National Aeronautics and
Space Administration

NASA Policies and Guidance for Conjunction Assessment and Mitigation

Smallsat LEARN Forum hosted at the Langley Research Center

October 2023

NASA Office of the Chief Engineer
Mission Resilience and Protection Program

Mission Resilience and Protection Program

Within the NASA Office of the Chief Engineer (OCE), the Mission Resilience and Protection Program (MRPP) provides three broad areas of technical guidance for space flight missions and their support systems: space sustainability, space system protection, and system security engineering.

Space Sustainability (Conjunction Assessment and Mitigation)

Maintains a sustainable space environment by proactively monitoring and mitigating high-risk conjunctions between an operating space system and another object.

Key documents:
- NPR 8079.1: Spacecraft Conjunction Analysis and Collision Avoidance for Space Environment Protection https://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=8079&s=1
- NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices https://nodis3.gsfc.nasa.gov/OCE_docs/OCE_51.pdf

Space System Protection

Improves the resilience and protection of space systems and space support systems from the effects of threat actors.

Key document:
- NASA-STD-1006A: Space System Protection Requirements https://standards.nasa.gov/standard/NASA/NASA-STD-1006

System Security Engineering

Integrates the consideration of potential threats into systems engineering processes and towards the success of a delivered system.

Key document:
- Scope of the Systems Security Engineer https://nen.nasa.gov/documents/11578539/14800788/sse_scope_v1_20211123.pdf/6eb0e567-b69f-e9c0-d430-08afad28218b?t=1637686478325

The MRPP coordinates closely on these topics with other NASA organizations, including the NASA Enterprise Protection Program, the Office of the Chief Information Officer, the Office of Protective Services, and the Office of Safety and Mission Assurance.

Space Sustainability

Conjunction Assessment and Mitigation

Context: Changes to the Ecosystem

Space is congested (and contested, and competitive)

- Dramatic increase in number of objects, discrete operators, launch capacity, etc.
- Major orbital debris events from weapons demonstrations
- Orbital conjunction rates are increasing, and on occasion “bursty”
- Certain orbits are particularly challenging

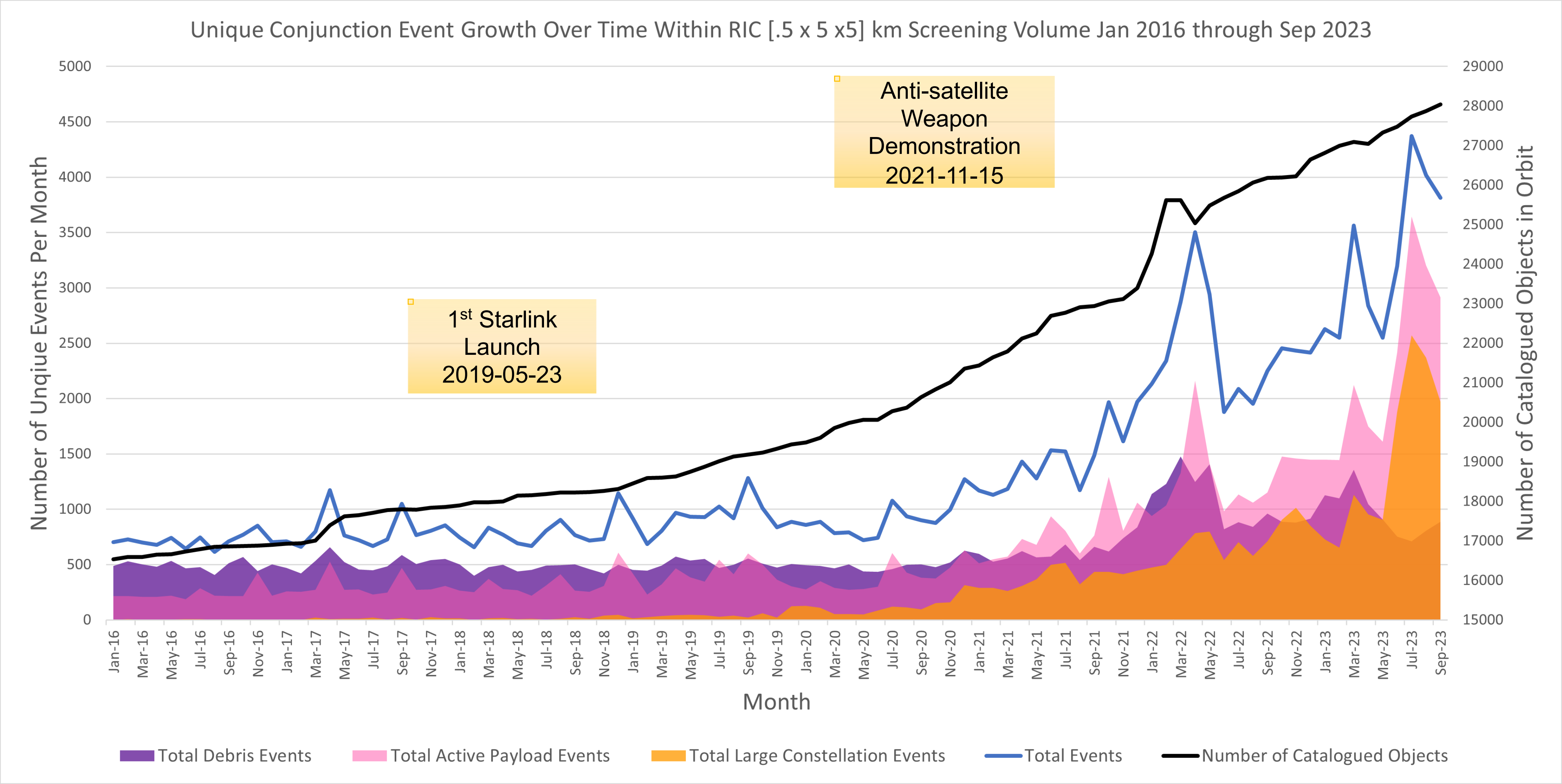
Protecting space vehicle safety and the space environment requires every operator to act responsibly, with intra-operator transparency and cooperation

- Extremely challenging without common “rules of the road”
- Lack of experience may lead to inadvertent poor assumptions or decisions
- Increased regulatory attention leading to more requirements
- Trackability is a critical aid to reduce aggregate risk and increase intra-operator trust

Advanced capabilities

- Newer technology is needed yet poses challenges (non-instantaneous propulsion, autonomy)
- Forward work to update capabilities, models (atmosphere, thrust, computation), and standards

Unique Conjunction Event Growth Over Time Within RIC [.5 x 5 x 5] km Screening Volume Jan 2016 through Sep 2023



https://www.nasa.gov/cara/unique-conjunction-events/

NASA Conjunction Assessment Support Organizations

Conjunction Assessment (CA) for human spaceflight (HSF) is performed by the Flight Operations Directorate (FOD) at the Johnson Space Center

- Begun in 1980s for Shuttle program
- ISS/visiting vehicles (VV), commercial crew, and exploration missions
- Support includes risk assessment and execution of collision avoidance maneuvers if required

The NASA Conjunction Assessment Risk Analysis (CARA) program is responsible for risk assessment and mitigation support for non-HSF spacecraft (~100)

- Started in 2005 based on HSF process
- Supports Agency and partner missions
- "middle-man" central service funded at the Mission Directorate level

CA at other central bodies (moon, Mars, etc.) supported by the MADCAP (Multi-mission Automated Deep space Conjunction Assessment Process) program at JPL

- Requirements flow through CARA

The CA Program Officer (CAPO) established within the Science Mission Directorate (SMD) oversees CARA and MADCAP

Overview of Collision Avoidance Guidance

NPR

NPR 8715.6B *NASA Procedural Requirements for Limiting Orbital Debris and Evaluating the Meteoroid and Orbital Debris Environments*
Effective 2017-02-16
(rev A was effective 2008-02-05)
Next revision under review

NPR 8715.6 conjunction assessment elements moved to NPR 8079.1.

NPR

NPR 8079.1 *Collision Avoidance for Space Environment Protection*
Effective 2023-06-27
Supersedes NID 7120.132

Key conjunction assessment items:

- Provide ephemeris to CARA
- Screen maneuvers via CARA
- Establish a plan (with CARA) to address identified conjunctions

Key additions from earlier policies:

- More comprehensive processes and implementation guidance
- Orbital Collision Avoidance Plan (OCAP) *[Formulation]*, with analyses performed by CARA or JSC FOD in support of the project
- Conjunction Assessment Operations Implementation Agreement (CAOIA) *[Operations]*
- Requirement for “trackability”

Policies are supported by the best practices handbook.

HBK

NASA Spacecraft Conjunction Assessment Best Practices Handbook
Released December 2020, updated February 2023 available to the public

New Per-Mission Deliverables

Orbital Collision Avoidance Plan (OCAP)

Initial Concept → Iteration and Refinement → Final OCAP

OCAP questions:

- How detectable is the spacecraft?
- Where can the spacecraft operate safely? How will it get there?
- How will we know where the spacecraft will be? With what precision?
- How will we mitigate a conjunction?
- Are there any special considerations?

Conjunction Assessment Operations Implementation Agreement (CAOIA)

Initial Design → Discussions → Final CAOIA

CAOIA content examples:

- Contact information and protocols
- Technical details of the spacecraft
- Notification and action thresholds
- Procedures and data specifications
- Special considerations

Life-Cycle Integration and Timelines

Life-Cycle Phase	Pre-Formulation	Formulation		Implementation			
7120.5 Life-Cycle Gates	MCR ① Notes: ① Project provides initial inputs for OCAP ② Iteration of OCAP content with CARA or JSC FOD ③ Achieve OCAP concurrence (Baseline)	SRR SDR ②	PDR ③	CDR SIR ④ Notes: ④ Project begins CAOIA development ⑤ Iteration of CAOIA content with CARA or JSC FOD ⑥ Achieve CAOIA concurrence (Final)	ORR FRR ⑤ ⑥	PLAR CERR DR	DRR Update as needed
Conjunction Assessment Products		① Initial OCAP inputs (required)	② Baseline OCAP (required)	④ Initial CAOIA (recommended)	⑥ Final CAOIA (required)	Update CAOIA (as needed)	Update CAOIA (as needed)
NPR-Related Activities	• As concepts develop, project manager coordinates with CARA (non-HSF) or JSC FOD (HSF) for orbit selection options	• Project manager demonstrates application of this NPR • Project manager provides initial OCAP inputs to CARA/JSC FOD review • CARA/JSC FOD begins OCAP analyses	• Project manager baselines OCAP and provides OCAP to CARA/JSC FOD for review and concurrence and subsequent final approval by the program manager	• Project manager fills in CAOIA template obtained from CARA/JSC FOD • Project manager provides an initial CAOIA to CARA/JSC FOD for review and comment	• Project manager finalizes CAOIA and provides to CARA/JSC FOD for reviews and approval • Project manager performs interface test and simulations with CARA/JSC FOD • Project manager reports test, launch, and checkout anomalies for issues affecting maneuverability to CARA/JSC FOD • CARA/JSC FOD submits ODRs to DOD on behalf of spacecraft as needed	• CARA/JSC FOD identifies conjunctions with high collision risks and advises project managers • CARA/JSC FOD reviews proposed collision risk mitigation strategies • CARA/JSC FOD submits ODRs to DOD on behalf of spacecraft as needed	• CARA/JSC FOD monitors disposal efforts for issues affecting conjunction assessment

Legend

CARA	Conjunction Assessment Risk Analysis	DRR	Disposal Readiness Review	ORR	Operational Readiness Review
CAOIA	Conjunction Assessment Operations Implementation Agreement	FOD	Flight Operations Directorate	PDR	Preliminary Design Review
CERR	Critical Events Readiness Review	FRR	Flight Readiness Review	PLAR	Post-Launch Assessment Review
CDR	Critical Design Review	HSF	Human Space Flight	SDR	System Definition Review
DOD	Department of Defense	MCR	Mission Concept Review	SIR	System Integration Review
DR	Decommissioning Review	OCAP	Orbital Collision Avoidance Plan	SRR	System Requirements Review
		ODR	Orbital Data Request		

Table 3-1 Example Conjunction Assessment Activities Throughout an NPR 7120.5 Project

OCAP timelines

- Start coordination early (at award!) with CARA to conduct the appropriate analyses leading to the OCAP.
- Concurrence for the final OCAP from CARA or JSC FOD is expected within 30 days of submissions.
- Program managers approve the final document.

CAOIA timelines

- CAOIA-related discussions with CARA should begin as soon as the design and operations concepts are initially understood.
- Plan 30 days for final document to be formally reviewed.
- Finalized with signatures by ORR or equivalent review.

Application of the Requirements [1]

For projects already in process, what requirements apply?

- The Mission Directorate proposes an approach and obtains OCE concurrence
  - Starting point: Existing projects apply the NPR requirements based on current and future life-cycle phases (e.g., if in Formulation, implement Formulation and later requirements)
  - Generally, if the project and CARA or JSC FOD agree, no major concerns remain

- Note: many requirements were already in place via NPR 8715.6; these must still be met by the project

Applicability of the Requirements [2]

The requirements in the NPR apply to spacecraft owned, developed, or operated by NASA or operated principally for NASA

- Check agreement language, as NASA uses a wide variety of agreements, with various legal implications

In-Scope (NASA-owned/operated)	Typically Out-of-Scope
Spacecraft developed via contract	Spacecraft developed via grants
SMD Principal Investigator-led missions	
Uses NASA processes for regulatory filings (spectrum, launch, remote sensing)	Uses commercial or other nation’s processes for regulatory filings (spectrum, launch, remote sensing)

All spacecraft developers and operators should consider how to effectively protect both their spacecraft, those of others, and the future state of the space environment

- Please consider reviewing the *NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook* and other emerging best practice guidance

Exception from Requirements: Tailoring / Waivers

NPD 1000.C NASA Governance and Strategic Management Handbook

- *3.5.3 Requirements' Tailoring Process*
  It is NASA policy that all prescribed requirements (requirements levied on a lower organizational level by a higher organizational level) are complied with unless relief is formally granted. Tailoring is the process used to adjust or seek relief from a prescribed requirement to meet the needs of a specific program, project, or activity. Among other things, it enables agility without sacrificing necessary rigor in development and testing. Tailoring is both an expected and accepted part of establishing proper requirements …

Options:

1. Processes and discussions resulting in an approved OCAP (and CAOIA) can resolve most concerns
2. OCAP's Compliance Matrix (comparable to other compliance matrices)
   - Some requirements (3) require OCE's approval (outside the OCAP)
   - Remaining requirements (8) require CARA or JSC FOD approval
3. Tailoring via higher-level policies

Trackability

New forward-looking requirement to address the question: how do operators avoid a formerly-active spacecraft still in space?

- Larger spacecraft are readily detected and tracked by, e.g., DOD’s Space Surveillance Network (SSN)
- Tracking passes via ground station provider can also assist when a transponder remains active
- Spacecraft physical characteristics may be a trade space

See also *NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook* section 4.5 “Trackability”

- Includes current specifications for SSN’s ability to detect

Launching an untrackable spacecraft increases risk to all operators.

Maneuvers

Maneuverable spacecraft definition (NPR 8079.1):

- *A spacecraft that has capability permitting the manipulation of the spacecraft's trajectory in a non-Keplerian fashion.*
- Includes differential drag and non-instantaneous propulsion capabilities

An approved CAOIA captures the coordination of maneuvers between the project and CARA (or JSC FOD)

- Maneuvers are screened (24-hours in advance) to avoid maneuvering into another object (that may itself be maneuvering)
- “Normal” orbit-keeping and conjunction mitigation maneuvers are described in the CAOIA (and screened)
- Changes to flight dynamics concepts (inc. maneuvers) that are not captured via the CAOIA require 30 days advance coordination
- Emergency maneuvers are reported to CARA (or JSC FOD) after the fact

Coordinated maneuvers remain the most capable method to mitigate high-risk conjunctions

- NASA does not have a requirement for spacecraft to be maneuverable, however U.S. regulators have considered mandating maneuverability as a condition of receiving a license

Questions?

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General questions for CARA

NASA CARA information (public web)
https://www.nasa.gov/cara

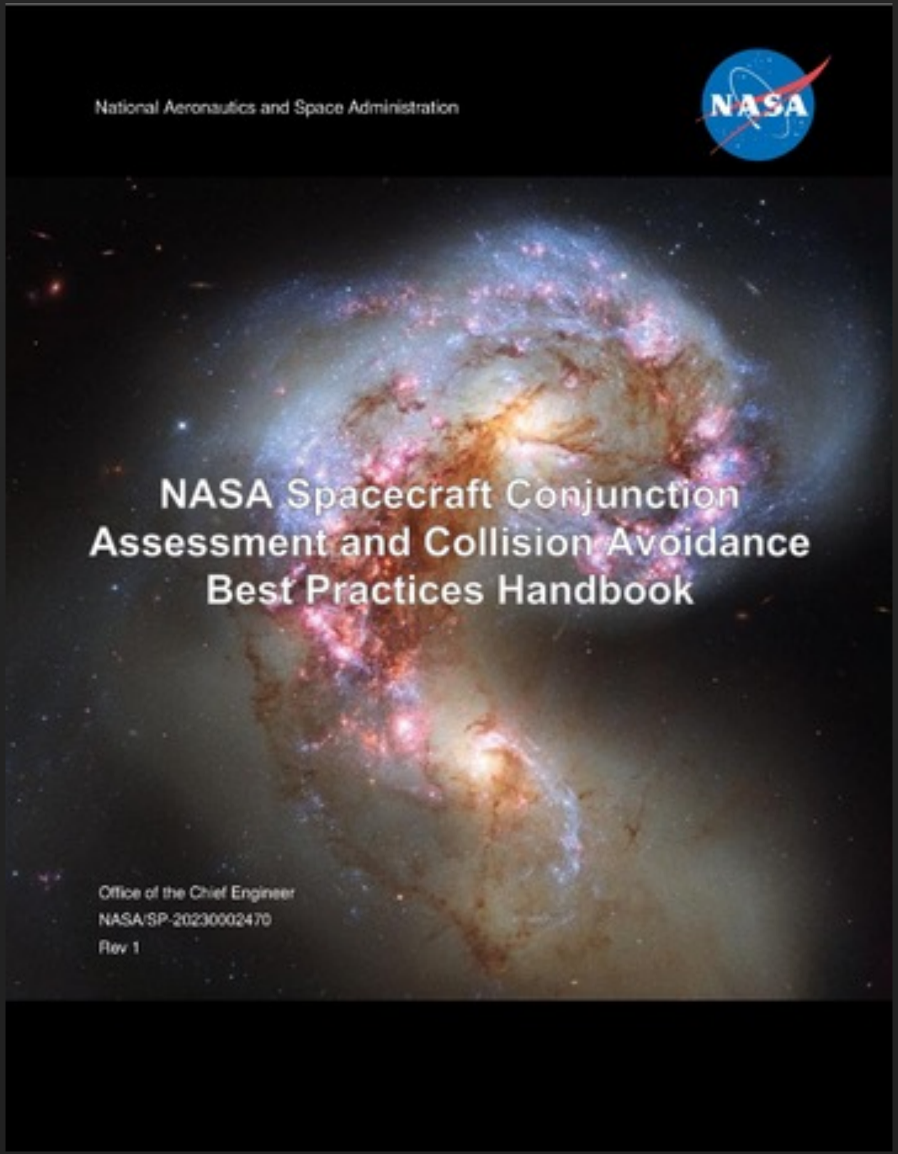
NPR 8079.1 NASA Collision Avoidance for Space Environment Protection
https://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=8079&s=1

NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook
https://nodis3.gsfc.nasa.gov/OCE_docs/OCE_51.pdf

NPR 8715.6B NASA Procedural Requirements for Limiting Orbital Debris and Evaluating the Meteoroid and Orbital Debris Environments
https://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=8715&s=6B

NASA-STD-8719.14 Process for Limiting Orbital Debris
https://standards.nasa.gov/standard/NASA/NASA-STD-871914

NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook



Comments or suggestions are welcome

- Send to ca-handbook-feedback@nasa.onmicrosoft.com

Downloadable from:

https://nodis3.gsfc.nasa.gov/OCE_docs/OCE_51.pdf

Supplemental Content

Guidance References

NPR 8079.1 *NASA Collision Avoidance for Space Environment Protection*

- https://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=8079&s=1

NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook

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NPR 8715.6B *NASA Procedural Requirements for Limiting Orbital Debris and Evaluating the Meteoroid and Orbital Debris Environments*

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NASA-STD-8719.14 *Process for Limiting Orbital Debris*

- https://standards.nasa.gov/standard/NASA/NASA-STD-871914

OCAP: Template Table of Contents

CAOIA: Template Table of Contents

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6. CARA TEAM DELIVERABLES TO THE PROJECT
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Appendix A. Product Formats
   - A.1 Ephemeris Format for Data Products 01, 02, and 03
   - A.2 Report Format for Data Product 04

Conjunction Assessment Special Topics

Lauri K. Newman
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HQ Science Mission Directorate
Office of the Deputy Associate Administrator for Programs

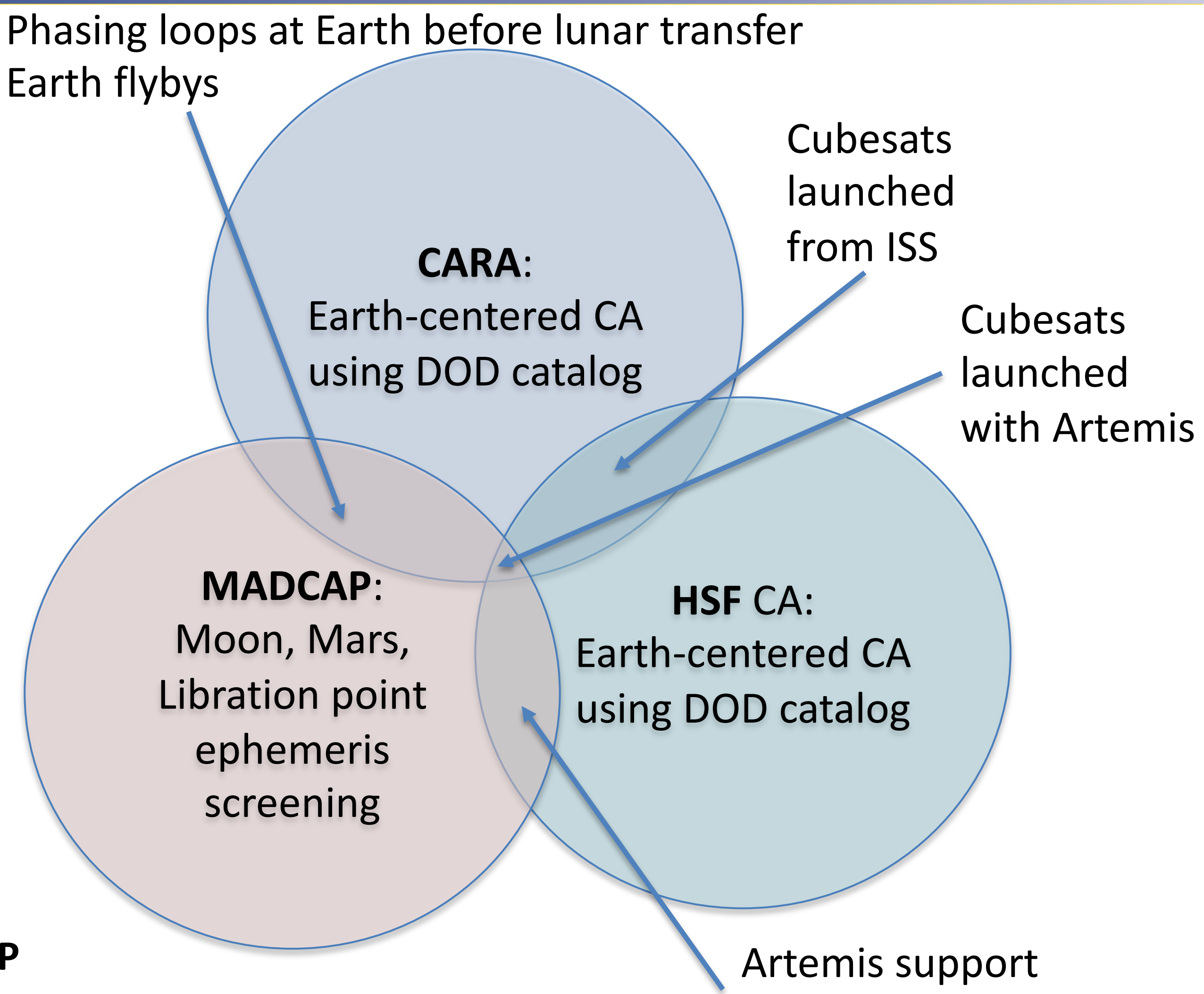
October 12, 2023

Agenda

- CA organizations at NASA
- Simplification of NPR
  - Flow chart
  - OCAP screening form
- Key Best practices
- Non-Earth CA
- Resources for Assistance

NASA Conjunction Assessment Entities

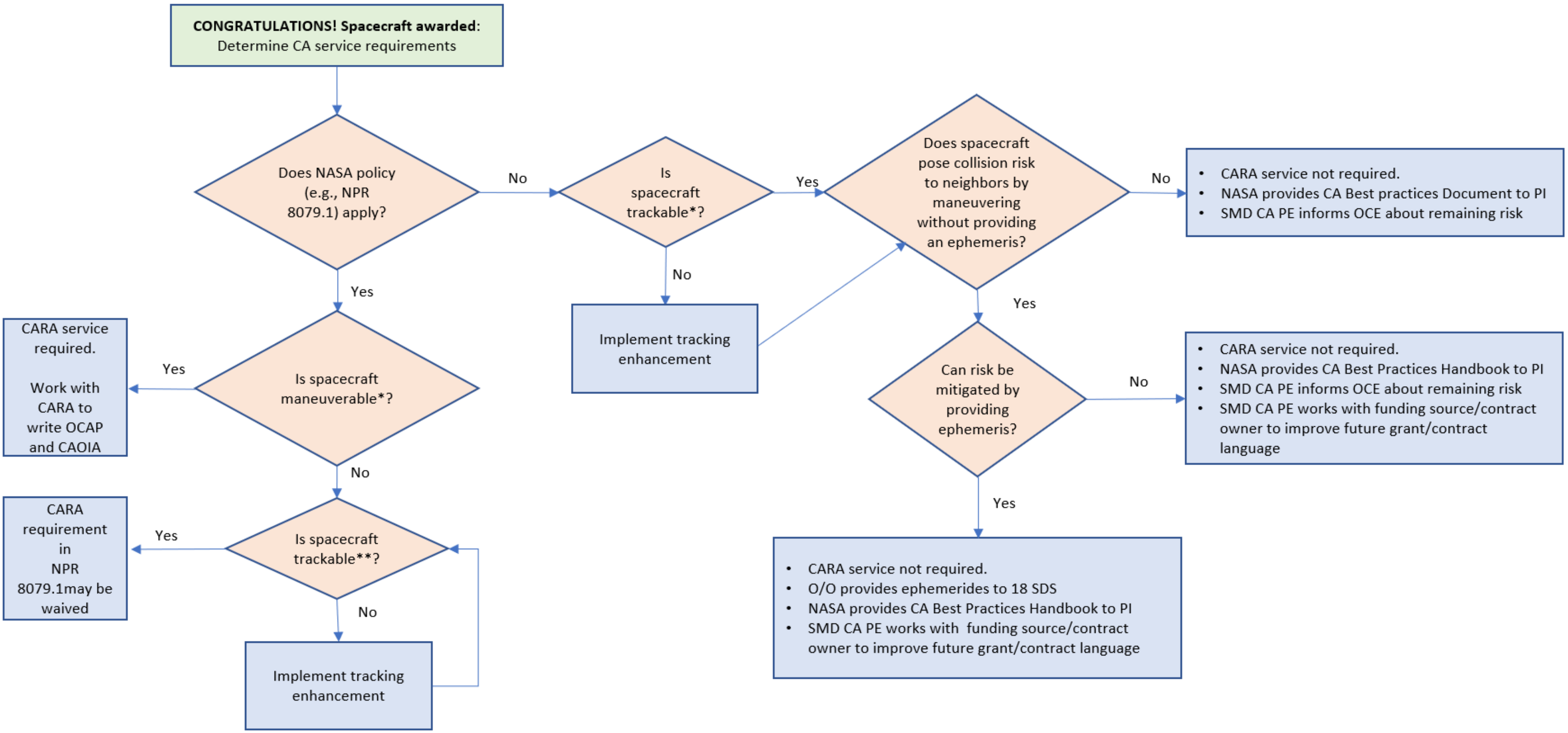
- **Human Spaceflight (HSF)**
  - **ISS and visiting vehicles**
  - **Commercial Crew**
  - **JSC-based**
- **CARA**
  - **Non-HSF, Earth-orbiting missions (~100 assets)**
  - **GSFC-based**
- **Multimission Automated Deepspace Conjunction Assessment Process (MADCAP)**
  - **Cis-lunar and beyond**
  - **JPL-based**
- **CAPO**
  - **HQ CA integrating function**
  - **Oversees CARA and MADCAP**



NPR Interpretation and Simplification

- We have been working to find ways to assist spacecraft with implementing the new NASA NPR 8079.1 and CA Best Practices
- Planning Resources
  - Flow diagram
  - OCAP Screening Form
  - FAQ available on website
  - White Paper forthcoming
- Selecting Hardware
- Selecting orbit determination/ephemeris options

CARA Flowchart for Mission Coordination



Note: *analysis performed for maneuverability determination .
**analysis described in OCAP may be needed to determine trackability if spacecraft is small.

OCAP Screening Form

- NPR 8079.1 requires an Orbit Collision Avoidance Plan (OCAP) document
  - Set of analyses performed by CARA
  - Mission makes implementation decision based on CARA recommendations
  - ***<u>Intended to be a conversation – not just a document</u>***
- Not all missions require a full OCAP based on orbit selected, spacecraft size, maneuverability, etc.
- The earlier after selection that the analyses are performed, the cheaper and easier the implementation of the necessary options is
- To determine which analyses are needed for a given mission, CARA developed a screening form
  - If it is determined that no analyses are needed, the screening form can be signed by mission and CARA and serve as the OCAP.
  - CARA will determine which analyses are needed and only perform those that are necessary.

CONJUNCTION ASSESSMENT RISK ANALYSIS ORBITAL CONJUNCTION ASSESSMENT PLAN (OCAP) SCREENING FORM

PROJECT INFORMATION

1. PROJECT NAME:	2. PROJECT POINT OF CONTACT *(Name and title)*:
3. KDP-B* & LAUNCH DATES *(Best current estimates)*: KDP-B*: Launch:	4. PROJECT POC EMAIL ADDRESS:

5. SCREENING QUESTIONS

QUESTION NUMBER	SCREENING QUESTION	PROJECT RESPONSE (a) YES	NO
1	Is your spacecraft larger than 10cm per side for LEO or 50cm/side for MEO/HEO/GEO?		
2	Does your spacecraft have a propulsion system? If yes, check one: ☐ chemical ☐ electric ☐ other		
3	For spacecraft without a propulsion system, are you intentionally performing actions that will change the spacecraft orbit (e.g., differential drag, ...)		
4	Is your spacecraft using a tether?		
5	Are there multiple spacecraft as part of your mission?		
6	Is your spacecraft deploying any child objects?		
7	Is your spacecraft a rideshare?		
8	Will ephemeris with covariance (including any planned maneuvers) be provided based on a mission tracking data source?		
9	Does your spacecraft perform autonomous maneuvering?		
10	Specify the mission orbit apogee ☐ perigee ☐ inclination ☐ If different than the mission orbit, specify the injection apogee ☐ perigee ☐ inclination ☐		

6. PROJECT CERTIFICATION

By signing below, I certify that the above information is an accurate representation of the project architecture.

a. PROJECT APPROVER *(Name and title)*:	b. SIGNATURE	c. DATE

7. OCAP COMPLETION RECOMMENDATION

(To be completed by CARA Representative)

Based on the information provided, CARA makes the following recommendation:

CLASSIFICATION (SELECT ONE) (a)	RISK CLASSIFICATION RECOMMENDATION (b)
☐	This project meets the criteria to utilize this form as OCAP. No further analysis is recommended unless future changes to the project would change the response to one of the screening questions.
☐	The project does not meet all of the criteria required to utilize this form as the OCAP; a tailored OCAP is required.
☐	The project screening criteria answers justify completion of a full OCAP.

c. CARA COMMENTS:

d. CARA REPRESENTATIVE (Name and title):	e. SIGNATURE	f. DATE

National Aeronautics and Space Administration

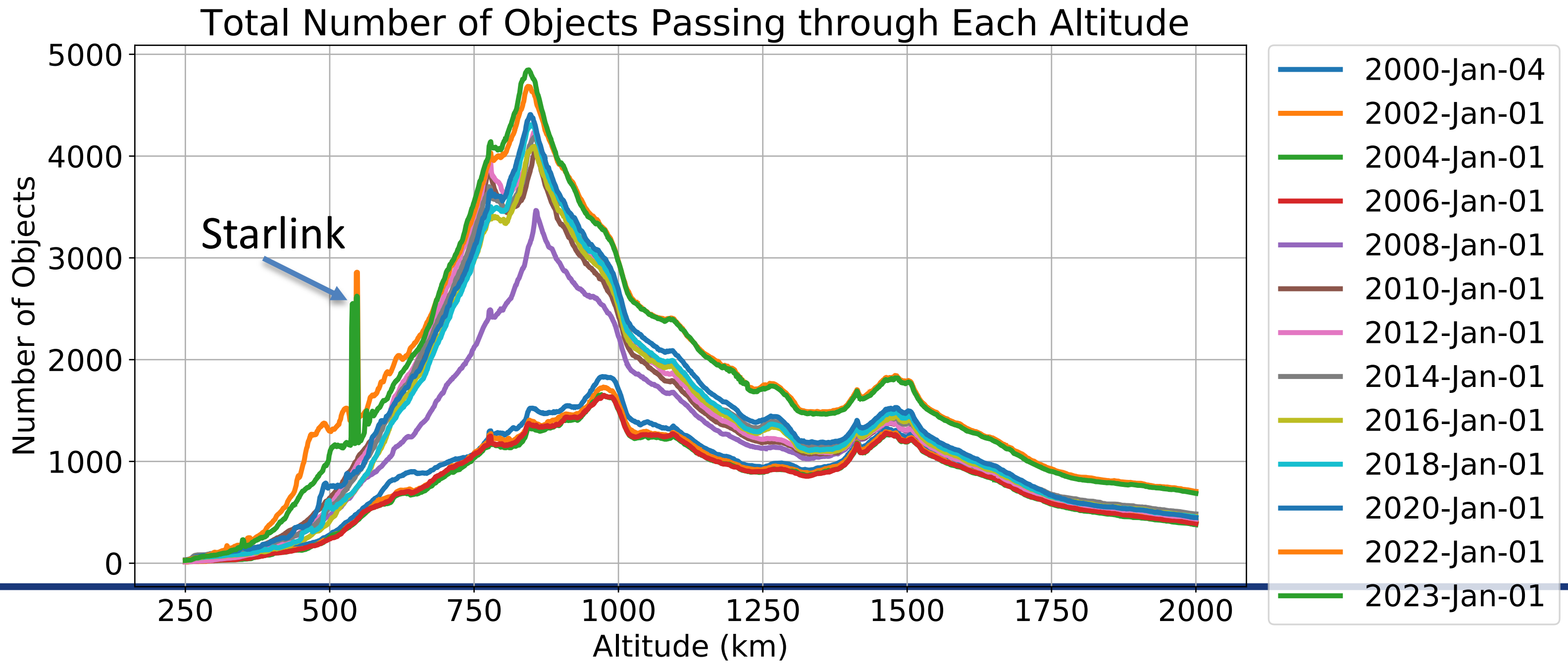
Key Best Practices

NASA Conjunction Assessment Risk Analysis

www.nasa.gov

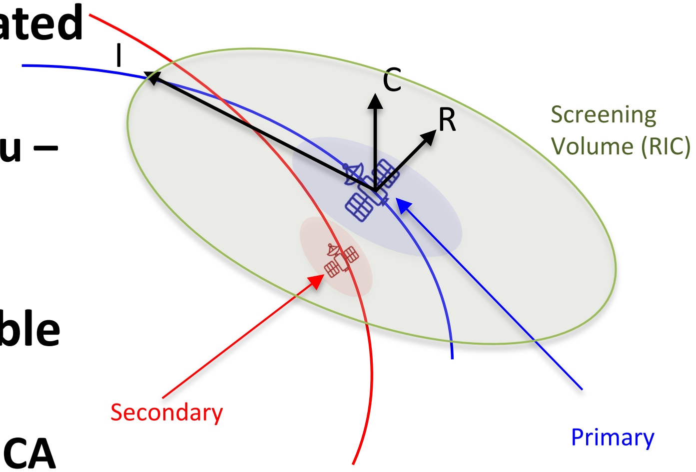
Choosing an Orbit

- **Choosing an orbit is one of the OCAP analyses**
- **Understanding the ramifications of choosing a particular altitude and weighing those against the benefits is a trade study that should be mindfully undertaken.**
- **Rideshare spacecraft can assist by raising awareness of the orbit crowding issue to their ELV provider**
  - **Often ELVs launch to highest possible orbit without considering that a lower orbit might be safer for their customers (and allow delivering more mass to orbit!)**



Producing a CA-Quality Ephemeris

- Since close approaches are computed using predictions of future spacecraft position, an ephemeris with associated covariance (uncertainty) is required for CA.
  - Other operators need to know your location to avoid you – occurs via screening of ephemeris by DOD
  - Computing probability of collision requires covariance.



- Position predictions must be accurate enough to enable avoidance maneuver planning.
  - No current quantitative accuracy requirement exists for CA
    - Due to complexity of conditions that affect prediction accuracy and conjunction remediation efficacy
    - (e.g., orbit regime, maneuver response time, conjunction geometry, covariance realism, etc.)
    - DOC Study underway that may provide discrete values
  - Close approaches identified using penetrations of large screening volume around the asset
  - The ephemeris accuracy is too poor for CA to be performed if the position uncertainty of the asset is a substantial percentage of that surrounding volume.

Analysis of ephemeris accuracy performed as part of OCAP preparation

Ephemeris Production

- Many smallsats rely on DOD data rather than produce their own ephemeris
  - For non-maneuverable spacecraft in most orbits this works, but should be examined before launch (OCAP) because there are some exceptions:
    - Does not work for maneuverable spacecraft as DOD doesn't have knowledge of predicted maneuvers
    - Spacecraft must be passively trackable by Space Surveillance Network (see next slide)
- Maneuvers must be screened before execution to protect other on-orbit spacecraft
  - No maneuver is too small to require screening
  - No altitude is too low to require screening
- Two Line Elements (TLEs, e.g. from SpaceTrack.org) are <u>NOT SUFFICIENT</u> FOR CA
    - 1-2 km theory error is too large for CA risk assessment and maneuver planning
    - No covariance available to compute probability of collision and make risk decision

OCAP includes determination of DOD solution sufficiency

Trackability

- Technology advances make possible spacecraft that are too small to be tracked by the Space Surveillance Network (SSN)
  - SSN is the DOD USSF resource assigned to track all on-orbit objects
  - Objects must be >10 cm to be tracked reliably in LEO
  - Objects must be >50 cm to be tracked reliably in GEO
  - Passive tracking not currently available beyond GEO (e.g., cis-lunar)
  - CA can be performed only against well tracked objects in the catalog

- Un-trackable objects on orbit pose a threat to flight safety
  - Objects in low inclination orbits (fewer SSN sensors with geometric visibility)
  - Objects in eccentric orbits (perigee can be away from radars and satellite can be too dim at apogee for optical sensors)
  - Objects too small to be regularly tracked in any orbit

Trackability should persist for full on-orbit lifetime, not just during operations.

Trackability Augmentation

- Potential workarounds options listed in CA Handbook
- One option is adding a GPS transponder
- Can either fly a GPS that transmits down a point solution and do orbit determination on that to make an ephemeris or use a GPS that computes and downloads its own covariance
  - Having this onboard from the receiver is likely too stringent a requirement, but it can be generated on the ground using free tools, e.g., GMAT, processing standard receiver point solution telemetry
  - Can hire provider to process your GPS data (e.g., Slingshot, Kayhan, SpaceNav, CommSPOC)
- Guidance for choosing:
  - Want fast convergence after launch to allow CA ASAP after separation
  - Must be space rated (or must test with a simulator)
  - Other features, like multi-frequency, multi-GNSS, and availability of pseudoranges, are nice-to-have, but the benefit is marginal vs. just having a receiver in the first place
- For Cubesats, there are GPS receiver kits on the market:
  - NovAtel OEM719 is a common receiver choice
  - Lockheed Martin and The Aerospace Corporation make GPS strap-ons
  - JAXA Mini Mt Fuji

SSCG annual report will contain a list in future updates of OD providers and GPS transponders.

COLA Gap

- Until the delivered spacecraft is tracked and cataloged by DOD (up to 2 weeks), CA is not possible – this is called the COLA Gap period
  - Important to provide state and covariance ASAP after launch to prevent collision
  - Work with ELV provider to request this data
  - Provide O/O ephemerides ASAP as ELV data is only good for a short period (accuracy degrades the longer the state is propagated).
- Many ELVs launch rideshares to 550 km, an orbit regime occupied by a large number of autonomously-maneuvering Starlink spacecraft.
  - If the spacecraft do not need to go to this altitude for science reasons, better to choose something lower, preferably below the ISS.

SpaceX SAA

- SpaceX has 5000 Starlink spacecraft maneuvering autonomously at 550 km
- NASA has a Space Act Agreement (SAA) with SpaceX under which SpaceX agrees to take the maneuver action in the event of a close approach with a NASA spacecraft
- In order to enable SpaceX to be able to take action, they require CDMs that represent close approaches based on an accurate ephemeris for the NASA asset
- NASA spacecraft that plan maneuvers should not change the maneuver within 24 hours of TCA in order for SpaceX to use the CDM data from the submitted ephem that includes the planned maneuver
- Spacecraft being injected near Starlink (530km – 578km) should provide ephemerides starting at injection, such as based on a separation vector, to ensure SpaceX can know the location of the spacecraft even prior to

NASA spacecraft must fulfill this need regardless of NPR applicability due to SAA governance.

Satellite Autonomous Maneuvering

- Becoming more common for satellites to employ autonomous maneuvering (especially large constellations)
- Maneuvers automatically commanded/executed
  - Often ground systems do not even know of maneuvers until after execution
- Automated maneuvers don't have to be real-time
  - Allow time to screen maneuvers so other operators know where your spacecraft will be
  - Consider this when designing maneuver CONOPS
- Two autonomously-maneuvering satellites in conjunction may be planning mitigation actions, but neither knows what the other is planning to do
  - Satellites could therefore maneuver into each other
- Consortium among NASA Ames, NASA CARA, SpaceX, and Emergent Technologies have developed and are demonstrating a prototype autonomous CA approach
  - Participants in Starlink/Starling formal experiment for autonomous CA
  - To run JAN-SEP 2024

CA Beyond Earth

- Catalog of non-cooperatively tracked objects used in CA only available near Earth
- Activity at Moon, Mars, and Libration points increasing; risk of collision without screening
- DOD developing cis-lunar catalog and screening capability
  - Requirements not yet defined
  - Implementation is years away
- NASA Multimission Automated Deepspace Conjunction Assessment Process (MADCAP) provides ephem-on-ephem screening for missions that utilize DSN
  - Relies on sharing of data; sharing of non-NASA data encouraged

NASA Mission Reminders

- NASA missions should reach out to CARA as soon as mission is awarded to ensure least impact in implementing CA requirements
- Any requests for DOD support related to SSA for NASA missions must flow through CARA
- CARA is available to assist with anomaly resolution
- Missions flying in Starlink regime must comply with Space Act Agreement with SpaceX – CARA assists

Where to go for help

- **General CARA questions:** CARA-MissionSupport@nasa.onmicrosoft.com
- **CARA Operations Team:** hq-cara-ops@lists.hq.nasa.gov; 301-286-9545
- **Submit an Orbital Data Request:** CARA-ODR-Liaison@nasa.onmicrosoft.com
- **NASA CA Policy Questions:** CAPO/lauri.k.newman@nasa.gov
- **CARA external website:** **https://www.nasa.gov/conjunction-assessment**
- **NASA CA website:** **https://www.nasa.gov/conjunction-risk-analysis-and-mitigation**
- **NASA is committed to refining and sharing appropriate best practices**

NASA CA Handbook **CARA Tool Repository** **NASA CA website**

Questions?

Ephemeris Accuracy Assessment

- **Pre-launch OCAP Analysis:**
  - **Evaluate planned orbit determination (OD) strategy to assure *capability* to produce accurate ephemeris**
  - **Evaluate expected ephemeris prediction uncertainty growth over time**
    - **If uncertainty > 25% of screening volume → recommend OD improvements**
      - **Examples: Increased/better tracking, more frequent ephemeris deliveries, more accurate dynamic modeling, covariance tuning**
- **In-flight Evaluation:**
  - **Compute *post facto* errors in predicted ephemerides**
    - **If errors > 25% of screening volume → recommend OD improvements**
  - **Perform ephemeris uncertainty (covariance) realism analysis**
    - **If uncertainty does not fairly represent errors → recommend OD improvements**
    - **If uncertainty is not small enough to make confident remediation decisions → recommend OD improvements**

Orbital Data Request (ODR)

- If a mission desires to obtain additional data or services from DOD related to CA or Space Situational Awareness, an Orbital Data Request must be submitted.
- Examples:
  - Launch and early orbit support
  - Anomaly support
  - Data redistribution (e.g. publish papers using CA results)
- Process
  - Obtain blank form from CARA, CARA and mission iterate contents
  - DOD requires 30 days to process non-emergency requests
  - Allow additional time for contents to be iterated with CARA before submission
- CARA submits the request on behalf of the mission to ensure compliance with existing agreements and to prevent duplication of effort (missions may not submit directly)
  - Specified in NID 7120.132 and ensures NASA complies properly with inter-agency agreements
  - CARA may already have or have access to the requested data
  - HSF ODRs submitted by JSC FOD

Anomaly Support

- The CARA team can provide assistance in unexplained anomaly resolution
- Examples of anomalies that CARA can assist with:
  - You cannot contact your spacecraft
  - Your spacecraft experiences force from an unknown source
- CARA can use its resources to determine:
  - Whether there were any trackable objects near your spacecraft at the time of the event
  - Whether your spacecraft is in a non-nominal attitude
  - Whether your spacecraft is intact
- Some CARA resources are classified, so only mission personnel having the appropriate clearance are able to receive the information. It is valuable to have decision-makers at the SECRET and SCI levels for this reason
- The earlier CARA is notified, the more likely that useful data can be obtained

CARA Operations Hours

CARA Nominal Business Hours
Monday- Friday
8:00am – 10:00pm (ET)

- **CARA Operations Team**
  - **Monday-Friday 08:00 to 16:00 (ET)**
    - **2 operators on-console [Prime and Back-up]**
  - **Monday-Friday 16:00 to 22:00 (ET)**
    - **2 operators on-console [Prime and Back-up]**
  - **Monday-Friday 22:01– 08:00 (ET), Weekends and holidays**
    - **1 prime operator is on-call (Follow up any email requests to hq-cara-ops@lists.hq.nasa.gov with a phone call to the operations phone *301-286-9545*)**

- **Orbital Safety Analysts Team (OSAs)**
  - 7 days/week **(including** most holidays**),** from 09:00 to 05:00 (ET) **(20 hours)**
    - **1 OSA is on-console per 10 hour shift**
  - **No OSA is on-console from 05:00-09:00 (ET) Daily**
  - **Holiday Note: One screening (~16:00 UTC) is performed on Thanksgiving, Christmas and New Year's Day**
  - **In FY 24, nominal staffing will be 24 hrs/day**

- **While there are different strains of on-board PNT receivers that could be used, collective experience suggests that in order to support Conjunction Assessment, one of the below choices is best: (nice to have)**

- **<u>Multi-frequency (or at least dual-frequency) receiver</u>. With multiple-frequency reception, one can examine the ratios of the received frequencies and the degree that those ratios differ from those for the transmitted frequencies, and from this determine the wavefront delay and thus correct the range measurement for ionospheric interference. This approach produces more accurate position fixes.**
- **<u>GNSS rather than GPS receiver</u>. A GNSS receiver can, with firmware updates, receive signals from different navigation systems (*e.g.,* GPS, Galileo, &c.). This allows changes of system during flight should that prove advantageous.**
- **<u>Output of pseudo-ranges</u>. Choosing a receiver that will output pseudo-ranges, rather than just position-velocity estimates derived from the receiver's own Kalman filter, allows the owner-operator much more control over the filter process used to derive state estimates. To do this, one runs the receiver as a "software-defined radio." This is a capability that typically requires licensed software, but GSFC may be able to provide this software for interested NASA users.**