CARA S-Band Fence Preparation Activities

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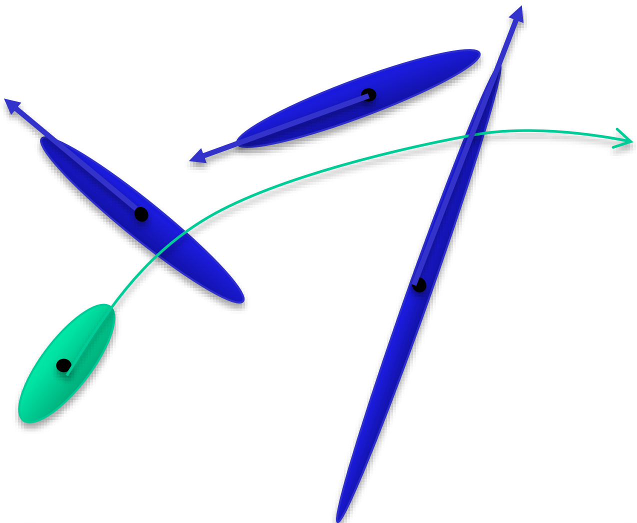
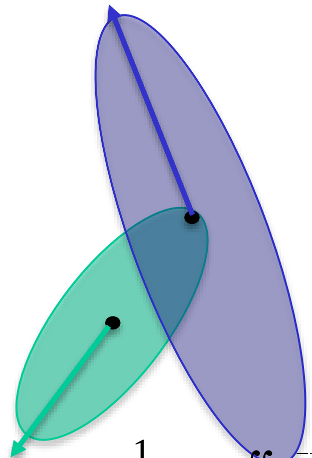
Agenda

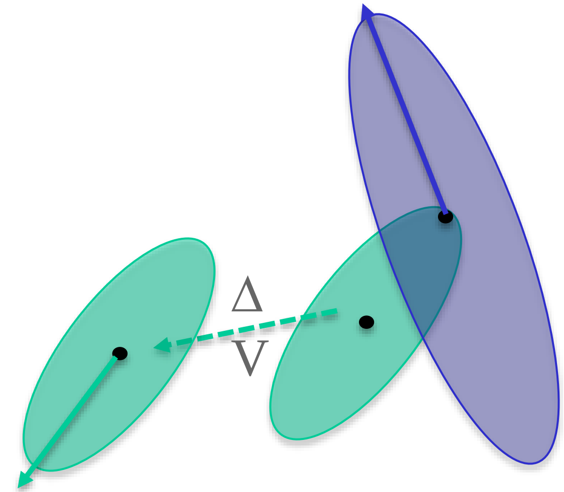
- **Overview of NASA CARA CA Process**
- **S-Band Fence (SF) description**
- **SF issues for CA**
- **CARA actions: problem definition and scoping studies**
- **CARA actions: new CA paradigms**
- **S-Band Study: current status and schedule**

The CARA Process





$$P_c = \frac{1}{2\pi\left[\det(\mathbf{C})\right]^{1/2}} \iint_A e^{-\frac{1}{2}x^{\mathrm{T}}\mathbf{C}^{-1}x}\, dA$$



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

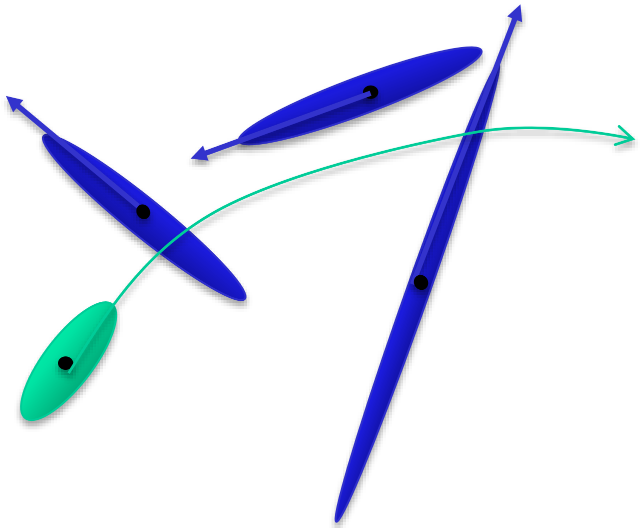
The **CARA** Team at NASA-GSFC provides CARA for all NASA operational robotic satellites, as well as a service provider for some other external agency/organizations

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**

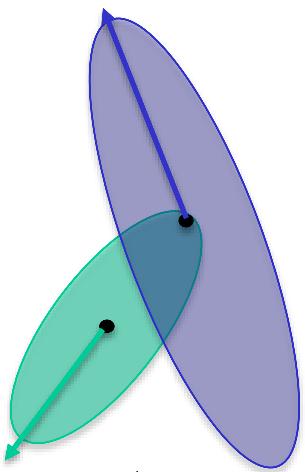


The **Screening Duration** is the "lookout" period of time for which conjunctions are identified. This is 7 days for LEO assets and 10 days for GEO/HEO assets

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**



$$P_c = \frac{1}{2\pi\left[\det(\mathbf{C})\right]^{1/2}} \iint_A e^{-\frac{1}{2}x^{\mathrm{T}}\mathbf{C}^{-1}x}\, dA$$

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

OSA Work List

- **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

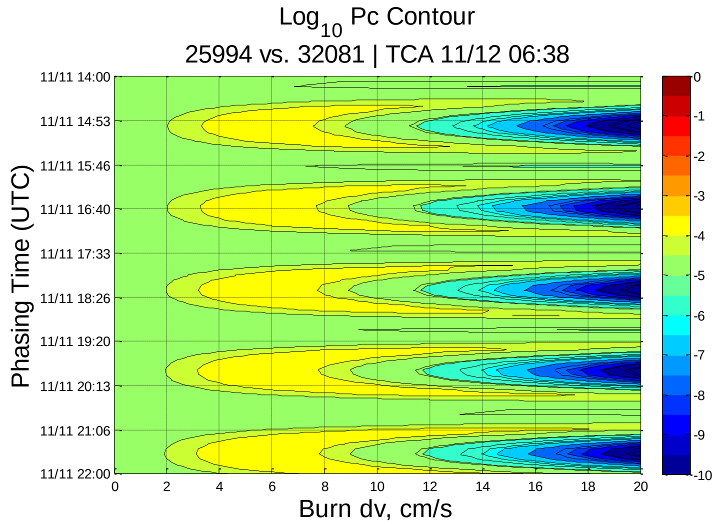
1. Aqua vs. 12345
2. Aqua vs. 23456
3. Aqua vs. 34567
4. Aqua vs. 45678
5. Aqua vs. 56789

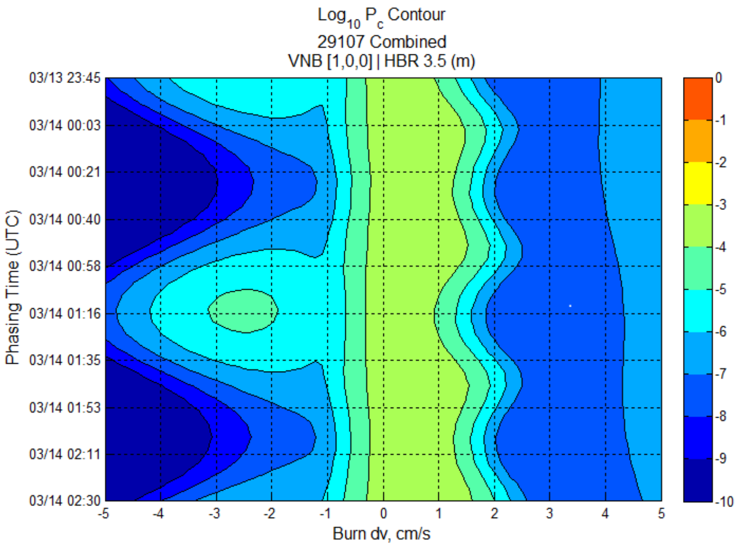
Rank-ordered within group by increasing OD quality

- **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

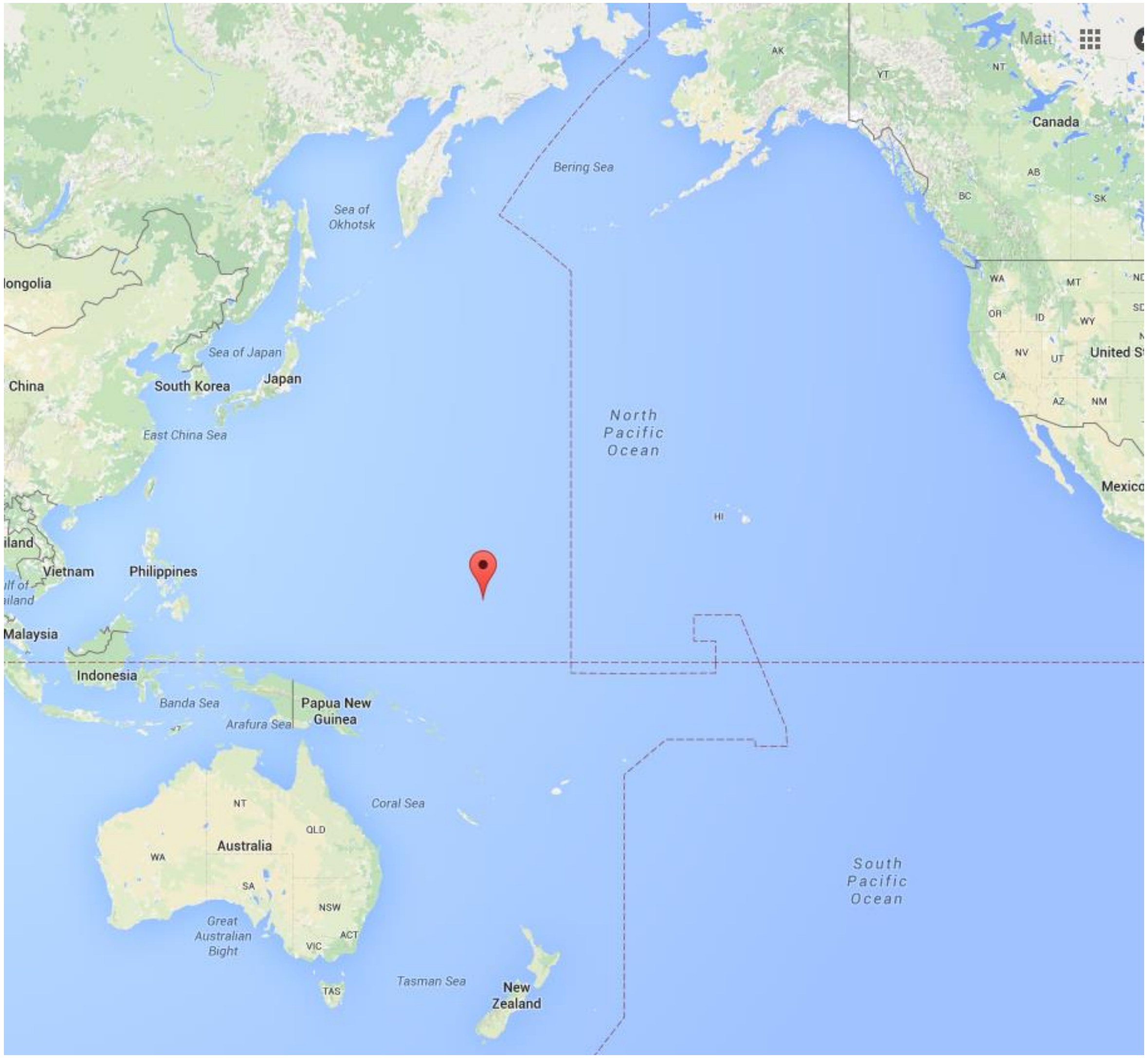




S-Band Fence: Description

- **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

S-Band CA Study: Status and Schedule

- **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**