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AeroCube 5 and Pea Collision Probability Analysis

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Background

- AeroCube 5 (AC5) will be deployed as a secondary payload on Atlas V mission
- A previous analysis generated the long-term orbital evolution and lifetime of the AC5 mission orbit (Ref. 1)
- In addition, AC5 will eject brass/glass tubes (“peas”) into orbit; a long-term evolution and lifetime analysis was also performed for these “peas” (Ref. 2)
- At the request of David Hinkley (Mechanics Research Office), a long-term collision probability analysis was performed; the results are presented in this briefing package

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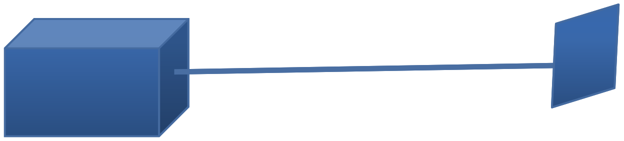
AeroCube 5 Drag Enhancement Device

- In order to comply with the 25-year LEO de-orbit requirement, a passive electrodynamic tether is deployed from AC5 bus.
  - *Orbit decays faster due to electrodynamic force*
  - *Increase in surface area also increases 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*



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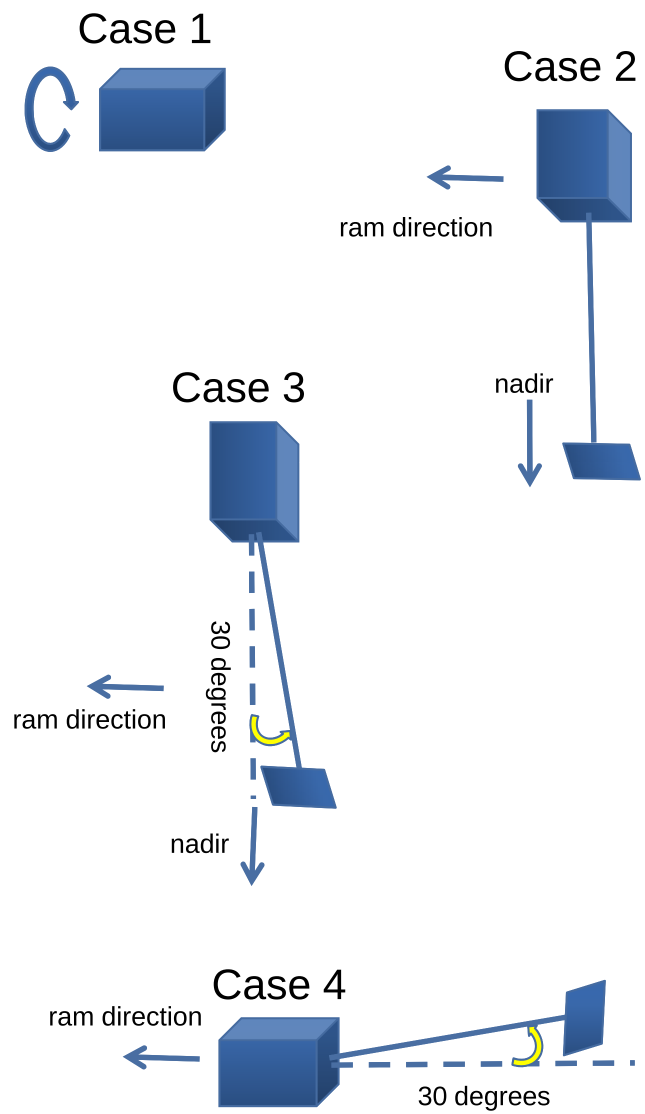
AeroCube 5.0 Case Descriptions

- 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.



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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*

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Collision Probability Assessment

- Used an orbit trace crossing method
  - *All crossings of the orbit traces of the primary (AC5 or “pea”) and the background objects as they evolve are determined*
    - Used TRACE evolution results for AC5 and “peas”
  - *The collision probability at each crossing is computed assuming the in-track position of the background object is uniformly distributed over 360 deg*
  - *Collision probabilities are accumulated across all orbit trace crossings over the probability assessment time interval*

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Computation of Collision Radius

- Collision probability at an orbit trace crossing depends on the collision radius
- For AC5 cases with no tether (Cases1, 5, and 9) and for a “pea”
  - *The primary (AC5 or “pea”) mean contact radius was computed by randomly picking unit vectors in three dimensions, using a simple rectangle model to represent the surfaces, and computing the root mean square*
  - *For a “pea”, the same process was used except a simple cylindrical model was used to represent the surfaces*
  - *For each primary/background object pair, the mean collision radius is the sum of the mean contact radius of both objects*
- For AC5 cases with a tether (Cases 2-4, 6-8, 10-12)
  - *An analytical formulation was developed that computes the combined mean collision radius given the AC5 tether configuration length, average width, and the background object contact radius (formulation assumes 3D random orientation of straight AC5 tether configuration)*
  - *This formulation is more accurate than the above method when the primary is elongated*

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Background Objects

- Used the current (as of November 20, 2012) version of the Aerospace Debris Environment Projection Tool (ADEPT) model of the current and future background population (Ref. 3)
  - *Model includes orbit trajectories and sizes for each object*
  - *Extends from LEO to GEO*
  - *Selected the Business as Usual population (background objects follow Disposal Option 2: "weak post-mission disposal," see Ref. 3)*
  - *Retained objects larger than 10 cm for this study*
- Model projects out 200 years and includes the following populations:
  - *0'th generation objects: Recent unclassified catalog population, a statistically-derived population of unknown objects (difference between cataloged and tracked populations), and future launched objects*
  - *1st generation debris from future explosions and from collisions between 0th generation objects (100 Monte Carlo scenarios)*
  - *2nd generation debris from collisions between 0th and 1st generation objects was not included in the collision probability analysis (contribution is small)*

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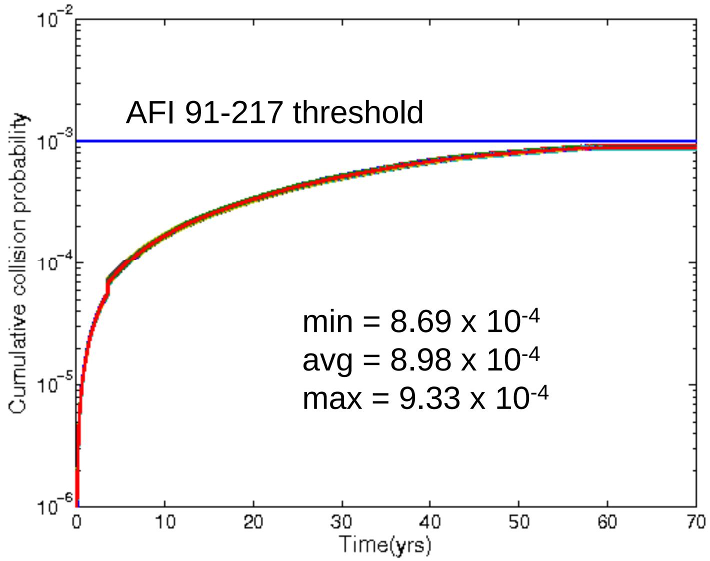
Collision Probability

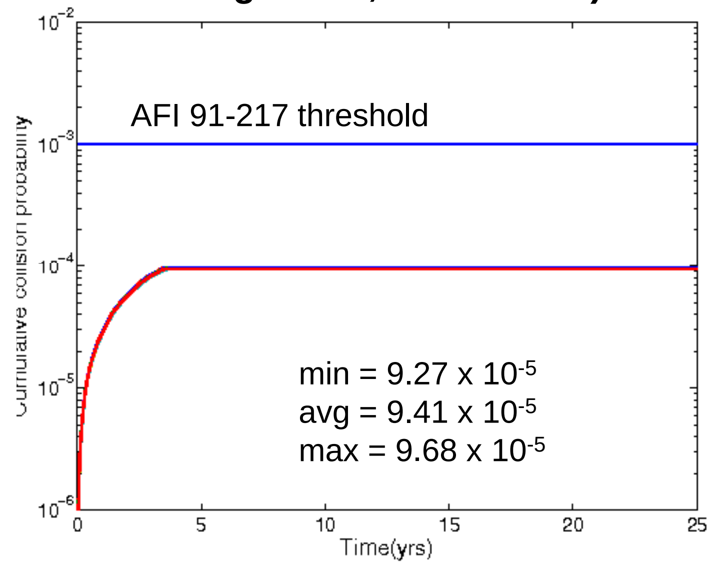
MSFC 5th percentile solar cycle, Cases 1 and 2

- The plot shows cumulative collision probability vs. time for AC5 for the MSFC 5th percentile solar cycle profile (one curve for each of 100 Monte Carlo debris populations)
- Collision probability < 0.001 for all cases

Case 1 (no tether)



Case 2 (tether in gravity gradient alignment, no libration)



Cumulative collision probability curves become horizontally flat after re-entry

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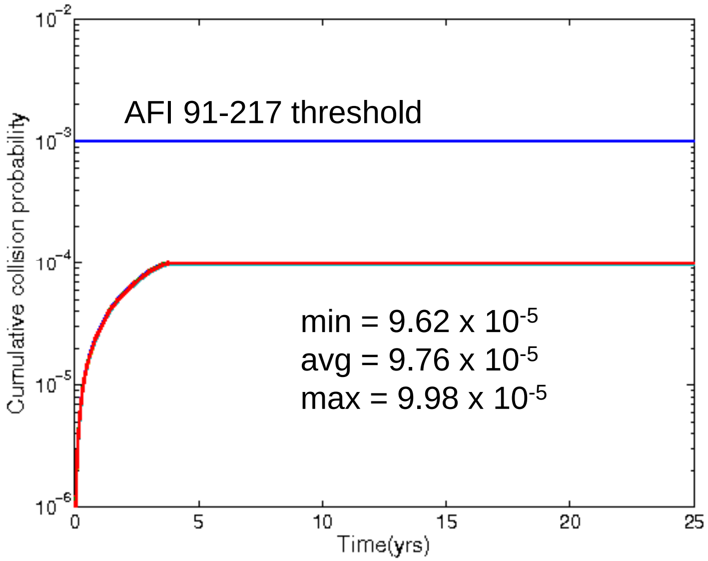
Collision Probability

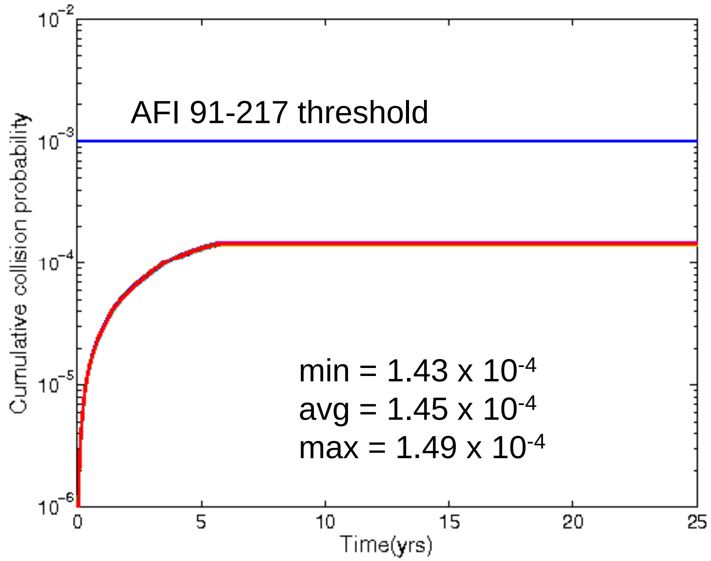
MSFC 5th percentile solar cycle, Cases 3 and 4

- The plot shows cumulative collision probability vs. time for AC5 for the MSFC 5th percentile solar cycle profile (one curve for each of 100 Monte Carlo debris populations)
- Collision probability < 0.001 for all cases

Case 3 (tether in gravity gradient alignment with libration)



Case 4 (tether in velocity alignment with libration)



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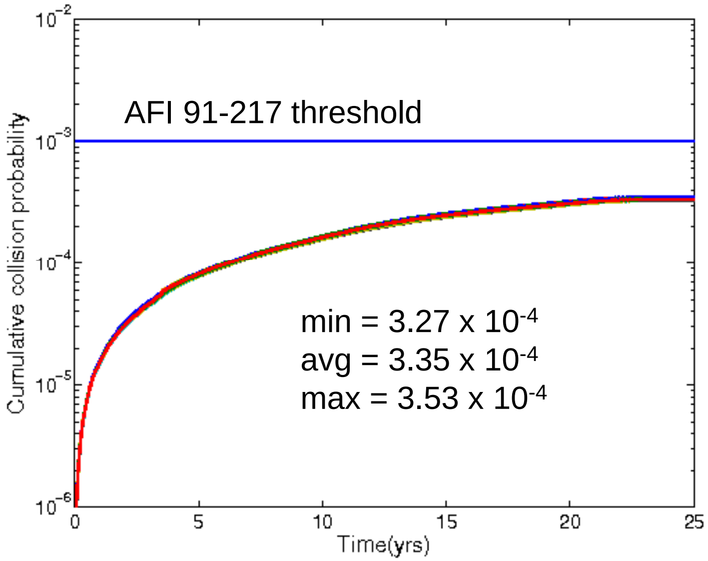
Collision Probability

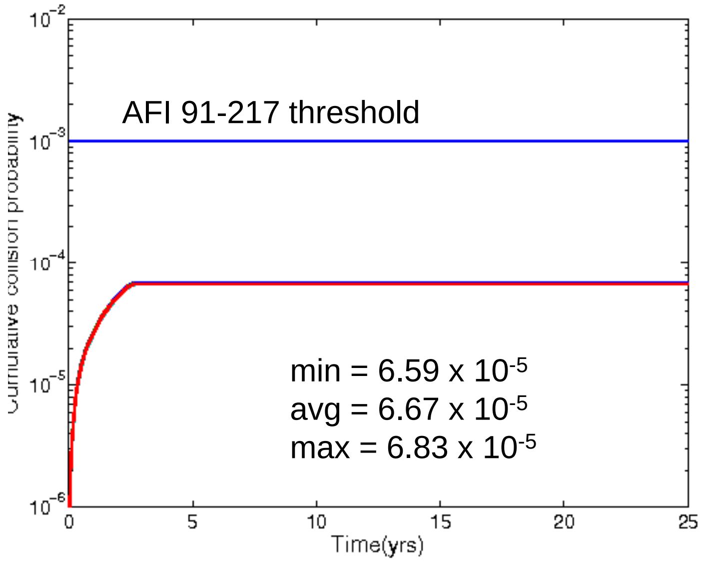
MSFC 50th percentile solar cycle, Cases 1 and 2

- The plot shows cumulative collision probability vs. time for AC5 for the MSFC 50th percentile solar cycle profile (one curve for each of 100 Monte Carlo debris populations)
- Collision probability < 0.001 for all cases

Case 1 (no tether)



Case 2 (tether in gravity gradient alignment, no libration)



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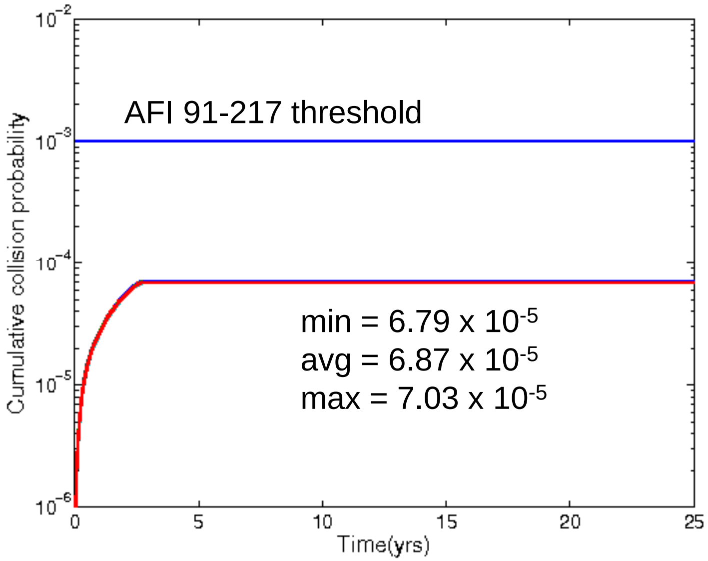
Collision Probability

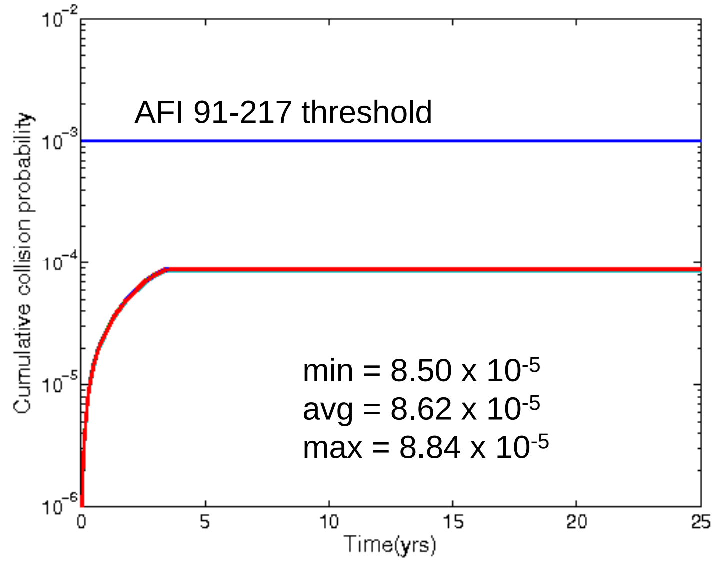
MSFC 50th percentile solar cycle, Cases 3 and 4

- The plot shows cumulative collision probability vs. time for AC5 for the MSFC 50th percentile solar cycle profile (one curve for each of 100 Monte Carlo debris populations)
- Collision probability < 0.001 for all cases

Case 3 (tether in gravity gradient alignment with libration)



Case 4 (tether in velocity alignment with libration)



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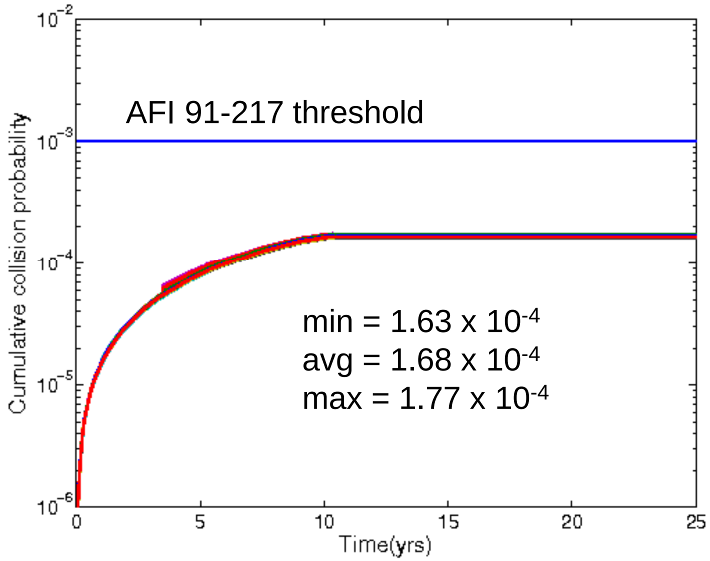
Collision Probability

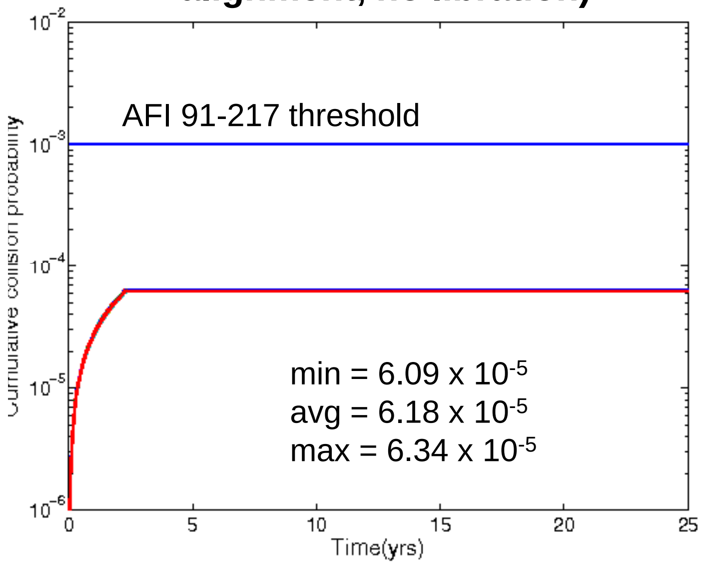
MSFC 95th percentile solar cycle, Cases 1 and 2

- The plot shows cumulative collision probability vs. time for AC5 for the MSFC 95th percentile solar cycle profile (one curve for each of 100 Monte Carlo debris populations)
- Collision probability < 0.001 for all cases

Case 1 (no tether)



Case 2 (tether in gravity gradient alignment, no libration)



Cumulative collision probability curves become horizontally flat after re-entry

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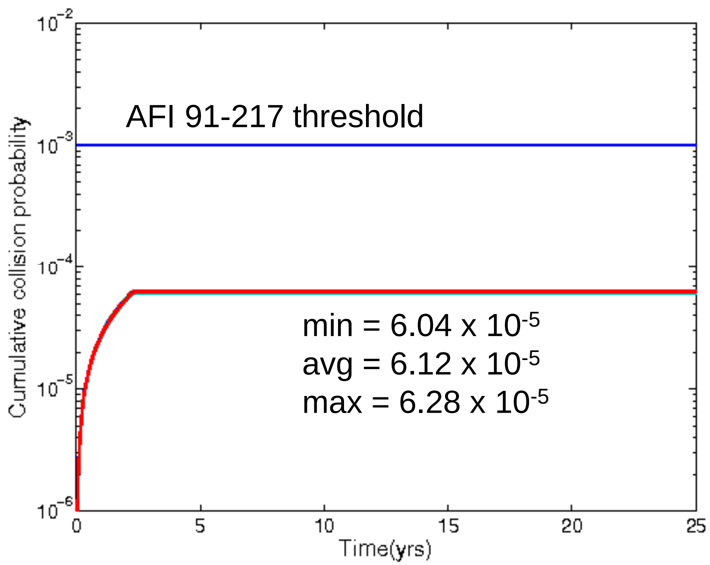
Collision Probability

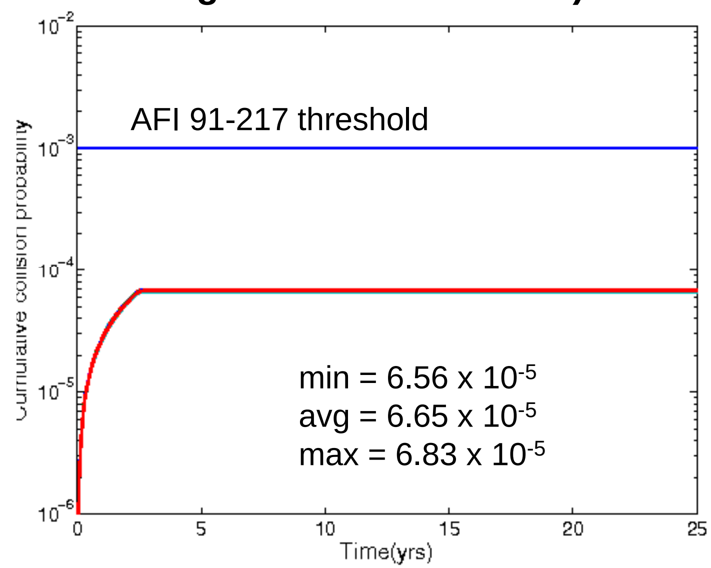
MSFC 95th percentile solar cycle, Cases 3 and 4

- The plot shows cumulative collision probability vs. time for AC5 for the MSFC 95th percentile solar cycle profile (one curve for each of 100 Monte Carlo debris populations)
- Collision probability < 0.001 for all cases

Case 3 (tether in gravity gradient alignment with libration)



Case 4 (tether in velocity alignment with libration)



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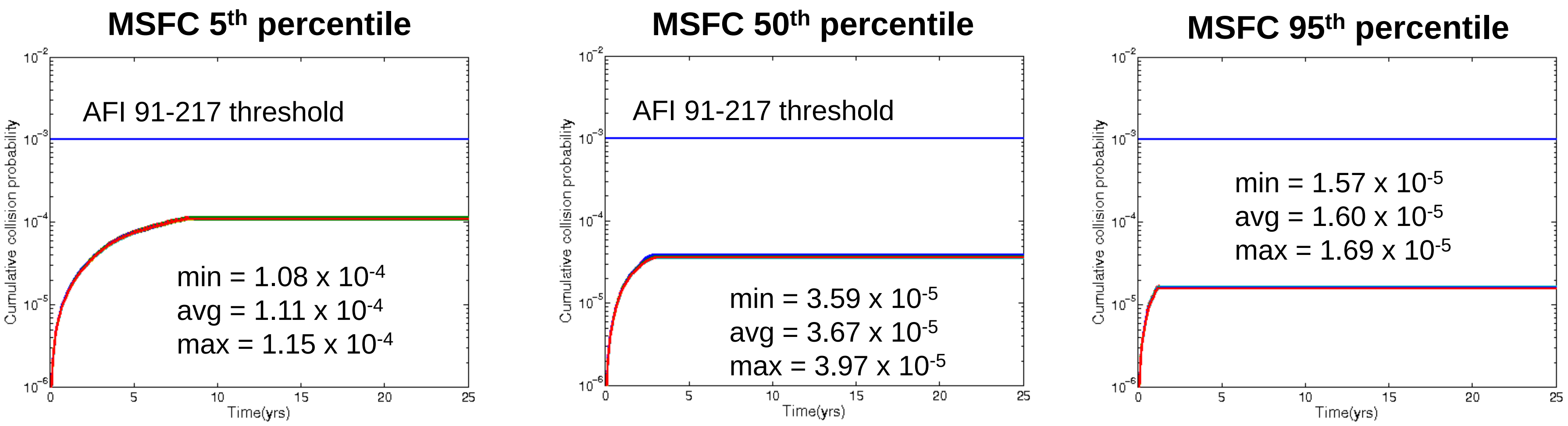
Collision Probability

"Peas"

- The plots show cumulative collision probability vs. time for a single "pea" for all three MSFC solar cycle profiles (one curve for each of 100 Monte Carlo debris populations)
- Collision probability < 0.001 for all cases



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Conclusions

- The range of collision probability between the AC5 with no tether and large background objects is
  - *8.69×10^{-4} to 9.33×10^{-4} for the MSFC 5th percentile predicted solar cycle*
  - *3.27×10^{-4} to 3.53×10^{-4} for the MSFC 50th percentile predicted solar cycle*
  - *1.63×10^{-4} to 1.77×10^{-4} for the MSFC 95th percentile predicted solar cycle*
- The range of collision probability between the AC5 with the tether deployed and large background objects is
  - *9.27×10^{-5} to 1.49×10^{-4} for the MSFC 5th percentile predicted solar cycle*
  - *6.59×10^{-5} to 8.84×10^{-5} for the MSFC 50th percentile predicted solar cycle*
  - *6.04×10^{-5} to 6.83×10^{-5} for the MSFC 95th percentile predicted solar cycle*
- The range of collision probability between a “pea” and large background objects is
  - *1.08×10^{-5} to 1.15×10^{-4} for the MSFC 5th percentile predicted solar cycle*
  - *3.59×10^{-5} to 3.97×10^{-5} for the MSFC 50th percentile predicted solar cycle*
  - *1.57×10^{-5} to 1.69×10^{-5} for the MSFC 95th percentile predicted solar cycle*
- **All ranges are less than the 0.001 threshold in AFI 91-217**

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References

1. McVey, J.P., Jenkin, A.B., “AeroCube 5 Lifetime Analysis,” Aerospace briefing package, January 8, 2013
2. McVey, J.P., Peterson, G.E., “AeroCube 5/Peas Lifetime Analysis,” Aerospace briefing package, January 11, 2013
3. Jenkin, A.B., Yoo, B.B., McVey, J.P., Peterson, G.E., Sorge, M.E., “MEO Debris Environment Projection Study,” Aerospace briefing package, September 17, 2012

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Study Analysts

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  - *Long-term propagation of AeroCube 5 and “peas”*
- Alan Jenkin
  - *Collision probability computation*

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