NASA Conjunction Assessment Risk Analysis Approach

Lauri K. Newman
NASA Robotic Conjunction Assessment Manager

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NASA’s Process: CARA

- NASA is committed to safety of flight for all of its operational assets
  - Performed by CARA at NASA GSFC for robotic satellites
    - Focus of this briefing
  - Performed by TOPO at NASA JSC for human spaceflight
- The Conjunction Assessment Risk Analysis (CARA) was created to offer this service to all NASA robotic satellites
  - Currently provides service to ~65 operational satellites
    - NASA unmanned operational assets
    - Other USG assets (USGS, NOAA)
    - International partner assets
NASA Human Spaceflight
Conjunction Assessment (CA) History

1988:
- Space Shuttle Discovery Return to Flight;
- Box method used for CA; later Shuttle adopts Pc method

1986:
- Challenger accident

1992:
- NASA begins Pc development for ISS CA
- NASA begins conjunction assessment of Mir space station

1996:
- NASA begins conjunction assessment of ISS CA

1998:
- ISS First Element Launch

1999:
- First attempted ISS DAM attempted and fails; a few months later first ISS DAM successfully executed

1990s – present:
- NASA works with USSTRATCOM to develop tools, data exchange formats, improve processes for catalog maintenance and CA

2005:
- NASA begins CA for robotic missions

Present:
- NASA continues work with USSTRATCOM to maintain high quality CA for human spaceflight and robotic missions

NASA has performed CA for 25 years. Initial USSTRATCOM capability developed with NASA.
Mission Context: Number of Conjunctions in LEO

- **Chinese ASAT**
  - 11 Jan 2007

- **Iridium/Cosmos Collision**
  - 10 Feb 2009

- **Jason-1 / TOPEX Repeating Conjunction**

- **NPR requiring all operational assets, not just maneuverable**
  - May 2009

- **SHY Changes**

- **Addition of NOAA & DMSP Satellites**

- **Landsat-5 / A-Train Crossover**

- **GRACE Satellite Re-positioning**

**Graph Details:**
- **Number of Unique Events**
- **Reporting Month**
- **Axes:**
  - Y-axis: Number of Unique Events (0, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000)
  - X-axis: Reporting Month (Sep05, Mar06, Sep06, Mar07, Sep07, Mar08, Sep08, Mar09, Sep09, Mar10, Sep10, Mar11, Sep11, Mar12, Sep12, Mar13, Sep13, Mar14, Sep14, Mar15, Sep15, Mar16)

**Legend:**
- Blue: All Secondary Objects
- Green: All Debris Objects
- Orange: Fengyun 1-C Debris
- Cyan: Iridium-33/Cosmos-2251 Debris
- Black: DMSP 5D-2 F13 Debris
- Yellow: NOAA 16 Debris
- Pink: Analysts
In 2015, 17% of the planned maneuvers resulted in maneuvers.
The CARA Process Helps Manage On-Orbit Collision Risk

Conjunction Assessment (CA) is the process of identifying close approaches between two orbiting objects; sometimes called conjunction “screening.”

The Joint Space Operations Center (JSpOC) – a USAF unit at Vandenberg AFB, maintains the high accuracy catalog of space objects, screens CARA-supported assets against the catalog, performs OD/tasking, and generates close approach data.

CA Risk Analysis (CARA) is the process of assessing collision risk and assisting satellites plan maneuvers to mitigate that risk, if warranted.

The CARA Team at NASA-GSFC provides CARA for all NASA operational robotic satellites, as well as a service provider for some other external agency/organizations.

Collision Avoidance (COLA) is the process of executing mitigative action, typically in the form of an orbital maneuver, to reduce collision risk due to a conjunction.

Each satellite Owner/Operator (O/O) – mission management, flight dynamics, and flight operations – are responsible for making maneuver decisions and executing the maneuvers.
CARA Operational Process: Close Approach Predictions at the JSpOC

- The JSpOC maintains an accurate state for all trackable objects
- In support of CARA, the dedicated Orbital Safety Analysts (OSA)
  - Perform routine screenings – 3x day for LEO, 1x for GEO/HEO
    - Against JSpOC’s Astrodynamics Support Workstation (ASW) solution and the O/O solution if available
  - Inspect orbit determination; perform manual orbit determination, if warranted
  - Adjudicate tasking level of secondary objects; request increased tasking, if warranted
  - Generate and deliver necessary data products
- JSpOC is staffed by Goddard-dedicated OSA 20 hours/day

The Screening Duration is the “lookout” period of time for which conjunctions are identified. This is 7 days for LEO assets and 10 days for GEO/HEO assets.

The Screening Volume is the geometric volume placed around the asset during the conjunction screening process; any objects that violate this volume trigger data products to be generated and delivered. The screening volumes are re-sized annually by CARA using a 95% capture of the relative uncertainties in each orbital regime based two-year moving window historical conjunction data.
CARA Operational Process:
NASA Robotic Collision Risk Analysis

- CARA is responsible for assessing, communicating, and assisting with mitigation of on-orbit collision risk
- As data is received, the CARA system automatically processes that data, and generates & delivers
  - CARA Summary Reports to O/O
  - Work List to JSpOC OSAs
- CARA team performs routine risk analysis
  - Pc; Pc sensitivity
  - Conjunction Geometry
  - OD Evaluation / Solution Consistency
  - Space Weather Sensitivity
  - Maneuver planning & evaluation
- For high-risk conjunctions, CARA builds and delivers a High Interest Event (HIE) briefing with detailed analyses, and planning & decision information

The Collision Probability (Pc) is the probability that, given the uncertainty in the two objects’ positions as described by their covariance matrix, that the actual miss distance is less than the hard-body region.

\[
P_c = \frac{1}{2\pi^{n/2} \sqrt{\det(C)}} \int_A e^{-\frac{1}{2} x^T C^{-1} x} \, dA
\]
Maneuver Planning

- A trade-space contour plot shows the effect that a range of phase times and delta-v magnitudes have on miss distance
  - Single conjunction event (top)
  - Multiple events (bottom)
- Assists with initial maneuver planning
  - Save time-expensive iteration cycles for high fidelity maneuver planning
  - Does not presume any constraints about satellite maneuver capability or conjunction mitigation strategies—allows flight support teams to decide on course of action