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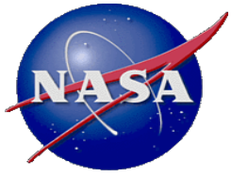

Misconceptions and Reality of Orbital Debris Risk

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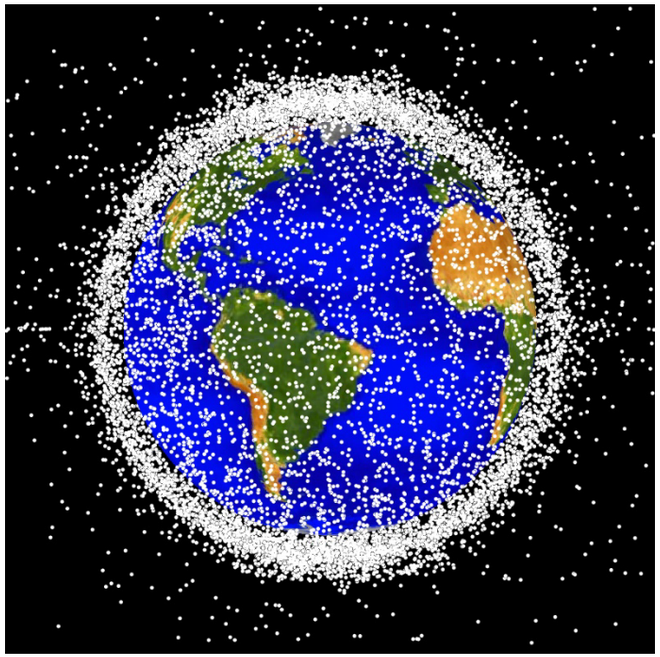
List of Misconceptions Addressed in this Talk

1. How much junk is “floating around” up there?
2. Doesn’t NASA track all that stuff up there?
3. The “Kessler Syndrome” could quickly make Earth orbit unusable
4. If we could just do collision avoidance better, we could solve the orbital debris problem
5. If we remove one object from space using Active Debris Removal (ADR), we stop one catastrophic collision from occurring
6. Space sustainability is an existential crisis

- This list is by no means comprehensive…

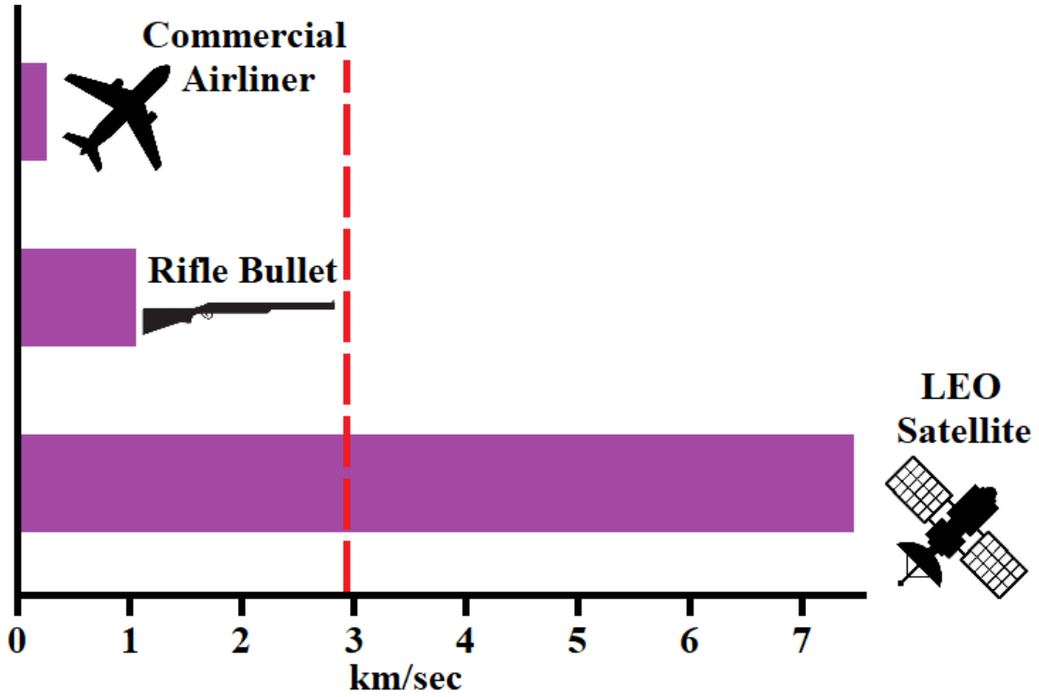
Misconception #1

- **How much junk is “floating around” up there?**
  - The movie “Wall-E” portrayed space junk in a static “solid shell” around the Earth
  - Orbital debris environment is not a “Dyson Sphere”



Misconception #1 – Floating Junk

- Of course, satellites in space don't "float around"
- In order for an object to maintain its orbit, it must "hurtle" around the Earth at orbital speeds
- If something is "floating" relative to you, you have spent a great deal of effort to rendezvous with it, and nothing else in the environment



Misconception #2

- **Doesn't NASA track all that stuff up there?**
  - "Tracking" means the ability to obtain an orbit measurement of sufficient accuracy to predict where it will be at a future time
  - The organization with the resources to track satellites is the U.S. Space Force (USSF) using the Space Surveillance Network (SSN)
  - The USSF maintains a catalog of objects, often including information on the object's origin, name, launch date, launch country, etc.
    - Does include some Analyst Satellites = trackable objects (usually small) of indeterminate origin

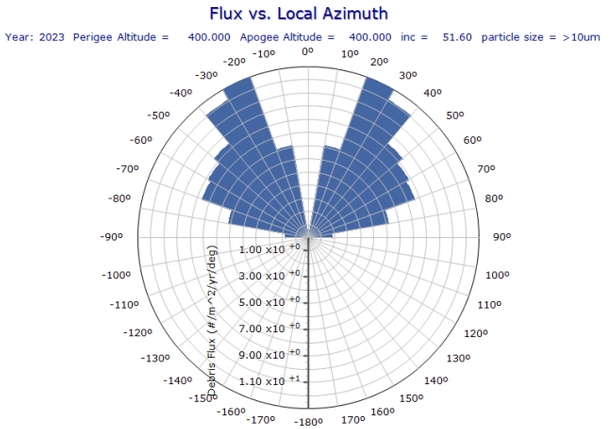
Source: GAO analysis of Department of Defense information. | GAO-23-105565

Misconception #2 – Who Tracks?

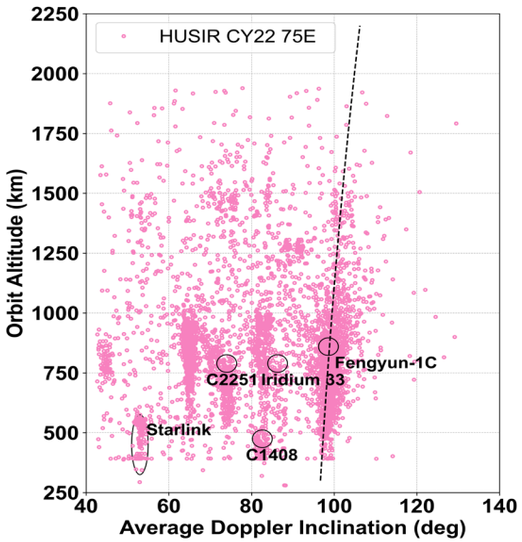
- **Tracking provides the capability to do collision avoidance warnings**
  - Currently provided to any registered user by the USSF
  - Note that US Dept of Commerce is tasked to take over some of these tasks in the near future
- **Because of sensitivity limits, only objects down to a minimum size can be tracked**
  - Historically > ~10 cm in LEO, > ~ 1m in GEO
  - Space Fence has extended that a bit lower in LEO
  - You can only avoid what you can track (= “the Catalog”)
    - You cannot avoid small stuff
    - You cannot avoid new stuff of any size until it is catalogued
- **A collision with an object >10 cm in size can cause catastrophic damage to any satellite**
  - Usually large enough to cause a catastrophic breakup of the “target”

Misconception #2 – Who Tracks?

- **NASA orbital debris efforts are concentrated on characterizing the smaller untrackable debris**
  - This consists of objects that can still cause significant damage to satellites
    - Most satellites can survive impacts by ~1 mm objects (but individual components can be damaged or destroyed)
    - Most satellites could experience significant damage by 1 cm objects
    - For every object we can track, there are many small objects we cannot track that will also damage your spacecraft



- **NASA uses several types of sensors in "staring" mode, to statistically estimate debris distributions in size, altitude, and orbit family**
  - Radar (objects > ~ 3 mm in LEO)
  - Optical telescopes (objects > ~10 cm in GEO)
  - Returned surfaces with damage (*in situ*, objects < ~1 mm down to a few μm in size)
- **NASA uses these data to construct Engineering Models**
  - These models define the environment to sufficient accuracy to calculate spacecraft risk and can be used to inform spacecraft design choices

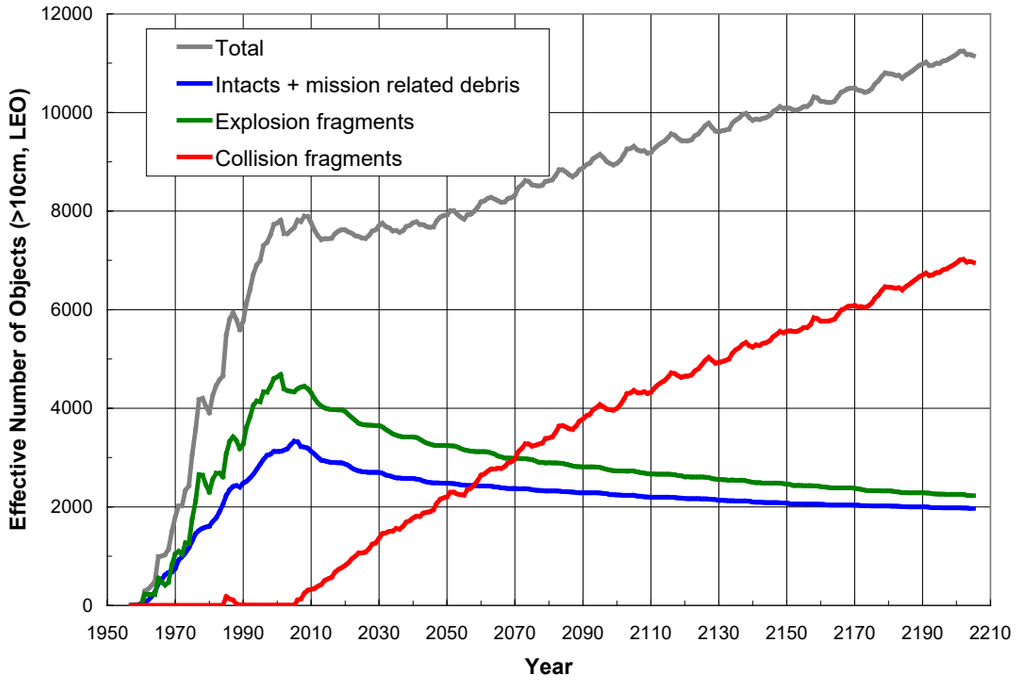


Misconception #3

- **The "Kessler Syndrome" could quickly make Earth orbit unusable**
  - In 1978, Don Kessler predicted that cascading satellite collisions could result in a "chain reaction" that would cause exponential growth in debris
  - The movie "Gravity" has the "Kessler Syndrome" accelerating in a matter of minutes
  - A "collisional cascade" occurs when the rate of debris production from collisions exceeds the rate at which debris are removed from the environment due to atmospheric drag
  - Don Kessler predicted that the "collisional cascade" eventually moves the environment toward a new equilibrium (cf. predator-prey equations), but you might not like the final state

Misconception #3 – Kessler Syndrome

- **Studies indicate the time scales of collisions and drag are on the scale of decades rather than minutes**
  - Current estimated catastrophic collision rate is 1 per ~10 years
  - Growth rate of fragmentation debris doubling time many decades



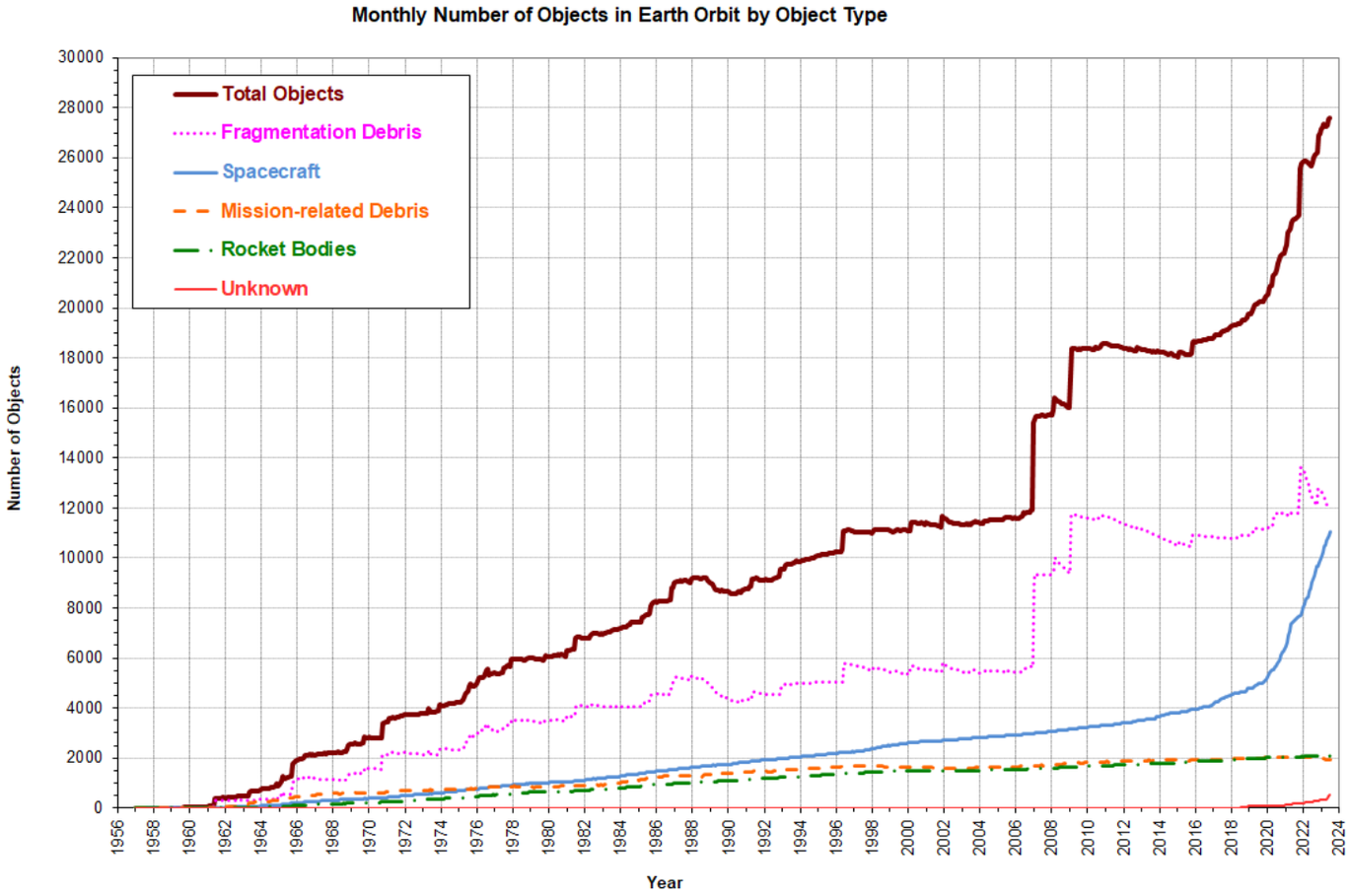
Misconception #4

- **If we could just do collision avoidance better, we could solve the orbital debris problem**
  - Long-term source of debris is from catastrophic collisions
  - Only a subset of satellites can maneuver and avoid collisions
    - Space-track.com lists:
      - 8900 active payloads
      - 19200 debris + 16600 analyst satellites = 35800 inactive objects
    - Assuming all these active payloads are 100% efficient at collision avoidance, and assuming all these objects can potentially collide with one another, collision avoidance mitigates

$$1 - \frac{(35800)^2}{(35800+8900)^2} \sim 36\%$$ of the catastrophic collision risk.

Misconception #4 – Collision Avoidance

- **Caveats:**
  - Not all active satellites can do collision avoidance (e.g., inert CubeSats)
  - Not all object orbits cross one another (many active satellites are in GEO)
  - The recent growth in active satellites is driven by large modern constellations, so they mitigate their own effects on the environment, but do not change the interactions of other types of objects present in the environment
  - Kessler Syndrome is still a long-term problem between inert objects (both legacy and new) in space
  - While collision avoidance is a prudent operational activity, it is only part of a larger comprehensive policy of debris mitigation



Misconception #5

- **If we remove one object from space using Active Debris Removal (ADR), we stop one catastrophic collision from occurring***
  - Despite the large number of objects in space, in reality only a small fraction will collide given their orbit lifetimes
  - Removing some large number of objects from space (the number varies with altitude and object size, but it is of order 30-50) will (statistically) prevent one collision
  - This means that in order for ADR to begin to be cost effective, each ADR *launch* will need to ultimately remove some minimal number of objects (~12?) from orbit

*thanks to Darren McKnight for calling my attention to this misconception

Misconception #6

- **Space sustainability is an existential crisis**
  - The orbital debris problem does have many characteristics of a conventional environmental problem
    - Tragedy of the Commons
    - Does not respect borders
  - In other aspects, however, it is different
    - While astronaut safety is important, most risks of space debris are purely economic in nature
    - Orbital debris has little effect on terrestrial biological ecosystems
    - There is no indication that on our current path space will be “unusable” in the foreseeable future, but that doesn’t mean we shouldn’t find ways to mitigate growth of debris
  - Recent concerns of “cultural” risks due to degradation of dark skies
    - However, this is primarily a space traffic issue with large constellations, not necessarily an orbital debris issue

Misconception #6 – Existential Crisis

- **Orbital Debris / Space Sustainability issues have historically offered excellent examples of how to address an environmental issue uncluttered by emotional appeals**
  - Space is a “domain”, like maritime and airspace, and despite many tragedies and challenges, we ultimately learn how to operate safely in these domains, and have the experience of cooperative international organizations to facilitate how to do this better
    - International Air Transport Association (IATA)
    - International Civil Aviation Organization (ICAO)
    - International Telecommunications Union (ITU)
    - UN’s International Maritime Organization (IMO)
  - When we started the Space Age in 1957, we did not understand the debris environment and its evolution and risk
  - Going forward, we can bring debris lessons learned forward for other regions of space activities (lunar, LaGrange regions) to avoid such problems in the future

Summary

- **Objects in orbit travel at very high rates of speed, with correspondingly high kinetic energies**
- **USSF is responsible for tracking and cataloguing large debris (> ~10 cm) in space, NASA is responsible for statistically categorizing debris too small to be tracked**
- **The Kessler Syndrome is expected to occur over long time scales, nevertheless, some regions in Earth orbit are sufficiently populated already to be unstable**
- **While collision avoidance is a prudent operational practice, it does not address the long-term risk of debris growth in the environment**
- **ADR missions would need to remove multiple objects per launch in order to be cost-effective**
- **Space Sustainability is an important environmental issue. It is not an existential crisis for the biosphere or even for space usage, but is an excellent model of how to be good environmental stewards in the future**

- **This list is by no means exhaustive – the subject is complex, and has entered the public consciousness, so misconceptions will likely continue**