How to Reduce Debris Impact Threats to and from Cubesats in LEO

Spring 2015 Cubesat Workshop
Cal Poly San Luis Obispo
April 22-24, 2015

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Should You Worry About Debris?

***No*, because:**

1. Cubesats have <1% as much target area as typical large satellites.
2. Nobody told us to (yet), and other cubesat programs don't worry about it.
3. We promise we'll learn about it before we bid on a big NASA program.
4. If we worry about one more unlikely problem, our project will fall apart.

***Yes*, because:**

5. Cubesats may be disabled even by <1 mm debris (at 10-15 km/sec).
6. Even a 1U cubesat can shred a ton-class intact object into lethal shrapnel.
   - *Damaging another space object makes you share its future liabilities.*
   - *So a 1 kg cubesat can share in liability for damage by a ton of debris.*
   - *This could trigger draconian new constraints on all future cubesats.*

It's your call—individually (#5), *and* as a community (#6).

A Useful Taxonomy for Debris in LEO

Untracked .... *Tracked* 

Cars
(~2500)

Intact objects, mostly ton-class; **~0.5%** of all lethal LEO objects
98% of target area & **99%** of mass for debris-creating impacts!
Easy to track & avoid, but the source of hubcaps & shrapnel

Hubcaps
(~10,000)

Tracked fragments, mostly >10 cm, <1kg: **~2%** of lethal objects
They dominate tracking costs, but most are too light to shred cars
46% are from just 2 collisions: Fengyun/A-sat + Cosmos/Iridium

Shrapnel
(~500,000?)

Lethal untracked fragments, <1cm; **>97%** of all lethal objects?
Too small to track & avoid (now), but too heavy to shield against
This is the main direct threat to assets, and it will remain so!

We worry mostly about a cascade of hubcap/car collisions in low earth orbit making more & more hubcaps. We should worry mostly about lethal shrapnel, and the car/car + hubcap/car collisions that create it.

Collision Threats to Cubesats (mostly ~1 mm)

~1 mm shrapnel can't shred a cubesat, but it is likely to disable it:

1. Typical impact velocities of 10-15 km/sec cause "internal hailstorms."
2. We don't know how many satellites have already been disabled by impact.
3. And we don't know what size impactor is needed to disable a cubesat.
4. And we don't even know how much mm-class shrapnel there is in LEO.

- Survival of the 4km x 2mm TiPS tether from 1996-2006 shows that NASA estimates of ~1 mm debris at ~750-1000km were ~10X too high. But now?

Most hypervelocity impact failures are hard to diagnose:

1. Changes in orbit period are likely to be well below drag variation "noise."
2. Resistive shorts due to aluminum deposits may be detectable & survivable.
3. A sudden change in attitude rates (if known) may be the best clue to impact.

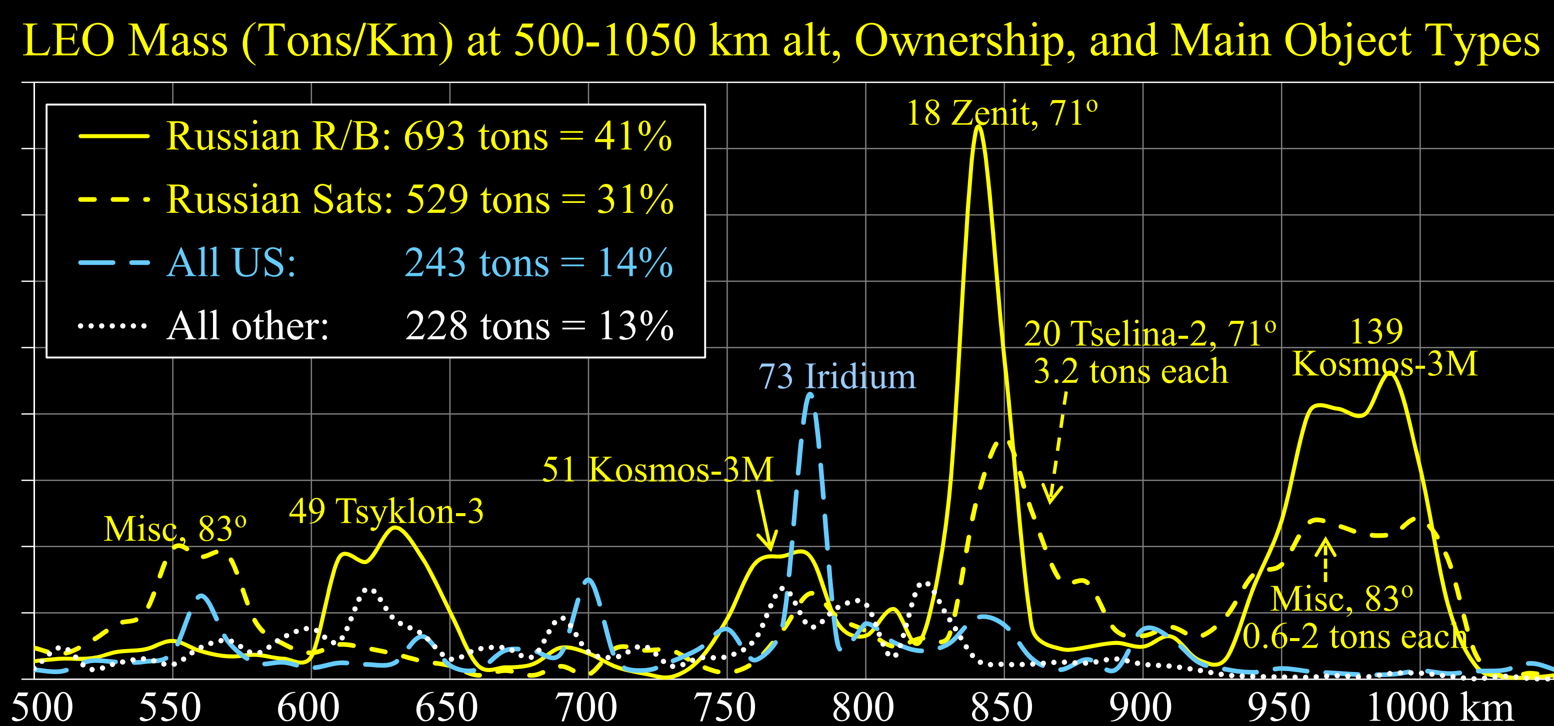
How to reduce this poorly quantified impact threat to cubesats:

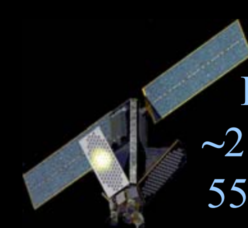
1. Cubesat orbit life scales with ~Alt^9, and tracked debris counts with ~Alt^6.
2. To minimize risks, fly as low as compatible with realistic mission needs.

What Can Long-Lived Cubesats Run Into?

1. The main thing to worry about <500 km is ISS (discussed in later slides).
2. Most shrapnel will come from >1 ton objects, which are also larger targets.
3. Shrapnel-creation by cubesat nearly scales with total target mass/km alt.
4. And the lifetime of that shrapnel also increases drastically with altitude.

➢ ***Flying lower cuts cubesat life, the # of objects it can hit, <u>and</u> shrapnel life.***





Shrapnel Creation by both Cubesats & "Cars"

Compare cubesat/car and car/car collisions at the same altitude:

1. Cubesat/car has only 1/2 the collision radius, so only 1/4 the area. (Good)
2. And cubesat/car collisions involve only 1/2 the total mass. (Also good)
3. And cubesat/car may create less shrapnel/kg. (But JSC doesn't think so)

- So cubesat/car shrapnel creation is ~1/4 * ~1/2 * ≤1, or ~10% of car/car.
  - But that is from cubesats weighing only 0.1-0.5% as much as typical cars.
- Do cubesats have a right to create 20-100X as much shrapnel per kg as cars?

Now compare cubesats in lower orbits (as most are):

1. Over the 350-750 km range, circular orbit life scales with ~Altitude^9.
2. And the mean orbit life of any shrapnel created also scales with ~Altitude^9.
3. Non-ISS "car" mass scales with ~$\text{Alt}^{5.5}$ at 250-570km; ~Alt^1 at 570-1000km.

- Over 350-750 km range, expected shrapnel-years scales with ~Altitude^{21}.
  - Flying 20% lower cuts life by a factor of 7.5, but mean shrapnel-yrs by ~100!

Cubesats and the >800,000 lb Gorilla (ISS)

ISS has most of the mass (and cost?) of all operating satellites in LEO.

Worry, even though you can't hit ISS (it will dodge all tracked objects):

- Having to dodge any cubesat could lead to new constraints on cubesats.

  (A useful definition of debris is "any space object that costs less than yours.")

How can you reliably avoid posing a threat to ISS?

1. Deploy from ISS into a slightly lower orbit:
   a) Without propulsion, cubesats ejected aft from ISS cannot re-contact ISS.
   b) Use propulsion plus reliable controls approved by the ISS program:
      1) Like ESA's GOCE, run in place below ISS, until you run out of propellant.
      2) Climb through ISS altitude, stay in orbit longer, then decay through ISS altitude.
2. Deploy from something else and avoid direct ISS control.
   - But implications remain similar, and have similar impact on the cubesat world.

Cubesat Deployment from ISS

Deploying non-propulsive cubesats from ISS seems best for many:

1. Deploying aft from ISS + ballistic coefficient limits preclude later re-contact.
   - By contrast, all cubesats that go above ISS will eventually decay through ISS orbit.
2. There is little to run into below ISS, and any shrapnel would deorbit quickly.
3. If an orbit life of months is enough for your mission, you should consider this.
   - 3U cubesats might roughly double their orbit life by flying end-on most of the time.
4. It helps ISS when non-propulsive cubesats deploy from ISS, not above it.
   - Policy folks have said they weren't thinking of this when they set ISS cubesat policy.
   - If we don't remind them of this benefit to ISS, we might accidentally lose ISS hosting.

But propulsive cubesats face multiple challenges:

1. Safety in and near ISS constrains use of toxic or energetic propellants
2. Control after leaving ISS: can you prove that your cubesat won't "go rogue"?
3. Propulsion is costly, and reliable cubesat control may make it far more so!

Conclusions

1. Cm-class shrapnel is the main direct debris threat to large LEO assets.
2. Cubesats pose ~10-100X typical shrapnel-creation risks per unit mass.
   - ➢ The actual risk is modest, but high relative risk could trigger new constraints!
3. Flying as low as compatible with the mission reduces:
   - ➢ The local population of "mm-class shrapnel" that can kill your cubesat.
   - ➢ Cubesat orbit life, which drives the chance of running into something else.
   - ➢ The population density of large objects that you could run into and shred.
   - ➢ The lifetime of shrapnel created by any collision with a ton-class object.
   - ➢ Orbit life scales with Alt^9; lifetime shrapnel risks from cubesats with $\sim Alt^{21}$.
4. Don't focus on 25-year rules; focus on ISS implications on cubesats.
5. For low cost and hassle, deploy from or below ISS, without propulsion.
6. If you need propulsion, consider using it to "run in place" below ISS:
   - ➢ This allows better resolution for earth imaging, and reduces radiation doses.
   - ➢ But any ability to reach ISS altitude seems likely to somehow raise your costs.

Backup Slides

A Larger Context for Debris in LEO

Debris and the 1972 UN Liability Convention

Key details in 1972 UN Convention on Liability for Space Objects:

1. Damage from reentry poses full liability; in space, it is "for fault" *(undefined!)*.
2. If A launches B's payload from C's territory, all 3 have launching state liability.
3. Selling and/or re-registering an object doesn't move the launching state liability.
4. Damaging another state's space object makes you share in its future liabilities.
5. But the convention lets signatories agree "off-line" on reimbursement terms for different cases, for losses suffered due to liability payouts under the convention.

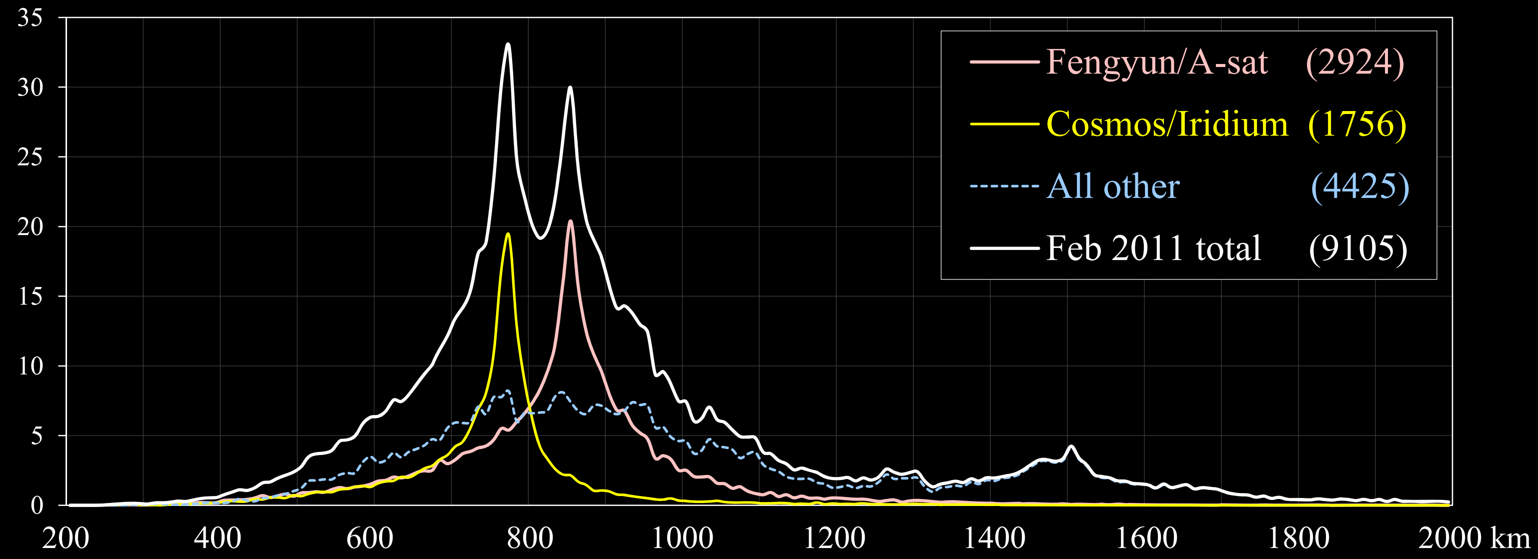
Possible implications:

1. Nudging US+Russian debris <1020 km can greatly reduce LEO shrapnel creation.
2. This prevents collisions now, while letting actual debris removal take more time.
3. A bilateral US/Russia agreement may be both necessary <u>*and*</u> sufficient; no UN or other multi-lateral agreement seems needed to deal with most current LEO debris.

What Does Existing "Hubcap" Tracking Data Tell Us?

1. Tracked fragments from two recent collisions are 46% of all tracked fragments!
2. Fragments typically depart from the source trajectory at 1-2% of orbit velocity.
   - Smaller fragments probably spread over a wider altitude range than hubcaps do.
3. RCS + decay data show typical 2007 & 2009 fragments are only ~100 grams.
   - So few hubcaps made by collision can shred ton-class "cars": $E_k < 40\ J/g_{total}$.
   - But 1-5 kg cubesats hitting ton-class cars at 10-15 km/sec have $E_k >> 40\ J/g_{total}$.
   - **And soon, most of the 1-5 kg tracked objects in LEO may be cubesats.**

Tracked <1 kg LEO "Hubcap" Population per Km Altitude, in February 2011



What Can We Do About Future Shrapnel Costs?

Options for individual operators:

1. Don't worry about it, but do accept a growing risk of asset loss from it.
2. Armor new assets, to increase the mass threshold for lethal impact.
3. Use lower altitudes, preferably below ISS. (Easiest option for cubesats!)

Options needing better debris detection & tracking (probably optical):

4. Detect and track shrapnel precisely, so assets can affordably dodge it.
5. Use pulsed laser ablation to nudge cars & hubcaps, to prevent collisions.

Options involving wholesale debris removal:

6. Melt <u>and vaporize</u> shrapnel (& hubcaps?) w/continuous laser heating.
7. Deorbit shrapnel & hubcaps (even cars?) using pulsed laser ablation.
8. Capture & deorbit large debris, or collect for later deorbit or recycling.

Creating a Shrapnel Risk Reduction Market

1. There will be no market for reducing shrapnel creation, until reduction costs less than impact loss or avoidance. The figure of merit for decision makers is $, not debris counts in 200 yrs.

2. But we don't even know lethal shrapnel populations or impact losses. And since we don't track shrapnel, we can't avoid it.

3. Detecting & tracking lethal shrapnel will put a $ cost on future impact losses and avoidance ops, allowing rational planning.

4. "Shrapnel birth control" may appeal mostly to major long-term LEO users like DoD & NASA, but only if it gets cheaper than the other options. But one can also argue that all LEO users should fund removal of as much risk as they add in the future.

Should LEO Parking Fees Pay for <u>Some</u> Removal?

<u>Debris risk changes form a continuum:</u>

+ Fragment by impact or explosion (or failed removal!)
  Put new non-maneuvering object into crowded orbit
  Launch new object into a low or uncrowded orbit

0 No change—eg, benign failure of launch or removal
  Nudge an object to preclude a potential collision
  Move an object from crowded to uncrowded altitude

- Deboost an object into a short-lived orbit or reentry

We expect free parking in the suburbs, <u>but not downtown</u> (LEO).

*If those adding risk won't pay for removal, **<u>why should anybody else?</u>***

To get $ for net reduction, LEO users may have to null out additions.

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EDDE

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Optical Tracking and Laser Debris Removal

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