Derelict Space Situational Awareness (SSA) for Free

(Paper 20105)

Darren McKnight
Harrison Shay
Rohit Arora
Centauri

ABSTRACT

The debris-generating potential of clustered massive derelicts in low Earth orbit (LEO) makes them a uniquely interesting component for monitoring and characterization. Massive objects (hundreds to thousands of kg in mass) that are abandoned in close proximity to each other create the possibility of collision events involving from 1,500 kg to 18,000 kg. This paper provides the structure and access to a new web site where intermediate data on nearly 1,300 massive derelicts can be accessed to encourage more research into this component of space situational awareness (SSA).

1. INTRODUCTION

The aerospace community has largely focused on how to prevent the potential for the cascading of the debris environment that was identified decades ago (i.e., the Kessler Syndrome). [1] The traditional response to combatting the Kessler Syndrome is the steady, long-term removal of abandoned rocket bodies and payloads (i.e., five large objects a year for 100 yr). [2] The typical active debris removal (ADR) analysis assumes that we are unable to determine which events might occur first so the overall effect is that one must remove 35-50 objects on average to prevent a single collision. Around 15 collisions are anticipated to occur in this scenario (which would erode space flight safety significantly even while preventing environmental instability).

Assurance of immediate space flight safety as the primary objective has encouraged us to examine the possible short-term, highly consequential events (vice trying to determine the average collision hazard across the entire cataloged population). This focus led us to examine debris "hot spots" in Earth orbit where the most massive objects might interact with each other at hypervelocity speeds (i.e., above 6 km/s).

It was shown previously that two SL-16 rocket bodies colliding around 850 km could potentially double the cataloged population in one instant which in turn would result in the reduction of the operational lifetime of all satellites in the 650-1050 km altitude range by an average of 10%. [3] An examination of the satellites residing within this altitude range amount to at least $10-15B [4] of operational space systems; 10% of this asset pool is indeed significant.

A focus on individual events within specific clusters of massive derelicts has produced empirical data documenting the number and proximity of conjunctions between these massive objects. In the spirit of establishing a culture of safety, it is imperative to monitor, characterize, and share information about these individual events in order to motivate responsible action. This experiment is called the Massive Collision Monitoring Activity (MCMA). [5]

A recent review of aerospace and business catastrophes clearly show the importance of such communications: *"Multiple near misses preceded (and foreshadowed) every disaster and business crisis we studied and most of the misses were ignored or misread.* Our work also shows that cognitive biases conspire to blind managers to near misses. Relevant cognitive biases are normalization of deviance (i.e., over time accept anomalies) and outcome bias (i.e., focus on results more than, often unseen, complex processes)." [6] More pointedly, the experts in the psychology of anomaly reporting and risk acceptance state that "viable approaches to preventing [such] catastrophes is to observe near-misses and use them to identify and eliminate problems before they produce large failures." [7]

Originally, MCMA began by examining only the interaction between paired rocket bodies and payloads that were deposited by the Soviets/Russians into four clusters; these are called the pure clusters. The MCMA clusters have evolved over time to be "complete" by adding other space hardware over 700 kg in LEO and focused on (1) proximity of apogees and perigees (i.e., clumped in altitude); (2) common inclination values (speculated to cause

Copyright © 2020 Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) – www.amostech.com

greater interaction rates); (3) total mass involved in a potential collision; and (4) altitude of the center of the cluster (i.e., high enough so that debris produced would be long-lived).

These criteria resulted in the selection of several clusters in low Earth orbit (LEO) that include nearly 1,300 objects that have an aggregate mass of nearly 2,300,000 kg. The table below provides the salient characteristics of these clusters that MCMA scrutinizes on a daily basis and is depicted in the web site that is the subject of this paper.

Tab. 2. MCMA now includes nearly ~1,300 objects comprising over 2.3M kg of mass. [8]

Cluster	#	Total Mass (kg)	Average Mass (kg)	Span (km)	Spatial Density, (#/km^3)	"Risk": Average Mass x SPD	Average Collision Rate/yr
C615	165	304,764	1847	369	0.147	272	~1/1,000
C775	154	242,407	1574	246	0.167	263	~1/400
C850	97	316,019	3258	201	0.174	567	~1/800
C975	355	417,618	1176	199	0.438	515	~1/90
C1200	40	55,905	1398	255	0.019	26	~1/10,000
C1500	73	95,730	1311	206	0.037	48	~1/1,500
cleo	196	350,462	1788	1,700	[redacted]		
chigh	189	572,814	3031	40,000			
TOTAL	**1269**	**2,355,720**	[redacted]				
[illegible]	[redacted]		[illegible]	[redacted]			

2. WEB SITE COMPONENTS

The web site that has been created to provide MCMA data is called the Massive Derelict Watch and a draft site is available at https://smcwebsite.wixsite.com/smcwebsite. This is a temporary site; the final site will be announced during the presentation of the poster. The purpose of the site is to show data related to the massive derelicts in LEO selected due to their debris-generating potential and has four primary sections: monitoring, characterizing, academic papers, and raw data query.

The home page describes this organization and provides commonly used terms:

Massive Derelict: Either an abandoned rocket body or a non-operational payload, with a mass of 700 kg or more. These are of greatest concern since they have no ability to avoid collisions and, if they were to collide, they would produce many thousands of debris fragments.

Lethal Non-Trackable (LNT): An LNT is a piece of debris in LEO that is large enough to cause mission-terminating damage to an operational satellite (> 5mm) but too small to be detectable by radar (< 10cm). LNTs make up 98% of the LEO debris population as the cataloged population in LEO is ~20,000 and there is an estimated ~600,000 to 900,000 LNT in LEO.

Conjunction: A conjunction is an instance when two derelicts pass less than 5 km from each other; also known as an "encounter."

Cluster: A cluster is a collection of massive derelict objects that reside in a narrow altitude range. Characterized by frequent conjunctions and a statistically higher probability of collision than average in LEO.

Pure Cluster: A pure cluster is a cluster of Soviet/Russian paired rocket bodies and non-operational payloads ("paired" meaning the payload plus the rocket that deployed it). The four pure clusters are C775, C850, C975, and C1500 (denoting the altitudes at which their orbits are centered) consists of 490 Soviet/Russian rocket bodies and non-operational payloads. These clusters have been monitored since May 2016.

Complete Cluster: Complete clusters are groups of massive derelicts (i.e., mass greater than 700 kg) in LEO (i.e., an altitude below 2,000 km) that reside in altitude bands that are identified by the approximate center of the cluster. The

Copyright © 2020 Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) – www.amostech.com

complete clusters are C615, C775, C850, C975, and C1500 that comprise objects from many nations. The complete clusters were identified and started being monitored within MCMA beginning 1 October 2019. Massive derelicts in LEO that span more than one cluster are included as the complete cluster CLEO. Likewise, massive derelicts in elliptical orbits with a perigee below 2,000 km and an apogee near semi-synchronous or geosynchronous orbits are included as the complete cluster CHIGH.

Risk: Risk is the product of the probability of an event occurring between two cluster members and the consequence of that event. The surrogate for probability of a collision is derived from the spatial density of the objects within the clusters. Similarly, the consequence is derived from the total mass involved in a collision; this is proportional to the number of fragments that will likely be produced as the result of a collision.

On the web site, the clusters are hyperlinked to listings of the objects in each cluster described above. For example, the members of the pure cluster C775 are listed in Fig. 2.

NoradId	Launch Date	Country
4391–SL-8 R/B	1970-04-25	CIS
5218–SL-8 R/B	1971-05-07	CIS
5555–SL-8 R/B	1971-10-13	CIS
6125–SL-8 R/B	1972-07-20	CIS
6271–SL-8 R/B	1972-11-01	CIS
6320–SL-8 R/B	1972-12-21	CIS
6683–SL-8 R/B	1973-06-08	CIS
6826–SL-8 R/B	1973-09-08	CIS
6853–SL-8 R/B	1973-10-02	CIS
6993–SL-8 R/B	1973-12-19	CIS
7273–SL-8 R/B	1974-04-23	CIS
7284–SL-8 R/B	1974-04-29	CIS
7426–SL-8 R/B	1974-08-29	CIS
10293–SL-8 R/B	1977-08-24	CIS
12115–SL-8 R/B	1980-12-23	CIS
12879–COSMOS 1312	1981-09-30	CIS
12880–SL-14 R/B	1981-09-30	CIS
12983–SL-8 R/B	1981-11-28	CIS
13589–COSMOS 1410	1982-09-24	CIS
13590–SL-14 R/B	1982-09-24	CIS
15171–COSMOS 1589	1984-08-08	CIS
15172–SL-14 R/B	1984-08-08	CIS
15469–COSMOS 1617	1985-01-15	CIS
15475–SL-14 R/B	1985-01-15	CIS
16138–COSMOS 1690	1985-10-09	CIS
16144–SL-14 R/B	1985-10-09	CIS
17146–SL-8 R/B	1986-11-21	CIS
17177–COSMOS 1803	1986-12-02	CIS
17178–SL-14 R/B	1986-12-02	CIS
17582–COSMOS 1827	1987-03-13	CIS
17588–SL-14 R/B	1987-03-13	CIS
18334–COSMOS 1875	1987-09-07	CIS
18340–SL-14 R/B	1987-09-07	CIS
18788–COSMOS 1909	1988-01-15	CIS
18794–SL-14 R/B	1988-01-15	CIS
19785–COSMOS 1994	1989-02-10	CIS
19791–SL-14 R/B	1989-02-10	CIS
20232–COSMOS 2038	1989-09-14	CIS
20238–SL-14 R/B	1989-09-14	CIS
20735–COSMOS 2090	1990-08-08	CIS
20741–SL-14 R/B	1990-08-08	CIS
21028–COSMOS 2114	1990-12-22	CIS
21034–SL-14 R/B	1990-12-22	CIS
21299–COSMOS 2143	1991-05-16	CIS
21305–SL-14 R/B	1991-05-16	CIS
21728–COSMOS 2157	1991-09-28	CIS
21734–SL-14 R/B	1991-09-28	CIS
21779–COSMOS 2165	1991-11-12	CIS
21785–SL-14 R/B	1991-11-12	CIS
22034–COSMOS 2197	1992-07-13	CIS
22040–SL-14 R/B	1992-07-13	CIS
22182–COSMOS 2211	1992-10-20	CIS
22188–SL-14 R/B	1992-10-20	CIS
22687–COSMOS 2252	1993-06-24	CIS
22693–SL-14 R/B	1993-06-24	CIS
22999–COSMOS 2268	1994-02-12	CIS
23005–SL-14 R/B	1994-02-12	CIS
23441–COSMOS 2299	1994-12-26	CIS
23447–SL-14 R/B	1994-12-26	CIS
23787–GONETS D1 1	1996-02-19	CIS
23793–SL-14 R/B	1996-02-19	CIS
24725–COSMOS 2337	1997-02-14	CIS
24731–SL-14 R/B	1997-02-14	CIS
27055–COSMOS 2384	2001-12-28	CIS
27061–SL-14 R/B	2001-12-28	CIS

Fig. 2 The members of pure C1500 include rocket bodies and payloads of Soviet/Russian origin.

Copyright © 2020 Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) – www.amostech.com

Fig. 3 shows the Monitoring section of the web site while Fig. 4 shows the Characterization page.

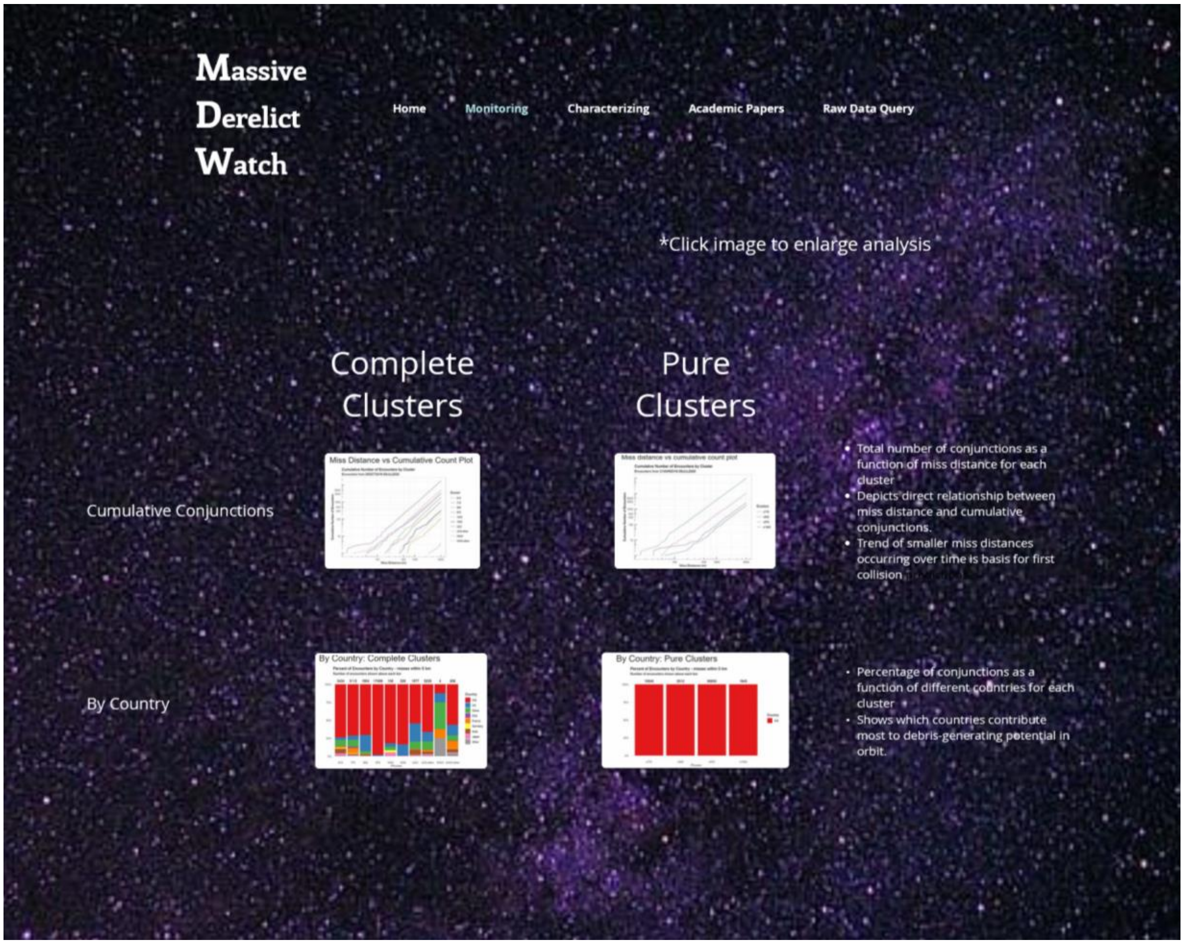

Fig. 3 The Monitoring page provides several summary graphics that give a high-level understanding of massive derelict interactions in LEO. The Cumulative Conjunctions plots for both the complete clusters and the pure clusters provide a quick depiction of total conjunction history. The y-axis is the cumulative number of conjunctions that exceed a given miss distance (i.e., x-axis). The maximum miss distance examined in MCMA is 5 km. The "By Country" stacked bar graphs provide a quick depiction of the country origins for objects involved in the conjunctions by cluster depicted in the Cumulative Conjunctions plots. When a user clicks on a graphic, the jpg is activated. For the "By Country" graphs, even though only the 5 km (or less) is shown on the web site, when the graphic is clicked on, the user is provided two plots: less than 5 km and less than 500 m. The 500 m miss is more relevant to reasonable probability of collision values whereas the misses above 500 m are useful for statistical risk assessments only.

Copyright © 2020 Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) – www.amostech.com

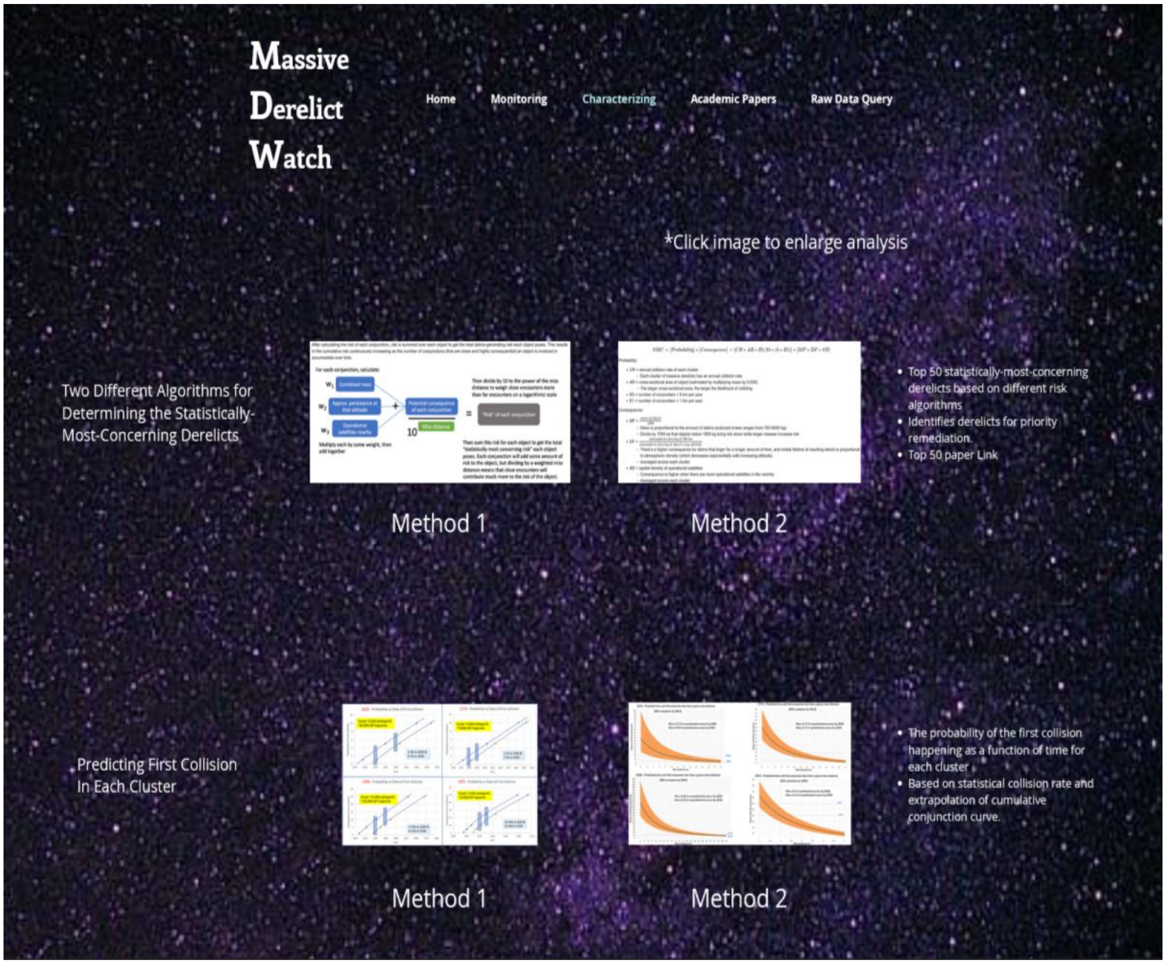

Fig. 4 The Characterization page provides summary graphs for two Statistically-Most-Concerning (SMC) algorithms applied to the complete clusters and two depictions of predicting the "first collision" within each complete cluster. The SMC algorithms were developed as part of a paper to be released at the upcoming virtual International Astronautical Congress (IAC) in which 11 different such algorithms were consolidated to create a composite top 50 SMC objects as a guiding document for remediation priorities. [9] The "first collision" assessments were developed to show the severity of the state of the clusters. The first method applies the Gamma distribution as described in [5]. The second method was developed internally to Centauri and used the MCMA data in a completely different way. As with the Monitoring page, when the user clicks on the graphic more details are provided along with a larger, exportable version of the graphic.

The Academic Papers page provides links to papers that detail previous efforts in MCMA research.

The Raw Data Query page is still under construction. The intent of this page is to provide the user to query the raw conjunction data form the 1,269 objects within the MCMA database based upon conjunctions performed by AGI's STK of TLEs derived from Space-track.org since May 2016 for the pure clusters and October 2019 for the complete clusters.

It is important to remember that, even though TLE accuracy has improved greatly since 2014, these conjunction results should not be used for collision avoidance purposes. They are valuable and accurate enough for statistical analyses but not for single event (i.e., deterministic analyses).

Copyright © 2020 Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) – www.amostech.com

3. CLOSING COMMENTS

The Massive Derelict Watch web site has been created to encourage others to apply research resources to better characterizing the debris-generating potential of the massive derelicts abandoned in LEO. It is hoped that as this data is exposed and used for research that further insights will be provided to those who are actively developing and operationalizing debris remediation solutions.

4. REFERENCES

[1] Kessler, D. “Collision Frequency of Artificial Satellites: The Creation of a Debris Belt”, Journal of Geophysical Research, Vol. 83, No. A6, 1978.

[2] Liou, J.-C., Johnson, N.L. A sensitivity study of the effectiveness of active debris removal in LEO. Acta Astronautica 64, 236–243, 2009a.

[3] McKnight, D., Di Pentino, F., and Knowles, S., “Massive Collisions In LEO - A Catalyst To Initiate ADR,” 65th International Astronautical Congress, Toronto, CA, September 2014.

[4] Approximate cost of existing satellite systems was determined by examining databases at http://www.satview.org and http://uscusa.org.

[5] McKnight, D., Walbert, K., Casey, P., Behrend, S., and Speaks, S., PRELIMINARY ANALYSIS OF TWO YEARS OF THE MASSIVE COLLISION MONITORING ACTIVITY,” 68th Astronautical Congress, Adelaide, Australia, September, 2017.

[6] Robin Dillon Merrill: Tinsley, C., Dillon, R., and Madsen, P., "How to avoid catastrophe," HBR, April 2011.

[7] Dillon, R.; Tinsley, C.; Madsen, P.; and Rogers, E.; "Organizational Correctives for Improving Recognition of Near-Miss Events" Journal of Management, Vol.42, No.3, March 2016 671-697.

[8] McKnight, D., Witner, R., and Arora, R., “Derelict Deposition Study,” International Orbital Debris Conference, Houston, TX, US, December 2019.

[9] McKnight, D., et al, “Identifying the Top 50 Statistically-Most-Concerning (SMC) Derelict Objects in LEO,” 71st International Astronautical Congress (IAC) – The CyberSpace Edition, Dubai, UAE, October 2020.

Copyright © 2020 Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) – www.amostech.com