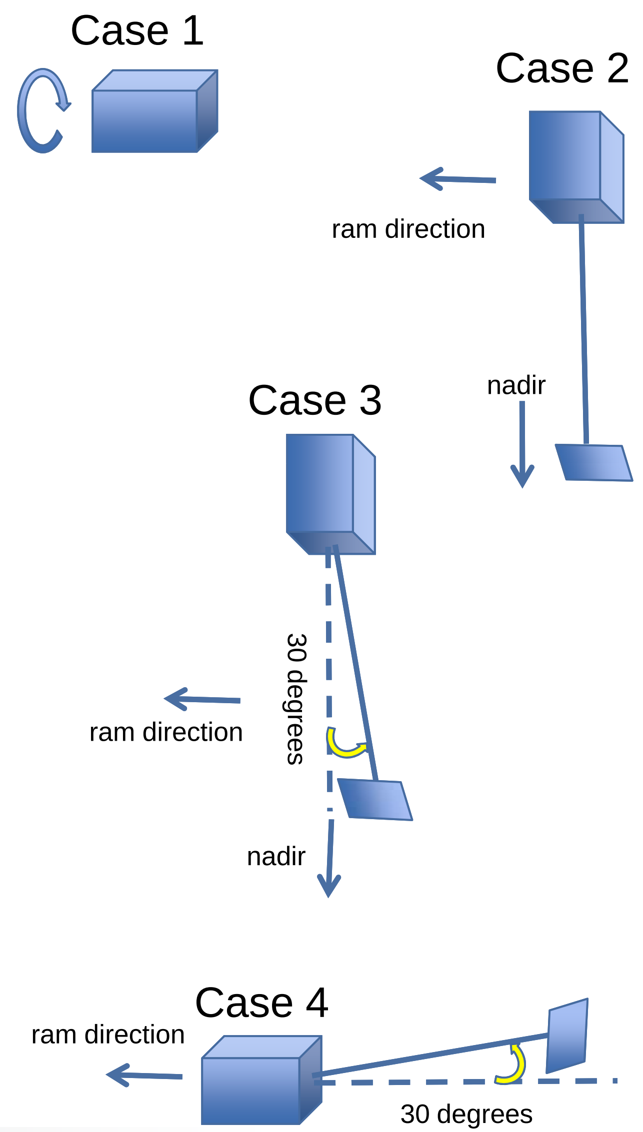
AeroCube 5 Drag Enhancement Device

- In order to comply with the 25-year LEO de-orbit requirement, a passive electrodynamic tether is deployed from AeroCube 5 bus.
  - *Orbit decays faster due to electrodynamic force*
  - *Increase in surface area also increase orbit decay rate (atmospheric drag)*
- The tether has an end mass plate for stabilization. The electrodynamic forces should passively stabilize the spacecraft and deployed tether system in a gravity gradient configuration.
  - *Device provided by a commercial company Tethers Unlimited Inc.*
  - *Total device mass = 83 grams*
  - *Tether tape dimensions (16 m length, 75 mm wide)*
  - *End plate dimensions (100 mm x 83 mm x 6.5 mm)*
  - *Deployed two years after spacecraft operations are complete*

AeroCube 5.0 Case Descriptions

- 4 cases were considered:
  1. *Aerocube body only (assumes average tumble configuration)*
     - Assumes tether is not deployed.
  2. *Aerocube and tether device deployed (assumes gravity gradient stabilization)*
     - Tether system is fully deployed and in a gravity gradient stabile orientation until reentry.
  3. *Aerocube and tether device deployed (gravity gradient stabilization with libration of the tether of ~30 degrees from nadir)*
     - Tether system deployed but uncertainty in the stabilization effects
       - *Assumption taken from conversations with Nestor Voronka and Rob Hoyt of Tethers Unlimited*
  4. *Aerocube and tether device deployed (alignment with velocity vector with libration of the tether of ~30 degrees from the velocity vector)*
     - A different orientation to determine the range of lifetimes.



AeroCube 5.0 Initial Conditions

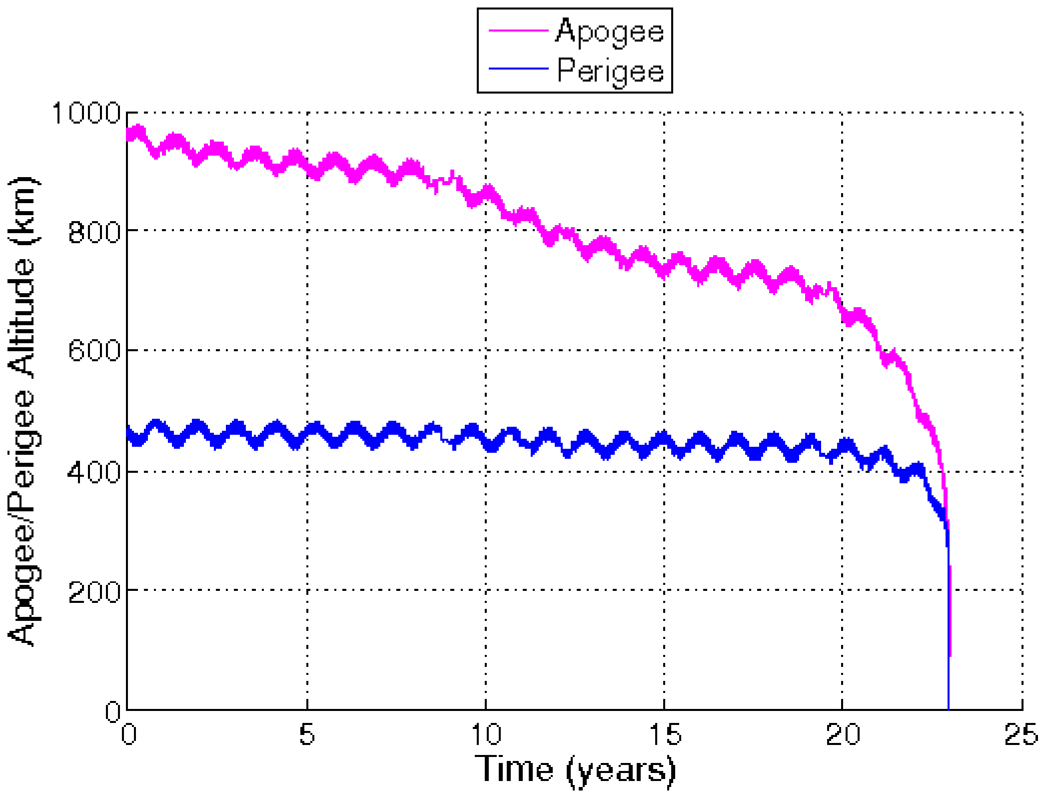
- Area estimation:

  The AeroCube 5 satellite core body is 10.26 x 10.26 x 17.02 cm

  - *Case 1: Aerocube body (assuming tumble) area = 0.023 m^2*
  - *Case 2: Aerocube body + tether system (gravity gradient alignment) with = 0.79 m^2*
  - *Case 3: Aerocube body + tether system (gravity gradient alignment with 30 degree libration about nadir)= 0.74 m^2*
  - *Case 4: Aerocube body + tether system (velocity vector alignment with 30 degree libration about ram direction) = 0.41 m^2*
  - *All areas with tether take into account twist.*
    - Ref. Noord, J.L., West, B., Gilchrist, B., "Electrodynamic Tape Tether Performance with Varying Tether Widths at Low Earth Altitudes.", AIAA, 39th Aerospace Sciences Meeting & Exhibit, Reno, NV, 2001
- Mass estimate: 2.2 kg
  - *includes CubeSat + tether drag device*
- Atmospheric Assumption: Considered 50th percentile (nominal) level of solar flux ($F_{10.7}$) and geomagnetic index (A_p)
  - *Used NASA Marshall Space Flight Center monthly predictions (based on NOAA data) from November 2012 to 2030; for years after 2030, repeated last 11-years (2019-2030) of Marshall predicted data*
- Initial orbit (provided by David Hinkley)
  - *469 x 972 km perigee/apogee altitude, 120^o Inclination, Epoch: December 1, 2013*

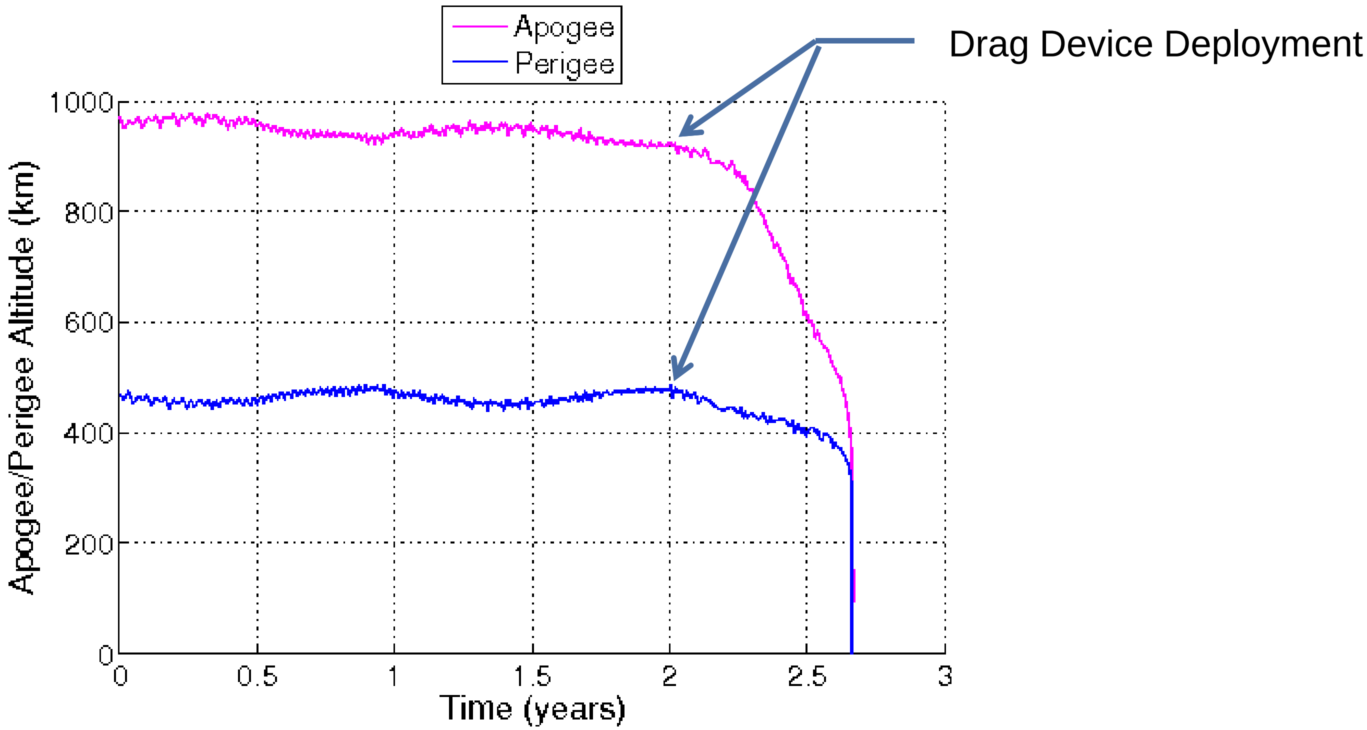
Lifetime Case 1: AeroCube5.0 Body (only)

- A 50th percentile atmospheric assumption (nominal solar activity) was used to determine the orbit lifetime
- The satellite by itself will de-orbit within 25 years after launch



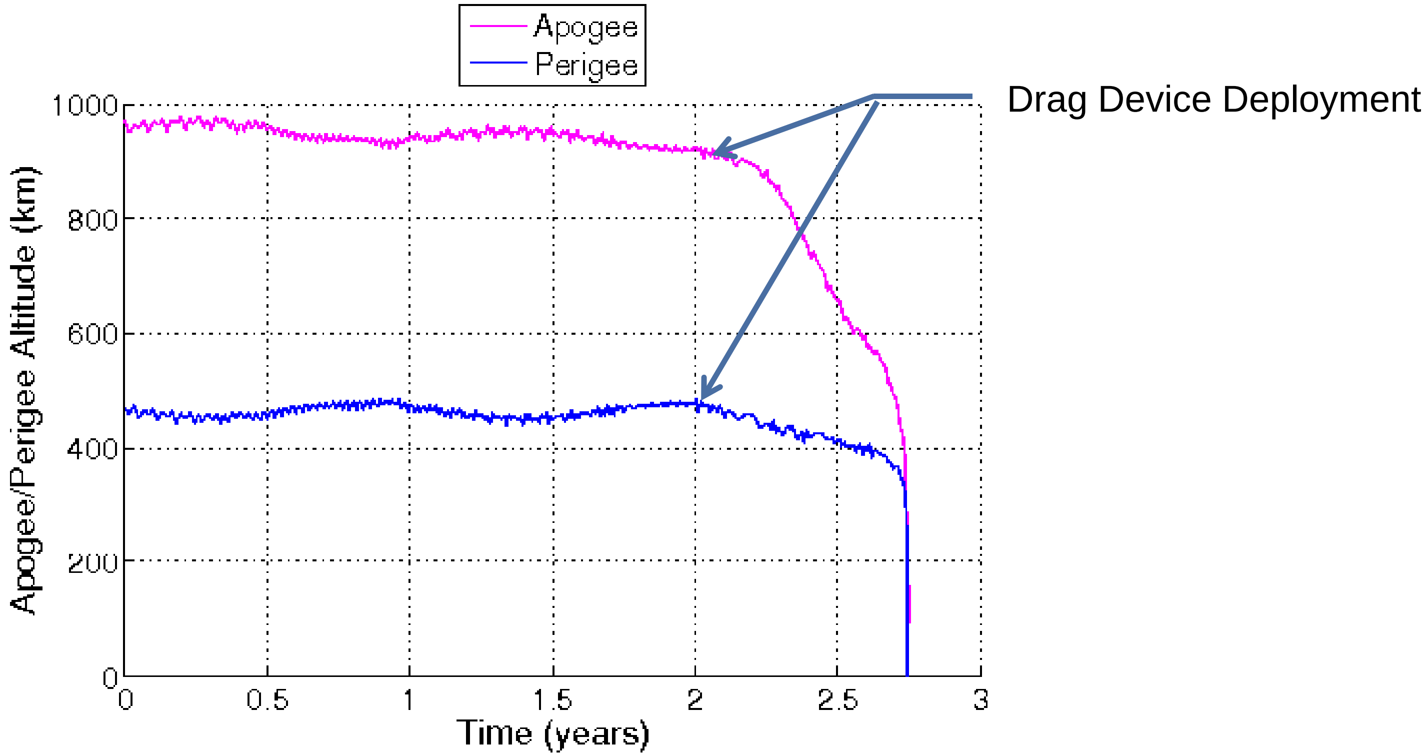
Lifetime Case 2: Aerocube 5 and Tether System (gravity gradient stabilized)

- A 50th percentile atmospheric assumption (nominal solar activity) was used to determine the orbit lifetime
- AeroCube will de-orbit well within 25 years after tether deployment at the 2 year mark



Lifetime Case 3: Aerocube 5 and Tether System (gravity gradient stabilized w/ 30 degree libration)

- The orientation of the spacecraft and drag device are assumed to oscillate about the nadir direction with an amplitude 30 degree (cone about nadir).
- 50th percentile atmosphere assumption (nominal solar activity)



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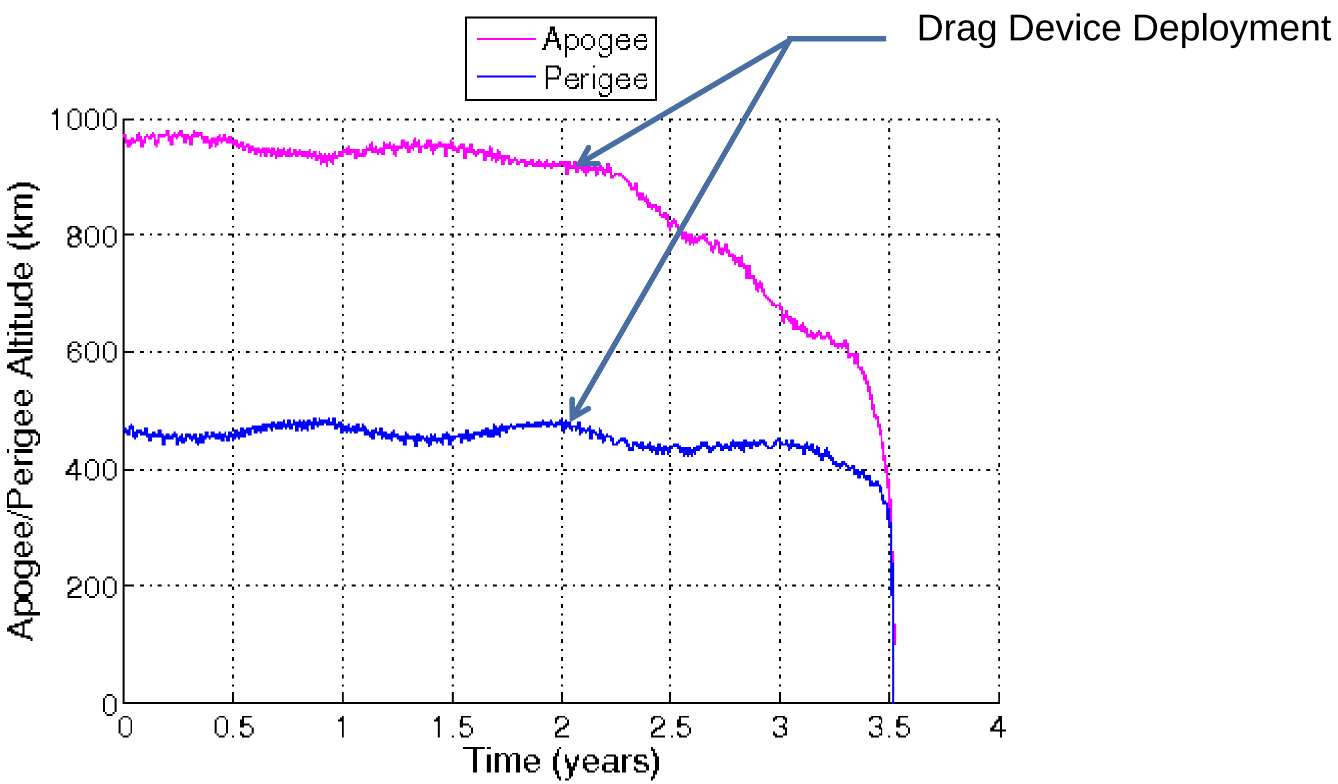
Lifetime Case 4: Aerocube 5 and Tether System (velocity vector aligned w/ 30 degree libration)

- The orientation of the spacecraft and drag device are assumed to oscillate about the negative velocity direction with an amplitude 30 degree (cone about negative velocity).
- 50th percentile atmosphere assumption (nominal solar activity)



Conclusions

- Case 1, where the AeroCube 5 satellite does not deploy the tether, results in an orbital lifetime of ~23 years
- Cases 2 - 4, significant reduction of orbit lifetime with successful deployment of the tether drag device
  - *Independent of orientation if successful tether deployment*
- Results are conservative since electrodynamic forces were not modeled.
- All cases comply with U.S. Debris Mitigation Standard Practice requirement of an on-orbit lifetime less than 25 years

Long-Term Orbit Propagation Tools

- Used precision integration code TRACE for orbit propagations
  - *Developed by Aerospace (TRACE is used throughout the industry, but we used the most recent Aerospace version)*
  - *MSISE-86 atmosphere model*
  - *70 x 70 modified EGM-96 Earth gravity model*
  - *Sun and Moon gravity*
  - *Solar radiation pressure (assumed reflectivity coefficient = 1.3)*
- AeroCube will perform operations for 2-years prior to deploying the drag device; this is accounted for in the propagation.
- Did not model electrodynamic force (conservative assumption for lifetime)