Conjunction Assessment Risk Analysis

CARA S-Band Fence Preparation Activities

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15 NOV 2016
• Overview of NASA CARA CA Process
• S-Band Fence (SF) description
• SF issues for CA
• CARA actions: problem definition and scoping studies
• CARA actions: new CA paradigms
• S-Band Study: current status and schedule
The CARA Process

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

The 18th Space Control Squadron at 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
  - Note that these solutions use non-cooperative tracking from the Space Surveillance Network (SSN), and do not contain maneuvers
- In support of CARA, the CARA-dedicated Orbital Safety Analysts (OSA)
  - Perform routine screenings – 3x day for LEO, 1x for GEO/HEO
    - Against JSpOC’s Astrodynamics Support Workstation (ASW) solution the O/O solution
      - 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 CARA-dedicated OSAs 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:
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 sent to CARA 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

\[
P_c = \frac{1}{2\pi[\det(C)]^{1/2}} \int_{A} e^{-\frac{1}{2}x^T C^{-1} x} \, dA
\]

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.
CARA system automatically generates & delivers a prioritized work list

- CARA OSAs perform their duties in priority order
- Ensures limited resources are used effectively – in the order of risk or potential to become high risk
- Closed-loop process between OSAs and CARA
- Representative format:

  Grouped by Risk using Pc thresholds

  1. Aqua vs. 12345
  2. Aqua vs. 23456
  3. Aqua vs. 34567
  4. Aqua vs. 45678
  5. Aqua vs. 56789

  Rank-ordered within group by increasing OD quality

- Also includes list of recent (for indicating when OD should be cut) and upcoming maneuvers (satisfies NASA maneuver reporting requirement)
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
S-Band Fence: Description

• Large-aperture S-band radar for small object tracking in LEO
• Near-equatorial placement at Kwajelain Atoll, Marshall Islands
  – Option for second site, probably in Australia
• Intended for surveillance fence operations
  – However, beams are electronically steerable to allow for extended tracking
    • Essentially a phased-array radar with “face” pointed up
    – Extended-range mode allows tracking of DS objects
• Detectable object size in LEO better than 10 cm
• Two-polarization processing (PP and OP) allows high-precision RCS determination
• IOC planned for latter part of 2018
S-Band Fence: Location
S-Band Fence: Issues for CA

• **New debris objects discovered (and maintained) only by SF**
  – Quantity of such objects (estimates range from 50k to ~150k)
  – Quality of maintenance ODs, which is governed by
    • Tracking rates
    • OD errors (expected obs errors, vector errors, and covariance sizes)
    • Maintenance strategy for objects at edge of SF detection
    • All of the above trace to issues of data actionability for CA

• **Existing debris tracked by SF**
  – OD improvements for current debris objects tracked by Shemya only
    • Effects on OD vector error and covariance sizes

• **Potential requirement for new CA paradigms, which could include**
  – CA remediation against “grouped” events using an aggregate Pc
  – Regular burns / DMU strategy to minimize conjunction risk, without actually remediating individual events unless an extremely high Pc

• **Study effort required to determine magnitude of these effects**
S-Band Study: Strategic Partnership

- NASA CARA, study lead organization
- S-Band Fence SPO (Hanscom AFB), developing command
  - Lockheed Martin, developing contractor
- NASA Orbital Debris Program Office
- NASA/JSC, human space flight CA
- AFSPC/A5, USAF requirements and Command management
- Aerospace Corporation
S-Band CA Study: Study Phases

• Phase I: screening results
  – Conduct screenings of selected primaries against catalogue augmented with S-band objects to determine the expected number of conjunctions per day

• Phase II: significant events
  – Calculate the Pc associated with each of the conjunctions identified in Phase I to determine the number of expected significant events open on any particular day

• Phase III: CA-related tasking
  – Based on the results in Phases I and II, determine which situations merit additional S-Band tasking and how much added benefit it provides
    • S-Band tasking simply produces longer tracks instead of increasing likelihood of tracking
  – Develop methodology to identify such situations
    • Number of incidences of desired increased tasking may be small enough that current procedures can be used
SF CARA Actions: Phase IV: New CA Paradigms

• Large increases in serious events may drive the following changes in CA operations conduct

• Aggregate or Total Pc
  – Risk assessment and remediation based on combined effect of a (potentially large) number of conjunctions, rather than on individual discrete events
  – Initial work performed on basics of calculation and use possibilities
    • Conference paper produced
  – Substantial additional work required on number of CONOPS issues, especially thresholding and potential “weighting” on nearer- vs farther-term conjunctions

• DMUs become amelioration RMMs
  – Craft DMUs to improve longer-term conjunction posture

• Fully stochastic, cloud-based approach
  – Would need substantial theoretical and practical development
  – May not be truly viable
• Phase I essentially finished
  – Screening runs executed against SF SPO S-Band catalogue, from their internal simulations
  – Last set of additional excursions executing
  – Ratios of Post-SF Conjunction Rate / Pre-SF Conjunction Rate calculated, based on inclination and perigee height of primary

• Phase II preliminary work beginning
  – Complicated because covariance estimation required
  – Current plan is to finish by Christmas

• Phase III activities dictated by findings of Phases I and II
• Public presentation of findings for Phases I and II expected in Jan/Feb 2017