Space Junk Research Notes

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Debris FAQ [1].
Acronyms:

- LEO = Low Earth Orbit
- OP = Orbital Plane

ToSite:

1. http://www.orbitaldebris.jsc.nasa.gov/library/IAR_95_Document.pdf
2. http://ccar.colorado.edu/asen5050/projects/projects_2003/wilson/
3. National Research Council Staff. Orbital Debris : A Technical Assessment. Washington, DC, USA: National Academies Press, 1995. ProQuest ebrary. Web. 28 January 2016.
4. https://fas.org/irp/agency/dod/jason/leo.pdf
5. http://www.esa.int/Our_Activities/Operations/Space_Debris/About_space_debris
6. http://www.globalcomsatphone.com/hughesnet/satellite/altitudes.html
7. http://www.nap.edu/read/4765/chapter/4#23

1 Model 3: Space Launches

Building upon model 3 we introduced yearly LEO spacecraft launches as stochastic events. These events will introduce a satellite to one of the levels in LEO and a constant amount of debris to that same level. There were three main components that we had to figure out in order to incorporate spacecraft launches into our model.
Target Level: In order to determine which level of our model a launch would arrive to we looked at the Space Launch Report yearly log files [4]. First we looked at the log files from 2010-2015 to calculate the average launches to LEO. These launches were categorized in the log files as: LEO/ISS, LEO/SS-O, and LEO (which we refer to as LEO/Other). From the data in Appendix we calculated the values in table

Avg. LEO Launches Per Year	Ratio of LEO/ISS	Ratio of LEO/S	Ratio of LEO/Other
36.4375	0.2850	0.3842	0.3308

Table 1: Calculated ratios from data in Appendix .

LEO/ISS (km)	LEO/SS-O (km)	LEO/Other (km)
$370 - 460$	$600 - 800$	$200 - 1600$

Table 2: Altitude ranges used to determine which level a given launch ends up in.

Launch Rate Per Level: In order to determine the launch rate, and incorporate as a stochastic event in our model we looked at the Space Launch Report yearly log files from 2000 to 2015 [4]. Using the data in these files we obtained the average number of launches per year.
Amount of released debris: Our model takes the amount of debris released per launch as a constant. We set this constant to 70 because according to [2] a detailed study of a Russian launch mission determined that 76 different objects were put into orbit.

2 Background

Since the launch of Sputnik in 1957 the number of artificial objects orbiting the Earth has been steadily increasing. In 1978, Donald Kessler of NASA hypothesized that there exists a critical mass for space debris, above which the frequency of collisions and creation of new debris would cascade and Earth's orbital space would become too densely filled with debris for space travel to be feasible. Thousands of spacecrafts have been sent into orbit, from which as of 2015, 696 are operational [?], making the rest of them space debris. Space debris is not only constituted by nonfunctional spacecrafts, as shown in Figure ??. Note that most of the objects in Figure ?? are either released at the beginning of a mission (after launch), during the lifetime of a satellite or the end of life of the satellite (breakups and/or malfunctions) [2, 3]. If the combination of all of these space travel related objects is not controlled in someway, Donald Kessler hypothesis poses a big threat to space travel in the future.

Assumptions

1. Spacecrafts and satellites in MEO and GEO have extremely low probabilities to be affected by the amount of debris in those orbits. Therefore, debris removal strategies should only target LEO.
2. The number of LEO launches per year is constant. This constant was obtained from the average number of LEO launches from 2010-2016.
3. The fraction of the total number of launches per year that go to the ISS (370-460) to the Sun Synchronous Orbit (SS-O) (600-800) and to Other altitudes (200-1600) in LEO is constant. This constant fractions from the total number of launches were calculated using the number of launches from 2010-2015 to these altitudes.
4. The altitudes for yearly missions to the ISS are uniformly distributed between 370-460km. The same goes to missions to SS-O and Other.
5. The amount mission-related debris is constant across missions, and all of the debris released by the mission is dropped at the altitude where the mission ends. For example, a mission going to the ISS will drop all of the debris somewhere between 370-460 km.
6. The amount of debris obtained from figure at a certain level is uniformly distributed throughout the level.

Systematic Production

We are going to define the term Systematic Production as the debris production due to space assets: i.e satellites, rockets, space stations, humans, etc.

- At launch rocket bodies are left orbiting the earth. These create multiple kind of debris: motor casings, aluminum oxide exhaust particles, nozzle slag, and solid fuel fragments. Basically a lot of stuff is freed in the early life of the spacecraft. [2]
- As the spacecraft is subjected to solar heating, solar radiation, and atomic oxygen material degradation begins to free small particles of paint and multi-layer insulation [2]
- Towards the end of life object breakup becomes a possibility. This can be due to a collision or explosion [2].
- Most spacecrafts that reach their end of life (EOL), either through termination or malfunction are left in orbit.[3]

This will be highly dependent on the rate of spacecraft launches. A log of the number of space launches is kept in the Space Launch Report [4]. We want to determine the distribution of LEO altitudes at which these spacecrafts end up. To this end, it is important to note that LEO altitude is usually determined by a target orbit lifetime, t_{orbit} [4]. Depending on the function of the satellite the altitude is chose accordingly. According to [6] these are:

- 300-600mi: Observation satellites used for photography, mapping, and environmental observations.
- 300-600mi: Search-and-rescue satellites also belong to this orbit. They are used to transmit emergency radio signals in case of an emergency.
- 3,000mi: Science satellites
- 6,000: GPS satellites
- Geostationary: Weather satellites, and communication satellites
- ISS orbital altitude range = [370km, 460km] [5]
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Mission-related Debris

Everything in this section was obtained from book [7]. The majority of functional spacecraft are accompanied into Earth orbit by one or more stages (or "rocket bodies") of the vehicles that launched them.

- Usually **1** rocket body is left in LEO.
- high-altitude spacecraft such as GOES (Geostationary Operational Environmental Satellite) may release up to three separate rocket bodies in different orbits along the way to its final destination. Relatively few spacecraft types
- Second stage and third stage are left at 200km
- Two mission related objects are left in LEO. Lifetime 6months to 36 months. We need to change into altitude
- The amount of debris released can be quite large; a detailed study of the debris released by one Russian launch mission revealed that 76 separate objects were released into orbit from either the launch vehicle or the spacecraft.

Appendix A. Launch Data

The amount of mission-related debris that is produced every year is proportional to the number of yearly launches. In order to calculate a reasonable measure for mission-related debris we had to first gather yearly LEO launch data. Furthermore, we had to estimate where in the LEO this debris would end up to determine in which level of our model it would end up. To this end we classified LEO launches as either: ISS (International Space Station), SS-O (Sun-Synchronous Orbit) or Other. Other launches are the ones that were not cataloged as either ISS or SS-O. The following tables contain the data gathered from [4], that was used to calculate an average number of launches and the percentage of the launches that go to either the ISS, SS-O or some other LEO altitude.

Appendix C. Altitude vs. Decay Times Extrapolation

The data in Figure **??** only shows us the decay times up to $1,000$km. The length of our final simulations was around a $100-200$ years, which means that all of the initial debris in the higher levels will have completely decayed. Therefore we decided to extrapolate the data so it would contain altitudes up to $2,000$km as shown in 1 so that not even in the longest simulations we have the debris from the higher levels reach the first level.

Year	LEO Launches	Total Launches
2000	33	85
2001	27	59
2002	31	65
2003	25	63
2004	26	54
2005	29	55
2006	33	66
2007	36	68
2008	36	68
2009	45	78
2010	37	74
2011	43	84
2012	40	78
2013	48	81
2014	50	92
2015	44	86

Table 3: Launch data obtained from the Space Launch Report log files [4].

Year	LEO ISS Launch	LEO SS-O Launch	LEO Other Launch
2010	12	12	14
2011	13	17	13
2012	12	14	14
2013	12	16	20
2014	13	23	14
2015	12	18	11

Table 4: LEO Launch data obtained from the Space Launch Report log files. ISS: International Space Station; SS-O: Sun Synchronous Orbit; Other: Not specified [4].

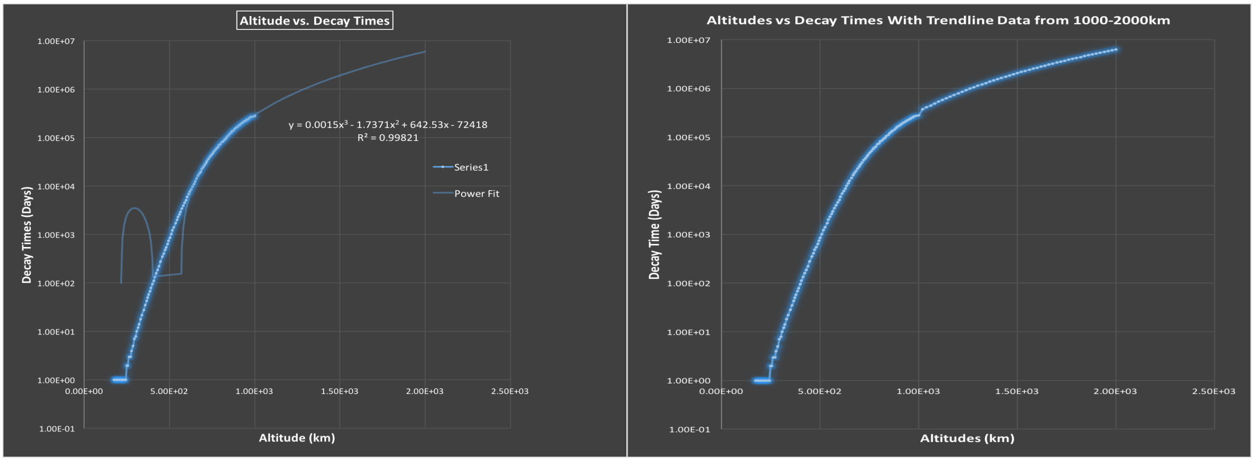

Figure 1: Left: Altitude vs Decay Times data with trendline. Right: Altitude vs Decay Times sample from both original data and extrapolated data of Left. Samples from from 175-1,000 km come from the original data and the sample from 1,000-2,000 km come from the trendline.

Natural Reduction

We are going to define the term Natural Reduction as the amount of debris that is reduced due to natural causes such as falling into earth.

- In LEO, satellites in circular orbits of 200 to 400km re-enter the atmosphere withing a few months [1].
- At 400 to 900km orbital lifetimes range from a few years to hundreds of years [1].
- Find plots of initial orbital altitude vs. orbital lifetime. This will allow us to find an average function at first and then we can refine it to take into account mass. One of these plot can be found in page 29 of the orbital debris book.
- The previous item needs to be combin

Initial Condition for the model

- A normal distribution radially and a uniform around the sphere. For this we will have to find some estimates of LEO
- Large object

Model Definition

- Collisions will be random. They will have a rate associated to the local amount of debris.
- Explosions will be random. It might be associated to number of spacecrafts
- Malfunctions will be random. Single debris added.
- End of mission fixed time.
- The launches will be random. Binomial throughout time. With this we can calculate a rate. Birth rate into each level will be normal, which is reasonable because of the initial distribution
-
- Large object

Sources of Debris

The following numbers were obtained from [5].

- 6% of the catalogued orbital population are operational spacecraft
- 30% are decommisioned satellites. These include upper stages and mission-related objects.
- Explosions are the cause of objects ¿ 1cm.
- Meteorite flux are the cause of 0.1mm - 1mm
- 25% of the trackable debris was increased in anti-satellite test of 2007.
- Other sources
  - Most important: ore than 1000 solid rocket motor firing produce aluminium oxide (Al2O3) in the form of micrometre-sized dust and mm- to cm-sized slag particles
  -

Random Stuff

Figure 2 was obtained from [6].

- One problem with the LEO catalog is that the accuracy of predictions of the future location of objects in LEO is not always good. Because of this, the use of the LEO catalog as a collision avoidance tool is not always practical [2].
- Function spacecraft represents only about one fifth.[3]

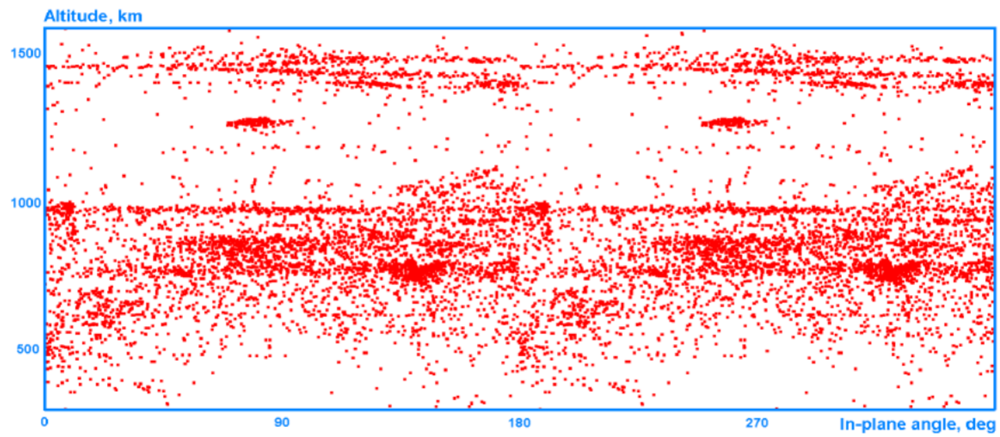

Figure 2: Tracked Objects Crossing the Orbital Plane of a Spacecraft in LEO

References

[1] National Aeronautics Space Administration (NASA). Orbital debris frequently asked questions. http://orbitaldebris.jsc.nasa.gov/faqs.html.

[2] J. Fagerberg, D.C. Mowery, and R.R. Nelson, editors. *Orbital Debris: A Technical Assesment.* National Academy Press, Washington D.C., 1995.

[3] Zach Wilson. A study of orbital debris. http://ccar.colorado.edu/asen5050/projects/projects_2003/wilson/.

[4] Ed Kyle. Space launch report. http://www.spacelaunchreport.com/index.html.

[5] European Space Agency (ESA). International space station. http://www.esa.int/Our_Activities/Human_Spaceflight/International_Space_Station/ISS_International_Space_Station.

[6] J. Pearson J. Carroll E. Levin. Active debris removal: Edde, the electrodynamic debris eliminator. *Space Manufacturing 14: Critical Technologies for Space Settlement*, October 2010.