Space Debris Mitigation Activities at ESA in 2015." All presentations are available at the UN COPUOS website: http://www.unoosa.org/oosa/en/ourwork/copuos/stsc/technical-presentations.html#stsc2016.

Established in 2010, the LTS Working Group (WG) has made significant progress developing a consensus report with voluntary best-practice guidelines that, if endorsed, could be implemented by States to help ensure the safe and sustainable use of outer space for peaceful purposes, for the benefit of all countries. The U.S. and many other COPUOS Member States have played an active role in the development of the LTS guidelines since that time. The LTS WG held 8 meetings in the STSC plenary and more than 10 informal consultation meetings on the margins to continue work on developing the draft guidelines. The WG Chair proposed a "phased approach" that would have allowed for adoption of an initial set of guidelines in 2016 and development of a second tranche of guidelines in 2017-2018. Although the U.S. and nearly all other COPUOS Member States agreed with this phased approach, ultimately it did not achieve consensus during the STSC session. The WG also did not reach consensus on a draft report to document the activities of the WG conducted during the STSC session. The current mandate for the LTS WG will expire at the end of the June 2016 COPUOS meeting. The LTS WG did agree to hold a two-day intersessional meeting immediately before the June 2016 COPUOS meeting in hopes of reaching a consensus on the initial set of draft guidelines. As the U.S. National Space Policy notes, "the U.S. calls on all nations to work together to adopt approaches for responsible activity in space to preserve this right for the benefit of future generations." ♦

ORDEM 3.0 Verification and Validation Document Available

The NASA technical publication "NASA Orbital Debris Engineering Model ORDEM 3.0 – Verification and Validation" document (NASA/TP-2015-218592, October 2015) is now available to the public. This document reviews the verification and validation (V&V) process, how it was applied to the ORDEM 3.0 computer model of the Earth orbiting population, and V&V outcomes for both the spacecraft and telescope modes of operation. Interested readers are directed to this issue's project review "ORDEM 3.0 Verification and Validation Findings" for a summary of several key determinations and may obtain a copy from the Johnson Space Center Technical Report Server at ston.jsc.nasa.gov/collections/TRS/_techrep/TP-2015-218592.pdf. Those wishing to obtain the ORDEM 3.0 model and its attendant User's Guide may request a copy at http://orbitaldebris.jsc.nasa.gov/model/engrmodel.html. ♦

PROJECT REVIEW

Top Ten Satellite Breakups Reevaluated

P. ANZ-MEADOR

Between the beginning of the Space Age on 4 October 1957 and 1 January 2016, more than 5160 space missions have been conducted worldwide. Of the over 40,000 objects cataloged by the U.S. Space Surveillance Network (SSN), 17,255 are on-orbit and are traveling independently as of the latter date. However, only 10 missions now account for approximately one-third of all cataloged objects now in Earth orbit. In this article we review developments since the previous publication of "Top Ten Satellite Breakups" (ODQN, vol. 14, issue 3, July 2010, pp. 2-3).

By far the source of the greatest amount of orbital debris remains the Fengyun-1C spacecraft, which was the target of a People's Republic of China anti-satellite test in January 2007 (see previous ODQN articles: vol. 11, issues 2 and 3, April and July 2007; vol. 12, issues 2 and 3, January, April, and July 2008; vol. 13, issues 1 and 3, January and July 2009; vol. 14, issues 2 and 4, April and October 2010; vol. 16, issue 3, July 2012; and issue 1 of volumes 17, 18, and 19, January 2013, 2014, and 2015, respectively).

This satellite alone now accounts for 3428 cataloged fragments or almost 20% of the entire population of cataloged manmade objects in orbit about the planet. Additional debris from this test and other events are currently being tracked by the SSN and are

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Top Ten Satellite Breakups

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officially cataloged on a routine basis.

The second and fourth most significant satellite breakups are Cosmos 2251 and Iridium 33 spacecraft, which were involved in the first ever accidental hypervelocity impact of intact objects in February 2009. While over 68% of the Cosmos debris cloud remains on orbit, only 58% of the Iridium cloud is on orbit, due in part to the higher area-to-mass ratio bias of the latter cloud. Because of their relatively high altitude, these clouds will continue to present a hazard for decades to come.

Conversely, the relatively high area-to-mass ratio distribution of the STEP 2 rocket body's debris cloud, the third most significant event, and the low altitude of the Cosmos 2421 event, the fifth most significant, have resulted in a minimal long-term environmental hazard. Only about 11% of the former, and none of the latter remain on-orbit at this time. Otherwise, only the order of the top 10 events has changed as the former tenth place entry, the CBERS 1/SACI 1 CZ-4 rocket body is now in eighth place in the list due to on-going cataloging of the cloud.

Not listed in Table 1 is the breakup of the *Briz-M* upper stage (International Designator 2006-006B, SSN# 28944) which broke-up into an estimated 1,000$^+$ fragments in February 2007 (ODQN, vol. 11, issue 2, April 2007, pg. 3). However, the highly elliptical nature of the stage's orbit (~500 km by nearly 15,000 km) has impeded the SSN's ability to detect, to identify, and to catalog the associated debris. As of January 2016, 102 debris from the Briz-M stage had been officially cataloged, of which 94 remain on-orbit.

While Table 1 allows the reader to adduce the effectiveness of international debris mitigation policies and guidelines over the course of the past decades, another way to examine the consequences of historical breakup events is presented in Table 2. In this table, the total number of debris on-orbit is regarded as the figure of merit in lieu of Table 1's total number of debris cataloged. This better illustrates the long-term environmental hazard posed by historical events. The reader should note that up to six of the events listed in Table 2 would have been potentially obviated by modern U.S. and international mitigation practices.

Half of Table 1's top 10 are replaced in Table 2 by older events, though Fengyun-1C, Cosmos 2251, and Iridium 33 debris clouds retain their primacy. Table 2's new entries have as their signal attribute a higher altitude of breakup. Indeed, four of the five reside in sun-synchronous orbits over 1000 km in breakup altitude. The fifth, the Cosmos 2227 SL-16/*Zenit* rocket body, is massive at an estimated dry mass of 8.9 metric tons, and experienced multiple breakup events. All members of this list will continue to pose a hazard to spaceflight for decades to come. Furthermore, many reside in popular low Earth orbits and pose an enhanced risk to other spacecraft due to their inclinations and attendant relative velocity. ♦

Table 1. Top 10 Breakups, January 2016

Rank	International Designator		Common Name	Year of Breakup	Altitude of Breakup	Cataloged Debris	Debris in Orbit	Assessed Cause of Breakup
1	1999	25	Fengyun-1C	2007	850	3428	2880	intentional collision
2	1993	36	Cosmos 2251	2009	790	1668	1141	accidental collision
3	1994	29	STEP-2 Rocket Body	1996	625	754	84	accidental explosion
4	1997	51	Iridium 33	2009	790	628	364	accidental collision
5	2006	26	Cosmos 2421	2008	410	509	0	unknown
6	1986	19	SPOT-1 Rocket Body	1986	805	498	32	accidental explosion
7	1965	82	OV2-1 / LCS 2 Rocket Body	1965	740	473	33	accidental explosion
8	1999	57	CBERS 1 / SACI 1 Rocket Body	2000	740	431	210	accidental explosion
9	1970	25	Nimbus 4 Rocket Body	1970	1075	376	235	accidental explosion
10	2001	49	TES Rocket Body	2001	670	372	80	accidental explosion
						9137	**5059**	

* as of 04 January 2016

Table 2. Number of Debris in Orbit, January 2016

Rank	International Designator		Common Name	Year of Breakup	Altitude of Breakup	In Orbit*	Total	Assessed Cause of Breakup
1	1999	25	Fengyun-1C	2007	850	2880	3428	intentional collision
2	1993	36	Cosmos 2251	2009	790	1141	1668	accidental collision
3	1997	51	Iridium 33	2009	790	364	628	accidental collision
4	1981	53	Cosmos 1275	1981	980	289	346	battery explosion
5	1970	25	Nimbus 4 Rocket Body	1970	1075	235	376	accidental explosion
6	1999	57	CBERS 1 / SACI 1 Rocket Body	2000	740	210	431	accidental explosion
7	1992	93	Cosmos 2227 Rocket Body #	1992	830	199	279	accidental explosion
8	1975	52	Nimbus 6 Rocket Body	1991	1090	199	274	accidental explosion
9	1973	86	NOAA 3 Rocket Body	1973	1515	179	201	accidental explosion
10	1976	77	NOAA 5 Rocket Body	1977	1510	174	184	accidental explosion
						5870	**7815**	

* as of 04 January 2016
# multiple events associated with this SL-16 Zenit second stage

ORDEM 3.0 Verification and Validation Findings

M. MATNEY, P. KRISKO, A. VAVRIN, AND P. ANZ-MEADOR

As is the case with any computer model purporting to accurately describe a physical process, the model should be subject to scrutiny and an enlightened skepticism until that model has been through a thorough verification and validation (V&V) evaluation. The NASA Orbital Debris Engineering Model (ORDEM) version 3.0 models the Earth orbital environment of man-made debris for those larger than 10 µm in size residing in low Earth orbit (LEO) and 10 cm and larger in geosynchronous orbit (GEO) from 2010 to 2035. Prior to its release, ORDEM 3.0 was subjected to a systematic V&V process and, as is reported in this issue's news, a NASA report documenting this process and the outcomes has been released and is now available to the public.

The purpose of the V&V document is to ensure that:

- the model is built correctly: verification; and
- the correct model was built: validation.

The complete V&V process generally encompasses the entire software lifecycle, and is therefore a task from inception to retirement. The process for ORDEM 3.0 borrows from the Institute of Electrical and Electronics Engineers (IEEE) in IEEE Std. 1012-1998 and includes standard verification activities (analysis, testing, inspection, demonstration) and validation activities (analysis and testing) [1]. This article highlights two sections of the ORDEM 3.0 V&V document – analysis verification of spacecraft mode and testing validation for LEO and GEO populations.

Analysis Verification

Because many of the algorithms used to compute fluxes in ORDEM 3.0 are unique, verifying them presented a special challenge. Several independent codes were created specifically for the V&V process that use different sets of assumptions and algorithms to compute the same or similar flux values as the ORDEM software. These special codes are slower and can take many hours to run compared to the corresponding ORDEM codes.

The legacy NASA Orbital Debris Program Office (ODPO) programs – GEO_KESSLER_IGLOO and LEO_KESSLER_IGLOO – were modified to use the ORDEM populations to compute fluxes sorted by direction and velocity and to handle special orbits with fixed nodes, specifically for spacecraft cases. These "Kessler" models use variants of Kessler's spatial density formulation [2]. The reason why a separate program is required for LEO and GEO is due to the differences in how the orbital elements of the populations are binned in the ORDEM model. The programs LEO_KESSLER_TELE and GEO_KESSLER_TELE use the same spatial density subroutines to compute fluxes for the telescope cases. The generic term "Kessler" refers to the results of any of these runs.

Six satellite test cases were used during the analysis verification of the spacecraft mode. Note that these satellites are chosen from six different regions – LEO (low), LEO (high), Middle Earth Orbit (MEO), *Molniya*, Geosynchronous Transfer Orbit (GTO), and GEO. Though not elaborated upon further in this article, the ORDEM telescope mode was also verified using four test cases; this mode is applicable to any pencil beam-type ground-based sensor. Two cases simulated Haystack radar observations at (Azimuth, Elevation) combinations of (90°, 75°) and (180°, 10°); a generic vertically-starring equatorial sensor; and the Meter-Class Autonomous Telescope (MCAT) located at Ascension Island at an orientation of (0°, 80°).

Spacecraft Mode Example

Figures 1, 2, and 3 are examples of analysis verification charts for a LEO orbit; in this case, the Tropical Rainfall Measuring Mission (TRMM) spacecraft orbit (International Designator 1997-074A, USSTRATCOM SSN catalog number 25036, in a 397-km circular orbit, inclination 35°). These plots are typical of LEO orbits, where the ORDEM fluxes match those computed by Kessler to high fidelity. Figure 1 shows the normalized distribution in relative velocity and Figure 2 shows the normalized distribution in yaw angle of the flux. In both cases, the lines for the different models are indistinguishable on the graphs. Figure 3 shows the sample data points taken from the ORDEM 3.0 and Kessler

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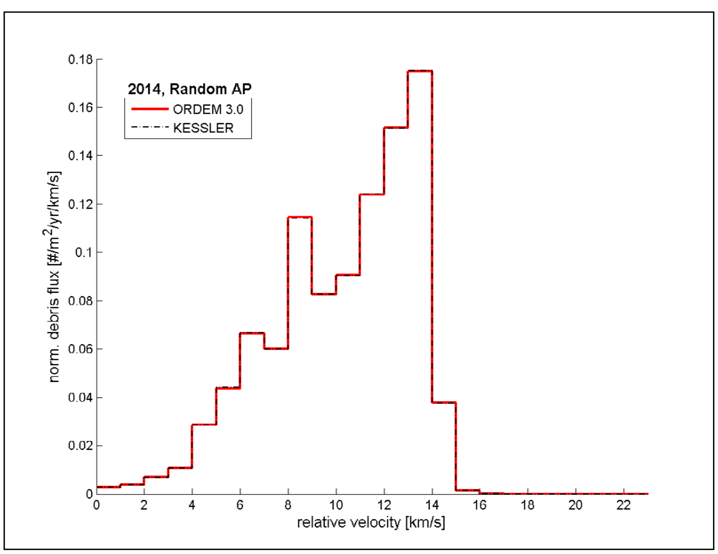


Figure 1. TRMM, Year 2014, Random Argument of Perigee (AP), debris flux (normalized) distributed over relative velocity bins, ORDEM 3.0 vs. Kessler.

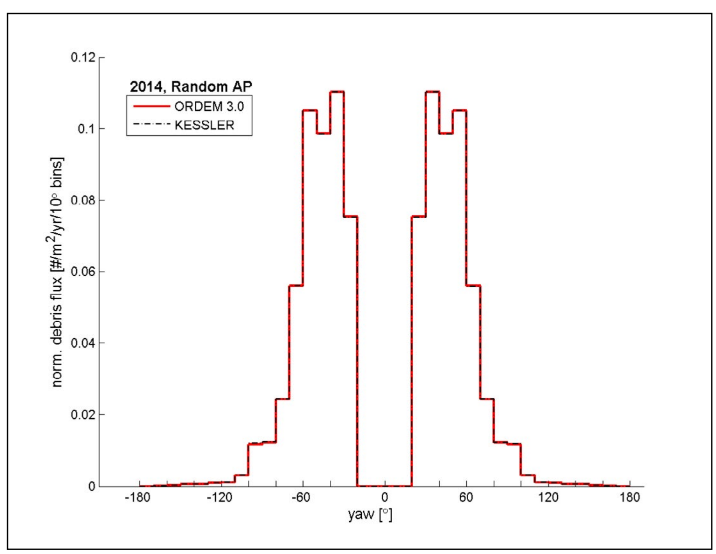


Figure 2. TRMM, Year 2014, Random AP, debris flux (normalized) distributed over yaw bins, ORDEM 3.0 vs. Kessler.

ORDEM 3.0 V&V

continued from page 7

bin-by-bin flux distributions (the igloo flux is divided into direction and relative velocity bins), supplemented with a best-fit line, 95% confidence interval (CI), and the 95% prediction interval (PI). An ideal match would fall along the 1:1 line, which this example does, except for the very small flux values where the contributions are the smallest. This example illustrates no statistically significant difference between ORDEM 3.0 and independent computer codes and therefore is considered to fully meet the intent of the verification process.

Testing Validation

Validation is provided through the systematic comparison of model populations and environmental *in situ* and remotely-sensed measurements. The validation of the ORDEM 3.0 modeled debris populations, in terms of the original NASA measurements, has been a high-priority effort for several years during the development of ORDEM. It has culminated in techniques and sets of metrics that were chosen by the developers to validate the model. Simply put, a study matrix that includes the parameters of debris size, altitude, and year, the measured environments of available sensors (Goldstone, Haystack, the Haystack Auxiliary [HAX] radar, and the Space Surveillance Network), and in-situ measurements are compared to the ORDEM 3.0 modeled environments. Comparisons of this kind are limited to those regions of space and time where measurements are available and have been analyzed.

Scaled Flux Deviations vs. Altitude in LEO

One set of metrics discussed in the ORDEM 3.0 V&V document is scaled flux deviations vs. altitude of LEO model populations. The > 3.16 cm and > 1 cm model populations currently used in ORDEM 3.0 are statistically estimated from available Haystack (pointing directions 75°E [90° azimuth, 75° elevation] or 20°S [180°, 20°]) and HAX (pointing direction 75°E) staring-mode data, using the ODPO LEO to GEO Environment Debris (LEGEND) source models as the initial population estimate. The population estimation is based on observed and predicted radar detection probability distributions in the two-dimensional space of radar range and range-rate. Due to the statistical nature of the limited radar samplings, the model populations are obtained as an average over all the detailed aspects such as altitudes, year, different radar viewing geometries, etc. This weighted average model parameter is a weighted average over different data sets (i.e., of different year and with different radar viewing geometry) based on the variances that include the dispersion parameter, which is a measure of the deviation of data from the assumption of pure Poisson statistics. In this regard, the observed OD fluxes are supposed to be randomly distributed around model predicted "mean" values. This has been tested, specifically for the deviations of radar-observed OD fluxes from ORDEM model predictions.

The radar data used in the model population estimations specifically exclude Sodium-Potassium (NaK) reactor coolant droplets deposited on-orbit by the Soviet Union's Radar Ocean Reconnaissance satellites (RORSATs) during end of mission operations. The special NaK populations are modeled separately due to their particular spherical shape. In addition, there are some specific families of populations that are not included in the LEGEND source populations and are modeled separately with a distinct approach.

Each validation test includes two charts: a scaled flux deviation ζ vs. altitude chart; a probability distribution function (pdf) histogram supplemented with a normal curve fit – $N(\nu,\sigma)$ using a fitted mean ν; and a pdf histogram supplemented with a normal curve fit of 1-sigma $N(\bar{\zeta},1)$. Figure 4 shows the ζ vs. altitude for Haystack 75°E pointing direction for years 1999 to 2003 for particles > 1 cm. The dots represent observational data points and the "unweighted" average $\bar{\zeta}$ and weighted average $\breve{\zeta}$ are portrayed as lines. Figure 5 shows the probability distribution function (pdf) histogram of ζ (solid black line) for Haystack 75°E pointing direction, 1999-2003, > 1 cm. This distribution is overlapped by a normal curve fit – $N(\nu,\sigma)$ (solid blue line). Notice the fitted mean ν is very close to $\bar{\zeta}$. The "unweighted" average $\bar{\zeta}$ is represented as a dashed red line. Figure 6 includes the same pdf histogram as before, but with a different curve fit – $N(\bar{\zeta},1)$. This example is considered to fully meet the intent of the validation process.

continued on page 9

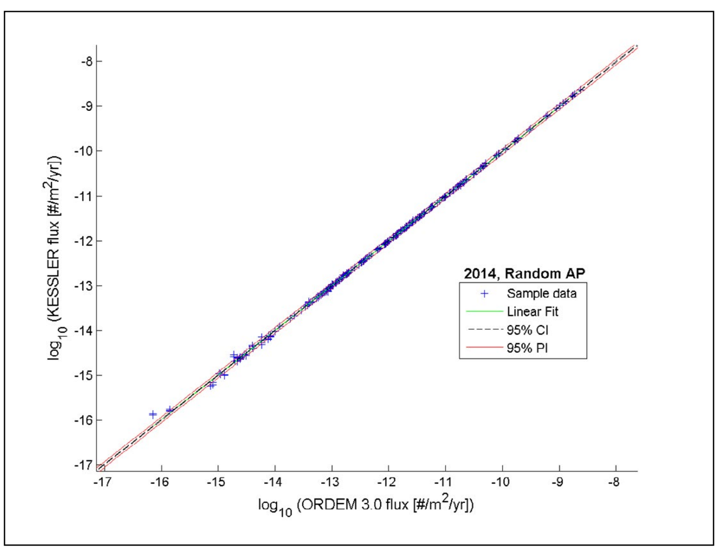


Figure 3. TRMM, Year 2014, Random AP, bin-by-bin debris flux comparison, ORDEM 3.0 vs. Kessler.

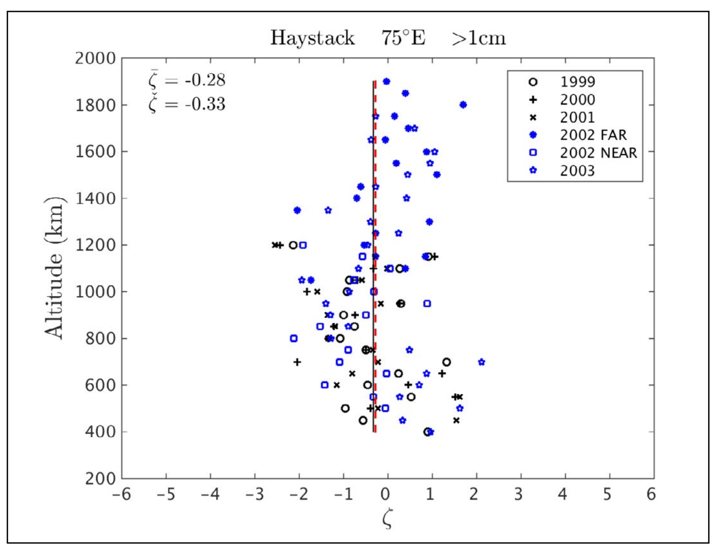


Figure 4. Haystack 75°E, >1 cm, altitude over scaled flux deviations.

ORDEM 3.0 V&V

continued from page 8

GEO Population Validation Example

Validation of ORDEM 3.0 in GEO is challenging due to a lack of available data. While the LEO SSN Catalog reliably tracks objects down to about 10 cm, and the Goldstone/Haystack/HAX sensor set contributes over 1,000 hours per year of statistical data to a minimum size of about 3 mm, the GEO regions must depend on the SSN Catalog (~ > 1 m) and the GEO survey data provided by the ODPO-sponsored Michigan Orbital Debris Survey Telescope (MODEST). The MODEST absolute magnitude is derived from the MODEST instrumental magnitude. The ODPO converts absolute magnitude to size by assuming that each object is a Lambertian sphere with an albedo of 0.13. The process is inverted to derive absolute magnitude from size. Absolute magnitude and size are inversely related. Bright/large objects have low magnitudes, while dim/small objects have larger magnitudes. The cutoff of the 20th absolute magnitude corresponds to 10 cm in size, the smallest size calculated in the GEO dataset. This is shown in Figures 7 and 8. For the purposes of ORDEM 3.0 GEO development, the ODPO considers the MODEST survey to be complete down to 30 cm. Observations support the hypothesis that the historical period has experienced a number of unobserved explosive breakups in GEO other than the two acknowledged events (Titan 3-C Transtage [USSTRATCOM SSN catalog number 3432] and Ekran 2 [USSTRATCOM SSN catalog number 10365]).

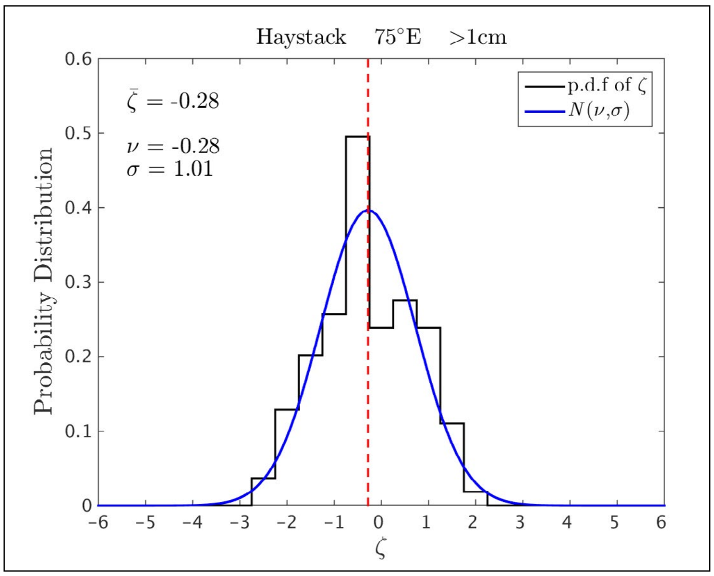


Figure 5. Haystack 75°E, >1 cm, pdf histogram of scaled flux deviations, overlayed with normal fit curve.

No attempt has been made to identify the origin of any fragments in the MODEST database. It was discovered after the ORDEM 3.0 software release that the Titan 3-C Transtage fragments were counted twice, once without identification in the MODEST and extended MODEST database and again in the LEGEND fragmentation deposit. This results in a 10% population error that will be rectified in the next ORDEM release.

The histograms in Figures 7 and 8 display the ORDEM 3.0 GEO population at the end of 2006 in terms of number vs. absolute magnitude and number vs. size, respectively. The individual curves represent source components. The cataloged objects (in red) include the complete set of cataloged objects in GEO. MODEST data does include fortuitous surveyed observations of cataloged objects, but the survey is intended to be statistical, where multiple observations are handled by estimating and correcting for the observation biases. For these reasons, the MODEST cataloged data is excluded from the ORDEM 3.0 GEO objects, relying instead on the more complete catalog and LEGEND database data.

Uncataloged objects in blue are MODEST observations (> 30 cm). For the construction of the ORDEM 3.0 populations, these objects are weighted by their observation probability. The drop-off in detections beginning at

continued on page 10

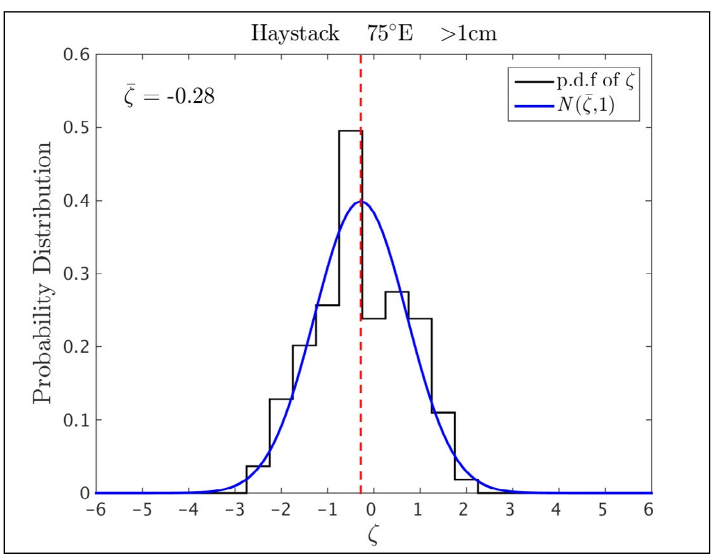


Figure 6. Haystack (75°E), > 1 cm, pdf histogram of scaled flux deviations, overlayed with normal fit curve of 1-sigma.

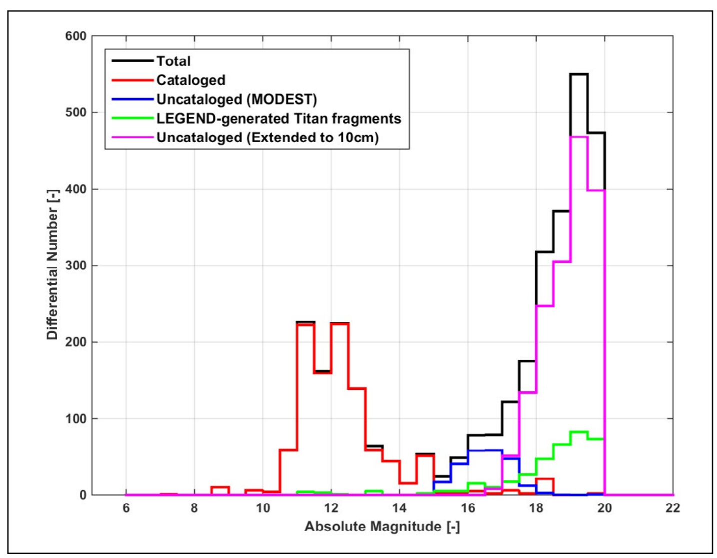


Figure 7. ORDEM 3.0 GEO file for 2006, absolute magnitude (bins = 0.5).

ORDEM 3.0 V&V

continued from page 9

around 17th absolute magnitude (~25 cm) is a function of the limiting magnitude of the MODEST system as object size decreases. Uncataloged objects in magenta represent an extension (30 cm to 10 cm) of the MODEST observation data based on the NASA breakup model. Uncataloged objects in green are derived from LEGEND for the two known breakups in GEO. These are the fragments (> 10 cm) that are distributed from statistical breakup events in the LEGEND process. The number of these objects continues to increase with decreasing size, as shown in Figure 8. The ODPO software development team considers the ORDEM 3.0 GEO environment to be validated to 10 cm characteristic sizes.

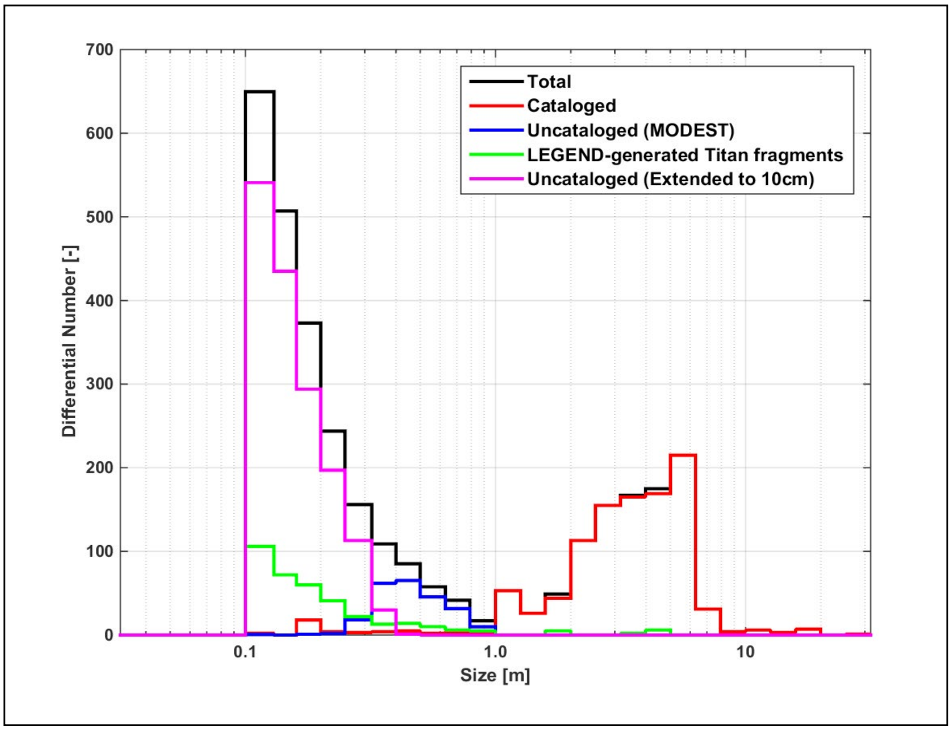


Figure 8. ORDEM 3.0 GEO file for 2006.

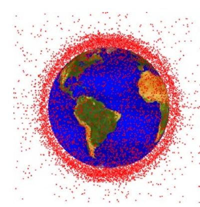
Conclusion

ORDEM 3.0 has been subject to extensive verification and validation by the ODPO software development team. The results of the validation activities used all available data. These findings correctly and completely represent the ORDEM 3.0 model specifications and requirements defined by NASA.

References

1. Anon., IEEE Computer Society. "IEEE Standard for Software Verification and Validation," IEEE Standard 1012-1998, 20 July 1998.

2. Kessler D.J. "Derivation of the Collision Probability between Orbiting Objects: The Lifetimes of Jupiter's Outer Moons," *Icarus*, vol. 48, p. 39-48 (Oct. 1981). ♦



CONFERENCE REPORT

The 66th International Astronautical Congress (IAC), 12-16 October 2015, Jerusalem, Israel

The 66th International Astronautical Congress (IAC) was held 12-16 October 2015 in Jerusalem. Like the previous IACs, the Space Debris Symposium during the IAC was organized by the International Academy of Astronautics (IAA). The Space Debris Symposium consisted of nine oral sessions, including one joint session with the Space Security Committee, one virtual forum with young professionals, and one interactive presentation session. The interactive session was a new format that replaced the traditional poster sessions. The 10 debris sessions covered a wide range of activities, including ground-based radar and telescope observations, space-based in-situ measurements, laboratory-based experiments, long-term environment modeling, hypervelocity impact testing and simulations, mitigation and remediation, as well as concepts and technology development for active debris removal. In total, 70 oral and 33 interactive presentations were given during the Space Debris Symposium, making it one of the most active symposiums of the 2015 IAC.

The two best attended debris sessions, with more than 100 participants overall, were "Space Debris Removal Technologies" and "Space Debris Removal Concepts" sessions. Highlights for the two sessions include updates on debris capture mechanisms, such as robotic arms and nets, and several planned active debris removal demonstration missions. In addition, a special presentation by OneWeb for an overview of their planned 720 spacecraft constellation in LEO was arranged by the symposium coordinators. All participants were highly impressed by OneWeb's proactive approach to address potential orbital debris issues associated with their constellation. If implemented as planned, OneWeb's debris mitigation effort to protect the near-Earth space environment would serve as a good model for others to follow. ♦

UPCOMING MEETINGS

20-22 April 2016: 13th Annual CubeSat Developer's Workshop, San Luis Obispo, California (USA)

This workshop continues the annual series hosted by the California Polytechnic University. For updates and more information please refer to the CubeSat Project website: http://www.cubesat.org/index.php/workshops/upcoming-workshops.

18-20 May 2016: 8th International Association for the Advancement of Space Safety (IAASS) Conference, Melbourne, Florida (USA)

In cooperation with the International Space Safety Foundation (ISSF), the IAASS will host its 8th conference, themed "Safety First, Safety for All." Among the conference's topics of interest to this readership are designing safety into space vehicles, safety of extravehicular activities, space debris remediation, re-entry safety, probabilistic risk assessment, space situational awareness (SSA) and space traffic control, and launch and in-orbit collision risk. In addition to conference sessions, a set of panel sessions will address Space Debris Reentry Safety, Space Traffic Management, Safety Standards for Commercial Human Spaceflight, and Human Performance and Safety on Long Duration Missions. For more information please refer to the conference website: http://iaass.space-safety.org/.

6-8 June 2016: 4th International Workshop on Space Debris Modeling and Remediation, Paris, France

CNES HQ will host the fourth workshop in this series. The workshop will include oral and poster sessions on space debris modeling, including uncertainties associated with modeling small satellites and constellations, and debris remediation. Remediation topics include policy, planning, system studies, remediation concepts and associated technologies, and economics. Please contact Organizing Committee Chair Mr. Christophe Bonnal, Christophe.bonnal@cnes.fr, for further information.

30 July - 7 August 2016: 41st Committee on Space Research (COSPAR) 2016, Istanbul, Turkey

The 41st Committee on Space Research (COSPAR) Assembly will convene in Istanbul's Congress Center on Saturday, 30 July 2016 and run through Sunday, 7 August. The COSPAR panel Potentially Environmentally Detrimental Activities in Space (PEDAS) will conduct a program entitled "Space Debris – Providing the Scientific Foundation for Action." PEDAS.1 sessions will include advances in ground- and space-based measurements of the orbital debris environment, micrometeoroid and orbital debris environment modeling, risk assessment, mitigation and remediation, hypervelocity impact range developments, and protection. Please see the COSPAR website at https://www.cospar-assembly.org/ and the Assembly website http://cospar2016.tubitak.gov.tr/ for further information.

6-11 August 2016: 30th Annual AIAA/USU Conference on Small Satellites, Logan, Utah (USA)

Utah State University will host the 30th Annual AIAA/USU Conference on Small Satellites at the Taggert Student Center in August 2016. In addition, the pre-conference 13th Annual Summer CubeSat Developer's Workshop will be conducted on 6-7 August. The conference program considers all aspects of small satellite development and deployment, and reviews the past 18 months of smallsat launches and previews the next 18 months. Please see the conference website at http://www.smallsat.org/index for further information.

20-23 September 2015: 17th Advanced Maui Optical and Space Surveillance Technologies Conference, Maui, Hawaii (USA)

The technical program of the 17th Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) will focus on subjects that are mission critical to Space Situational Awareness. The technical sessions include papers and posters on Orbital Debris, Space Situational Awareness, Adaptive Optics & Imaging, Astrodynamics, Non-resolved Object Characterization, and related topics. Additional information about the conference is available at http://www.amostech.com.

26-30 September 2016: 67th International Astronautical Congress, Guadalajara, Mexico

The Mexican Space Agency, Agencia Espacial Mexicana (AEM), will host the 67th IAC Conference with a theme of "Making space accessible and affordable to all countries." The 2016 Congress will include the 14th International Academy of Astronautics (IAA) Symposium on Space Debris to address the complete spectrum of technical issues of space debris measurements, modeling, risk assessments, reentry, hypervelocity impacts and protection, mitigation and standards, and space situational awareness. These topics will be covered in nine oral sessions and one poster session. For conference information as it is posted, visit the IAF conference webpage at http://iac2016.org.

INTERNATIONAL SPACE MISSIONS
1 October 2015 – 31 December 2015

International Designator	Payloads	Country/ Organization	Perigee Altitude (KM)	Apogee Altitude (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
2015-055A	PROGRESS-M 29M	RUSSIA	397	408	51.6	1	0
2015-056A	MORELOS 3 7	MEXICO	35779	35794	7.1	1	0
2015-057A	LQSAT	CHINA	639	665	98.0	0	0
2015-057B	LINGQIAO VIDEO A	CHINA	639	665	98.0		
2015-057C	LINGQIAO VIDEO B	CHINA	638	664	98.0		
2015-057D	JILIN 1	CHINA	638	664	98.0		
2015-058A	USA 264	USA				1	1
2015-058B	AEROCUBE 5C	USA					
2015-058C	AEROCUBE 7	USA					
2015-058D	FOX-1	USA					
2015-058E	BISONSAT	USA					
2015-058F	ARC-1	USA					
2015-058G	SNAP-3 ALICE	USA	NO ELEMENTS AVAILABLE				
2015-058H	LMRST-SAT	USA					
2015-058J	SNAP-3 EDDIE	USA					
2015-058K	PROPCUBE 3	USA					
2015-058L	SINOD-D 1	USA					
2015-058M	SNAP-3 JIMI	USA					
2015-058N	PROPCUBE 1	USA					
2015-058P	SINOD-D 3	USA					
2015-059A	APSTAR 9	CHINA	35774	35799	0.0	1	0
2015-060A	TURKSAT 4B	TURKEY	35776	35798	0.0	1	1
2015-061A	TIANHUI 1-03	CHINA	488	502	97.4	1	2
2015-062A	NAVSTAR 75 (USA 265)	USA	20158	20207	55.0	1	0
2015-063A	CHINASAT 2C	CHINA	35778	35797	0.5	1	0
2015-064A	YAOGAN 28	CHINA	467	483	97.3	1	3
2015-065A	GSAT 15	INDIA	35775	35798	0.0	1	1
2015-065B	BADR 7	ARAB SCO	35757	35798	0.0		
2015-066A	COSMOS 2510	RUSSIA	1588	38770	63.8	1	0
2015-067A	LAOSAT 1	LAOS	35779	35794	0.1	1	0
2015-068A	TELSTAR 12V	CANADA	35776	35798	0.1	1	0
2015-069A	YAOGAN 29	CHINA	628	630	97.8	1	0
2015-070A	LISA PATHFINDER	ESA	SUN-EARTH LAGRANGE 1			1	0
2015-071A	COSMOS 2511	RUSSIA	88	298	98.2	2	0
2015-071B	COSMOS 2512	RUSSIA	684	694	98.2		
2015-072A	CYGNUS ORB-4	USA	397	408	51.6	0	0
2015-073A	CHINASAT 1C	CHINA	35780	35793	0.0	1	0
2015-074A	ELEKTRO-L 2	RUSSIA	35779	35793	0.3	2	7
2015-075A	COSMOS 2513	RUSSIA	35776	35797	0.0	1	1
2015-076A	SOYUZ-TMA 19M	RUSSIA	397	408	51.6	1	0
2015-077A	VELOX C1	SINGAPORE	533	550	15.0	1	0
2015-077B	KENT RIDGE 1	SINGAPORE	534	550	15.0		
2015-077C	ATHENOXAT 1	SINGAPORE	531	550	15.0		
2015-077D	TELEOS 1	SINGAPORE	535	551	15.0		
2015-077E	GALASSIA	SINGAPORE	529	549	15.0		
2015-077F	VELOX 2	SINGAPORE	536	551	15.0		
2015-078A	DAMPE	CHINA	488	505	97.3	0	0
2015-079A	GALILEO 12 (269)	ESA	23511	23568	55.0	1	0
2015-079B	GALILEO 11 (268)	ESA	23552	23618	55.0		
2015-080A	PROGRESS MS-01	RUSSIA	396	407	51.6	1	0
2015-081A	ORBCOMM FM 114	USA	615	658	47.0	0	0
2015-081B	ORBCOMM FM 119	USA	614	658	47.0		
2015-081C	ORBCOMM FM 105	USA	614	657	47.0		
2015-081D	ORBCOMM FM 110	USA	614	657	47.0		
2015-081E	ORBCOMM FM 118	USA	614	657	47.0		
2015-081F	ORBCOMM FM 112	USA	614	657	47.0		
2015-081G	ORBCOMM FM 113	USA	613	655	47.0		
2015-081H	ORBCOMM FM 115	USA	613	655	47.0		
2015-081J	ORBCOMM FM 108	USA	613	655	47.0		
2015-081K	ORBCOMM FM 117	USA	613	653	47.0		
2015-081L	ORBCOMM FM 116	USA	613	654	47.0		
2015-082A	EXPRESS AMU1	RUSSIA	35777	35796	0.0	1	1
2015-083A	GAOFEN 4	CHINA	35780	35791	0.4	1	0

DAS 2.0 NOTICE

Attention DAS 2.0 Users: an updated solar flux table is available for use with DAS 2.0. Please go to the Orbital Debris Website at http://www.orbitaldebris.jsc.nasa.gov/mitigate/das.html to download the updated table and subscribe for email alerts of future updates.

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Technical Editor
Phillip Anz-Meador

Managing Editor
Debi Shoots

Correspondence concerning the ODQN can be sent to:

Debi Shoots
NASA Johnson Space Center
Orbital Debris Program Office
Mail Code JE104
Houston, TX 77058

debra.d.shoots@nasa.gov

INTERNATIONAL SPACE MISSIONS
1 January 2016 – 31 March 2016

International Designator	Payloads	Country/ Organization	Perigee Altitude (KM)	Apogee Altitude (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
2016-001A	BELINTERSAT 1	BELARUS	35780	35791	0.0	1	0
2016-002A	JASON 3	USA	1332	1344	66.0	0	0
2016-003A	IRNSS-1E	INDIA	35696	35879	28.1	1	0
2016-004A	INTELSAT 29E	INTELSAT	35775	35798	0.1	1	0
2016-005A	EUTE 9B	EUTELSAT	35779	35791	0.1	1	1
2016-067HP	AGGIESAT 4	USA	394	399	51.6	0	0
2016-067HQ	BEVO 2	USA	391	395	51.6	0	0
2016-006A	BEIDOU M3-S	CHINA	21523	21532	55.0	2	0
2016-007A	NAVSTAR 76 (USA 266)	USA	20174	20188	55.0	1	0
2016-008A	COSMOS 2514 (GLONASS)	RUSSIA	19104	19156	64.8	1	0
2016-009A	KMS 4	N. KOREA	463	501	97.5	1	0
2016-010A	USA 267	USA	NO ELEMS. AVAILABLE			0	0
2016-011A	SENTINEL 3A	ESA	802	803	98.6	1	0
2016-012A	ASTRO H	JAPAN	560	580	31.0	1	1
2016-012B	CHUBUSAT 2	JAPAN	559	579	31.0		
2016-012C	CHUBUSAT 3	JAPAN	559	578	31.0		
2016-012D	HORYU 4	JAPAN	557	577	31.0		
2016-013A	SES 9	SES	EN ROUTE TO GEO			1	0
2016-014A	EUTE 65W	EUTELSAT	35779	35794	0.1	1	0
2016-015A	IRNSS 1F	INDIA	EN ROUTE TO GEO		5.1	1	0
2016-016A	RESURS P3	RUSSIA	468	473	97.3	1	0
2016-017A	EXOMARS	ESA	EN ROUTE TO MARS			0	1
2016-018A	SOYUZ-TMA 20M	RUSSIA	403	406	51.6	1	0
2016-019A	CYGNUS OA-6	USA	403	406	51.6	0	0
2016-020A	COSMOS 2515	RUSSIA	542	595	97.6	1	0
2016-021A	BEIDOU IGSO 6	CHINA	EN ROUTE TO GEO		55.0	1	0

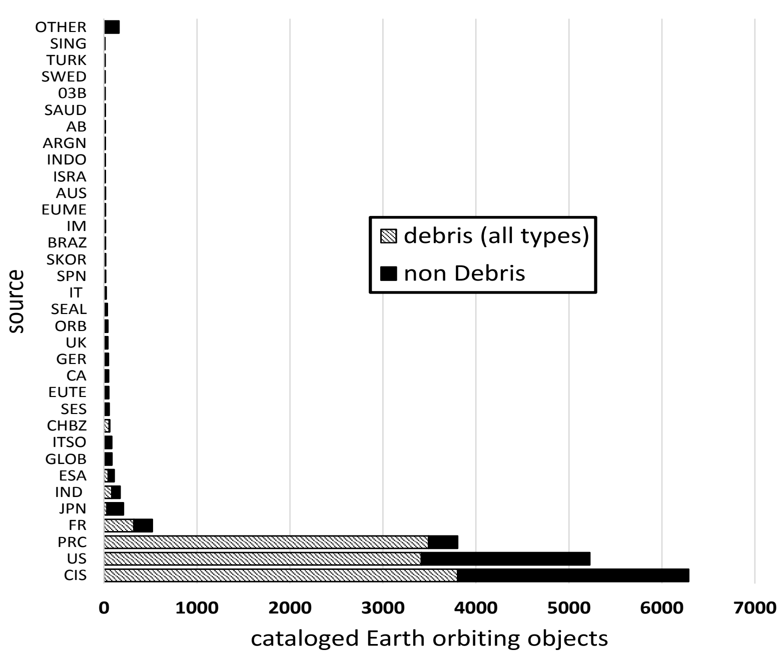
SATELLITE BOX SCORE

(as of 6 April 2016, cataloged by the U.S. SPACE SURVEILLANCE NETWORK)

Country/ Organization	Payloads	Rocket Bodies & Debris	Total
CHINA	215	3576	3791
CIS	1468	4808	6276
ESA	56	53	109
FRANCE	60	460	520
INDIA	64	112	176
JAPAN	140	75	215
USA	1338	4145	5483
OTHER	700	115	815
TOTAL	4041	13344	17385

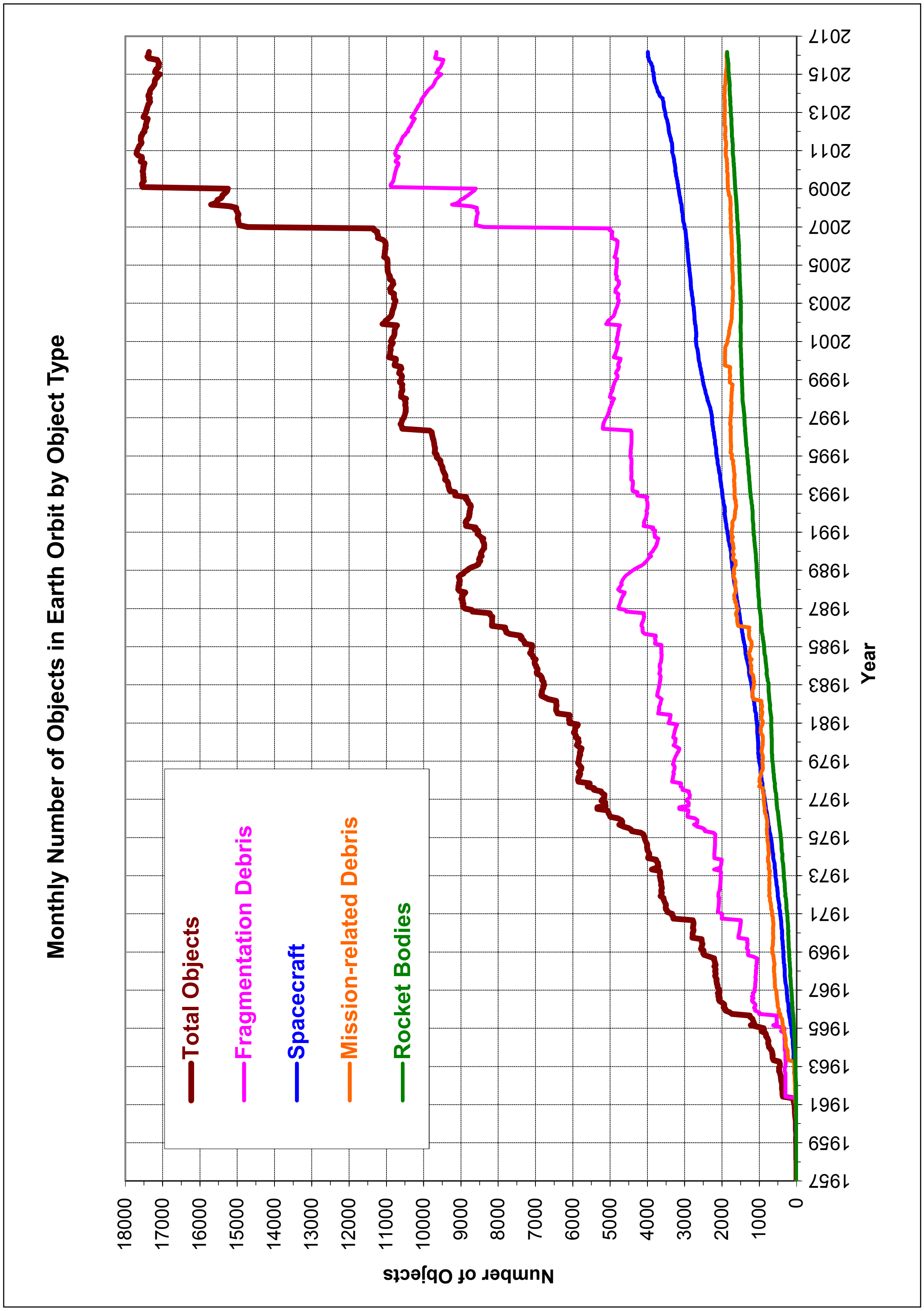
Visit the NASA Orbital Debris Program Office Website

www.orbitaldebris.jsc.nasa.gov



This chart shows the relative proportions of debris to non-debris as of January 2016. Debris in this case includes mission-related debris, anomalous debris, and breakup debris. Non-debris includes spacecraft (including non-functioning spacecraft) and rocket bodies. The vast majority are breakup debris. In this chart, launching entities with 10 or more objects on orbit are listed individually; those with less are lumped into the 'other' category. Launching entities include countries, international agencies or consortia, and commercial organizations. International government-level partnerships include the European Space Agency (ESA), ArabSat (AB), InMarSat (IM), the EuMetSat organization (EUME), the EuTelSat organization (EUTE), and the China-Brazil partnership (CHBZ). Commercial concerns include Sea Launch (SEAL), Orbcomm (ORB), Globalstar (GLOB), SES, Other 3 Billion Networks (O3B) and since 2001, Intelsat (ITSO).

Source: 6 January 2016 JSpOC boxscore.



Monthly Number of Cataloged Objects in Earth Orbit by Object Type: This chart displays a summary of all objects in Earth orbit officially cataloged by the U.S. Space Surveillance Network. "Fragmentation debris" includes satellite breakup debris and anomalous event debris, while "mission-related debris" includes all objects dispensed, separated, or released as part of the planned mission.

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
2101 NASA Parkway
Houston, TX 77058

www.nasa.gov
http://orbitaldebris.jsc.nasa.gov/