NASA ORBITAL DEBRIS LARGE-OBJECT BASELINE POPULATIONS IN ORDEM 3.0

P. H. Krisko
Jacobs, Mail Code JE104, 2224 Bay Area Blvd., Houston, TX, 77058, USA, paula.krisko-1@nasa.gov

A. B. Vavrin* and P.D. Anz-Meador[t]

The NASA Orbital Debris Program Office (ODPO) has created and validated high fidelity populations of the debris environment for the latest Orbital Debris Engineering Model (ORDEM 3.0). Though the model includes fluxes of objects 10 µm and larger, this paper considers particle fluxes for 1 cm and larger debris objects from low Earth orbit (LEO) through Geosynchronous Transfer Orbit (GTO). These are validated by several reliable radar observations through the Space Surveillance Network (SSN), Haystack, and HAX radars. ORDEM 3.0 populations were designed for the purpose of assisting, debris researchers and sensor developers in planning and testing. This environment includes a background derived from the LEO-to-GEO ENvironment Debris evolutionary model (LEGEND) with a Bayesian rescaling as well as specific events such as the FY-1C anti-satellite test, the Iridium 33/Cosmos 2251 accidental collision, and the Soviet/Russian Radar Ocean Reconnaissance Satellite (RORSAT) sodium-potassium droplet releases. The environment described in this paper is the most realistic orbital debris population larger than 1 cm, to date. We describe derivations of the background population and added specific populations. We present sample validation charts of our 1 cm and larger LEO population against Space Surveillance Network (SSN), Haystack, and HAX radar measurements.

I. INTRODUCTION

Over the last three decades, NASA researchers in the field of orbital debris have sought insight into the mechanisms of debris generation and propagation. They have been aided over time by more sophisticated instrumentation and data analysis techniques.[1] Today, the radar systems of the SSN, the Haystack radar, and the Haystack Auxiliary (HAX) radar contribute heavily to the detections of LEO debris (i.e., ranging from an altitude of about 200 km to 2000 km). Haystack and HAX typically provide 1000 hours per year of statistical data (5 mm and larger and 3 cm and larger, respectively). These data sets supported the development of a Bayesian statistical model for the ORDEM 3.0 yearly populations, with the LEGEND model populations serving as the *a priori* condition.[2] The final product is a set of individual objects larger than 1 cm in size that span LEO to GTO. The orbital dynamic forces and mechanism for fragmentation are considered similar.

II. LEGEND-BASED POPULATIONS

The LEGEND model provides the generic population background for the environment presented here. Coupled with a set of yearly launch, maneuver, and breakup event files, LEGEND deposits intact objects (e.g., spacecraft, rocket bodies, mission related debris) into initial operational orbits, and deposits breakup fragments from known breakup events (by the NASA Breakup Model in LEGEND).[3] For the purpose of building this orbital debris baseline population, all such orbiting objects 1 cm and larger in size are propagated yearly within the code. The statistical radar data sets are used in the Bayesian method to hone these larger sized objects

Figures I-A and I-B display the generic population background 1 cm and larger in LEO and in LEO through GTO, respectively. Inclination families are clearly seen in LEO (Figure I-A). For example, old Soviet SL8 rocket bodies populate the inclination straddling 83°. Sun-synchronous spacecraft must inhabit the inclinations around 100°. Figure I-B extends perigee height through geosynchronous heights. Here low inclination GTO objects are seen, as well as MEO constellations (i.e., GPS, GLONASS) roughly clustering around 15000-25000 km perigee heights and 55°-65° inclinations.

* GeoControls, Mail Code JE104, 2224 Bay Area Blvd., Houston, TX, 77058, USA
[t] Jacobs, Mail Code JE104, 2224 Bay Area Blvd., Houston, TX, 77058, USA

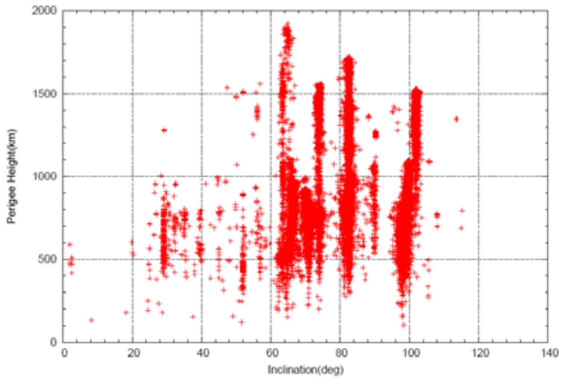

Fig. I-A: LEGEND-based 1 cm and larger object inclination vs. perigee height in LEO.

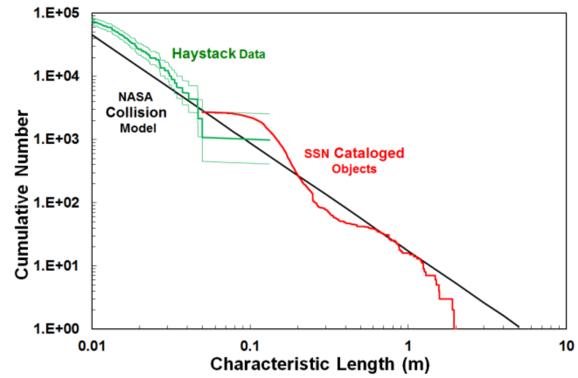

Fig. II: FY-1C fragments (SSN, Haystack data) with NASA collision model comparison. Courtesy P.D. Anz-Meador and M.J. Matney (NASA).

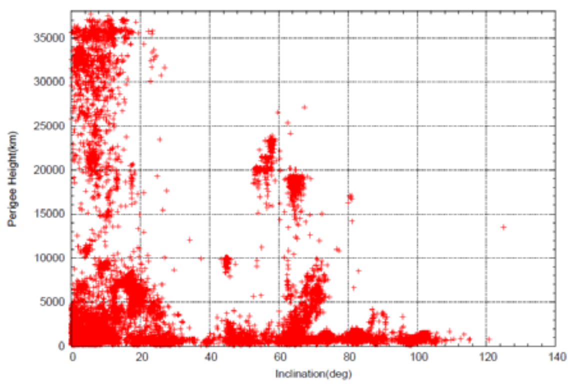

Fig. I-B: LEGEND-based 1 cm and larger object inclination vs. perigee height in LEO through GTO.

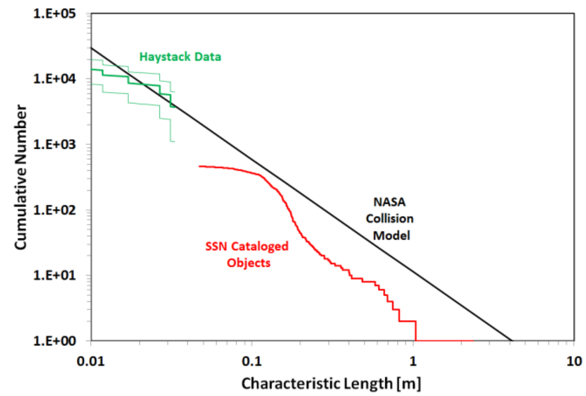

Fig. III-A: Iridium 33 fragments (SSN, Haystack data) with NASA collision model comparison. Courtesy P.D. Anz-Meador and M.J. Matney (NASA).

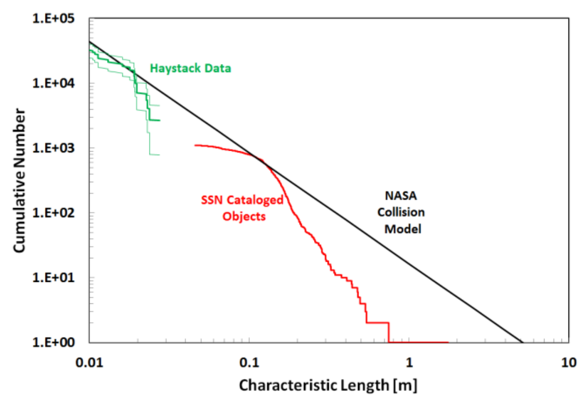

Fig. III-B: Cosmos 2251 fragments (SSN, Haystack data) with NASA collision model comparison. Courtesy P.D. Anz-Meador and M.J. Matney (NASA).

III. ADD-ON POPULATIONS

Two significant breakup events occurred during the development of ORDEM 3.0, the FY-1C anti-satellite test that occurred on 11 January 2007 at a 860-km altitude, and the accidental collision of Iridium 33 and Cosmos 2251 on 10 February 2009 at 779 km. Together they increased the catalogued LEO debris population by 60% and negated decades of international cooperative-mitigation activities. They also provided opportunities to view young debris clouds in LEO and further refine breakup modeling. Figures II, III-A, and III-B display the cumulative number of objects vs. size (1 cm and larger) for each of these breakups. The NASA collisional breakup model distribution for each event is overlaid on each figure. Haystack statistical data is derived from observations of the FY-1C cloud in 2007 and from observations of Iridium 33 and Cosmos 2251 debris in 2009.

One other earlier population is included separately in the database. It is actually a compilation of 16 events of RORSAT nuclear reactor core ejection (at end-of-life) in the 1980s. These reactors used liquid sodium-potassium (NaK) metal for their coolant. This coolant vented from the main coolant loop when the reactors were jettisoned (i.e., these events are not breakups).

These objects are easily identified by their spherical shape, which gives a radar signature with a high circular polarization ratio (larger than 0.94), and by their release altitude of ~900 km. Figure IV shows the full population in orbit.

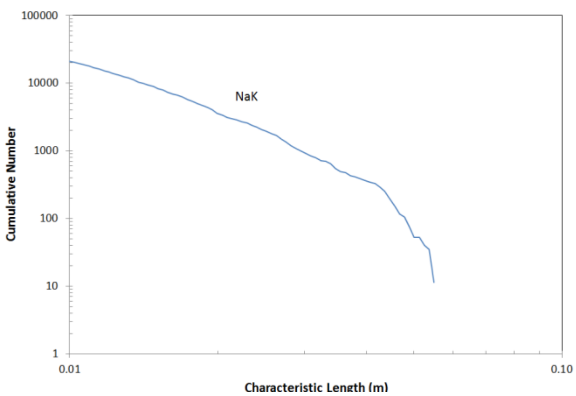

Fig. IV: RORSAT NaK droplets. Sizes in the figure range from 1 cm to 6 cm.

IV. POPULATION VALIDATION

The populations derived from the Bayesian process are validated by direct comparison with radar measurement populations. The observations (counts) were used to derive populations with observation hours, object RCS-to-size conversion and altitude, and inclination estimates. The LEGEND model results and population overlays were properly scaled, resulting in the final ORDEM 3.0 population. Over 200 comparison charts were available and reviewed for validation.

Figures V-A and V-B are illustrative of typical radar derived population fluxes vs. object size. In Figure V-A, radar measurements from Haystack, HAX, and SSN give a cumulative population flux within the altitude range of 900 – 950 km. The calculated ORDEM 3.0 flux is overlaid along with its 1-σ uncertainty bars. Radar error bars are also given. In the figure, the horizontal 'Haystack (75E)' line (with crossing constant error bars) above 10 cm is indicative, in the cumulative picture, of no data. The 'SSN (BU frag. only)' population peaks at 10 cm and decreases nearly linearly toward larger sizes. The overall comparison between radar and model fluxes is very good.

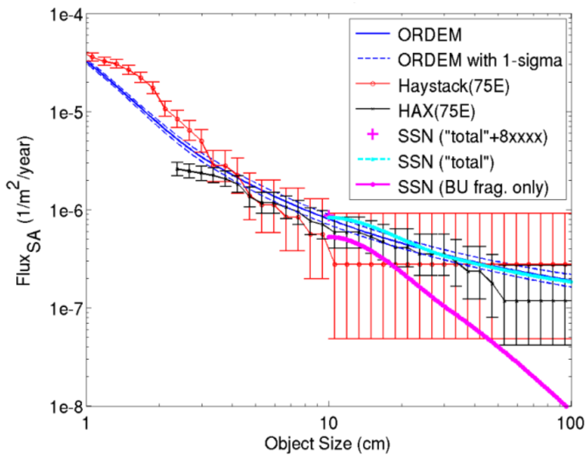

Fig. V-A: Radar- and model-derived population fluxes, Alt: 900 km – 950 km, Haystack/HAX counts 279/44. Courtesy Y.-L. Xu (NASA).

Not all radars and yearly data sets yield a large number of observations. An example is shown in FigureV-B. Again the region of no data is obvious, this time in both Haystack and HAX. The only population comparison is below 2 cm, and ORDEM 3.0 with 1-σ is within the radar error bars.

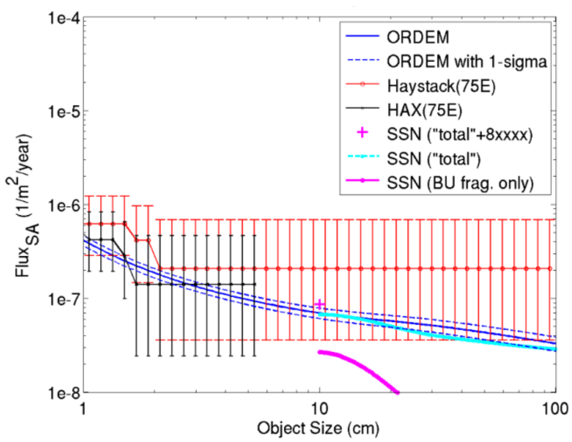

Fig. V-B: Radar- and model-derived population fluxes, Alt: 400 km – 450 km, Haystack/HAX counts 22/8. Courtesy Y.-L. Xu (NASA).

Another available comparison is that of radar-derived population fluxes vs. object altitude. In Figure VI, 50 km-wide altitude bins with 1-σ are displayed for ORDEM 3.0 populations. Available Haystack fluxes with error bars are overlaid. In this figure, the radar was operating in a 'Near Range-Window' mode. An example of a 'Far Range-Window' mode is shown in Figure VII.

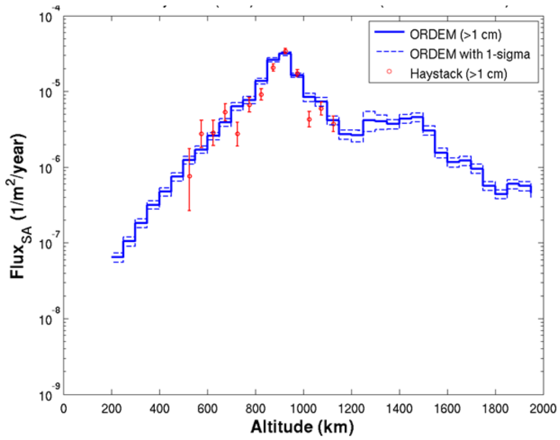

Fig. VI: Radar and model derived population fluxes, near range-window, observation hours 264.9, number of detections of 1 cm and larger objects is 522. Courtesy Y.-L. Xu (NASA).

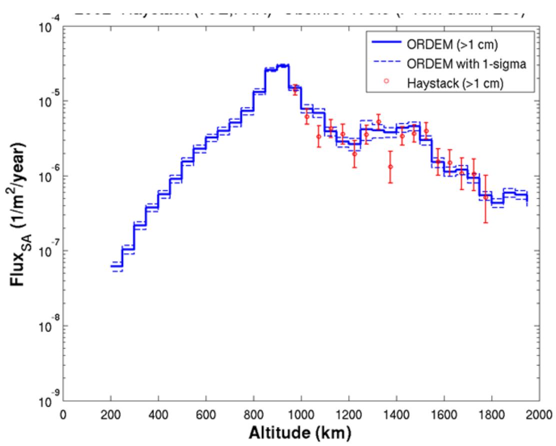

Fig. VII: Radar and model derived population fluxes, far range-window, observation hours 175.5, number of detections of 1 cm and larger objects is 250. Courtesy Y.-L. Xu (NASA).

V. SUMMARY

The NASA ODPO has developed and validated the orbital debris model ORDEM 3.0. This paper highlights populations in LEO through GTO larger than 1 cm in size. The model includes a background derived from the LEGEND environmental model, with a Bayesian rescaling of statistical radar data (Haystack/HAX). It also includes recent specific breakup events, namely the FY-1C anti-satellite test, the Iridium 33/Cosmos 2251 accidental collision, and the RORSAT sodium-potassium droplet releases. The populations have been compared favorably to hundreds of radar population data sets. It is the most realistic orbital debris population database to date.

VI. REFERENCES

1. Xu, Y.-L. Statistical inference in modeling the orbital debris environment, IAC-06-B6.2.03, *57th International Astronautical Congress*, Valencia, Spain, October 2006.

2. Xu, Y.-L., et.al. Modeling the LEO orbital debris populations for ORDEM2008, *Adv. Space. Res. 43* (2009), pp. 769-782.

3. Johnson, N.L., et al. NASA'S new breakup model of EVOLVE 4.0. *Adv. Space. Res. 28* (9), pp. 1377-1384, 2001.