

Conjunction Assessment Risk Analysis

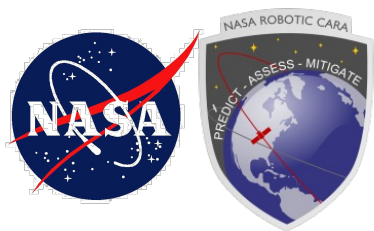


Collision Avoidance “Short Course”

Part III: CA in Changing Space Flight Environment

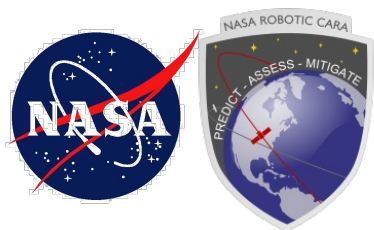
Lauri Newman

NASA Conjunction Assessment Program Officer



Changing Space Environment

- **Space environment has been changing, and will continue to evolve rapidly over the next few years due to the following drivers:**
 - Space Fence
 - Proliferation of large constellations
 - New space actors
 - SmallSat proliferation
- **New technologies and methodologies are evolving, adding complexity to the CA enterprise**
 - Maneuver Plan Streamlining
 - Increasing on-board autonomy
- **CA practices will need to evolve to meet growing needs**
 - New methodologies
 - AI/ML
 - Best practices
 - Data sharing
 - Cis-Lunar CA



Space Fence (SF) Sensor

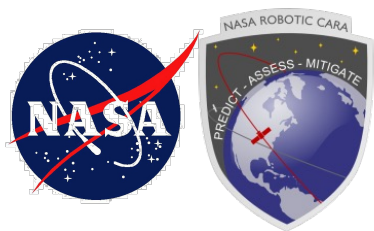
- **New(ish) Space Surveillance Network (SSN) sensor**

- Equatorial phased-array S-Band sensor
- Can track to at least 5 cm (SSN capability 10 cm)
- Initial Operations Capability achieved 2020

- **Expected impact on CA**

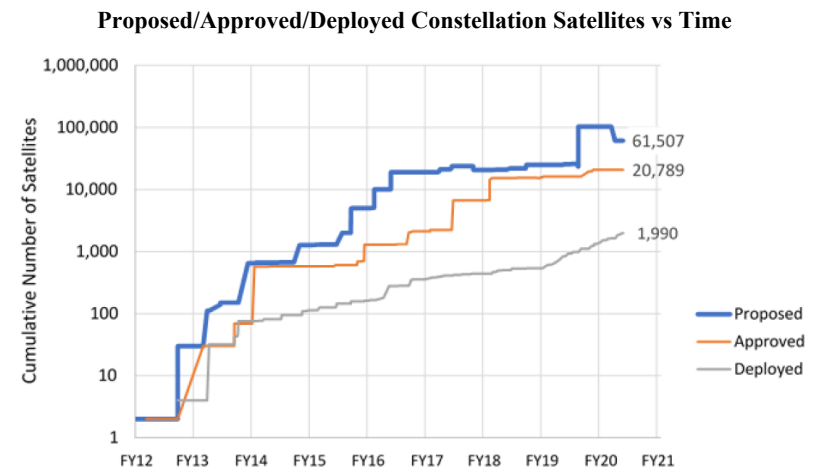
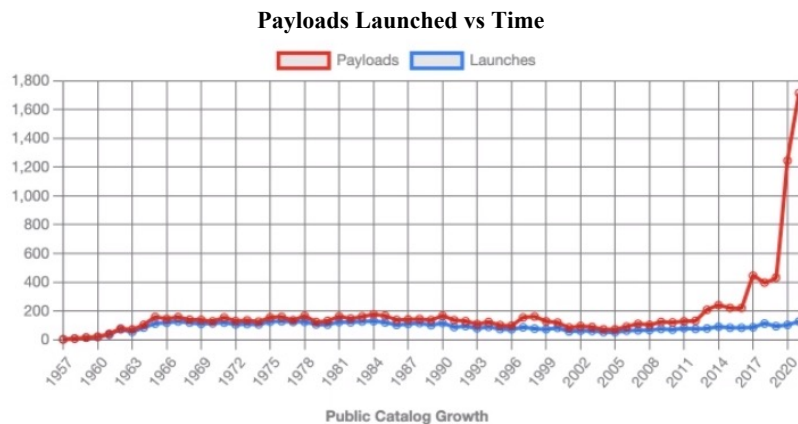
- Increased quantity of new objects
 - SF-maintained objects expected to be introduced to CA enterprise over next several months
 - Overall CA workload increase estimate: low at present; potentially as much as 100% once all new objects introduced
- Quality of maintenance ODs
 - Newly-discovered objects that can be tracked regularly should have reasonably good ODs
 - Objects on edge of detection may have quality issues and create data actionability problems
- Workload increases will be felt both by CA practitioners and individual missions

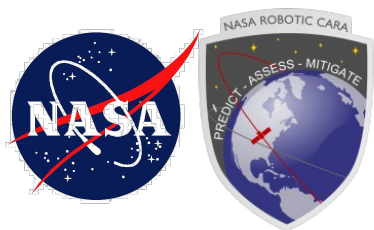




Active Payload Growth: “Large Constellation” Effect

- **New active payload growth due to large constellations substantial**
 - 20,000 new satellites approved, of which only 2000 launched
 - Filings for new constellations exceed 100,000 satellites
- **Active payload conjunctions more demanding than with debris**
 - Coordination/negotiation with other O/O required—more demanding
 - Potential consequence higher: collision would destroy two active satellites and create substantially larger debris field
- **Imputed additional operational workload considerable**





Increasing CA Workload

Predicted Tracked Object Density
by Altitude in 2030*

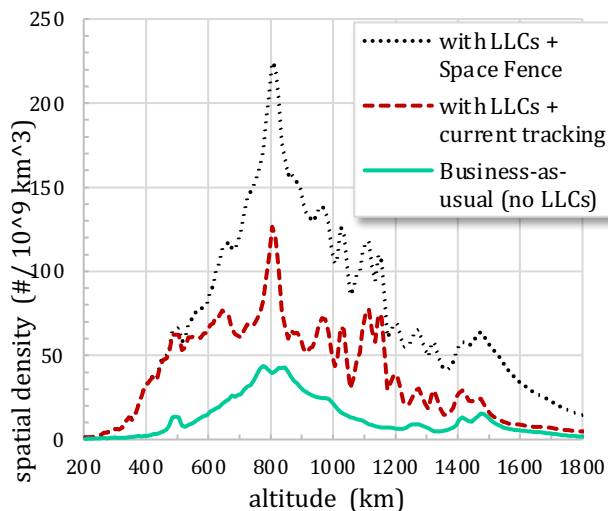
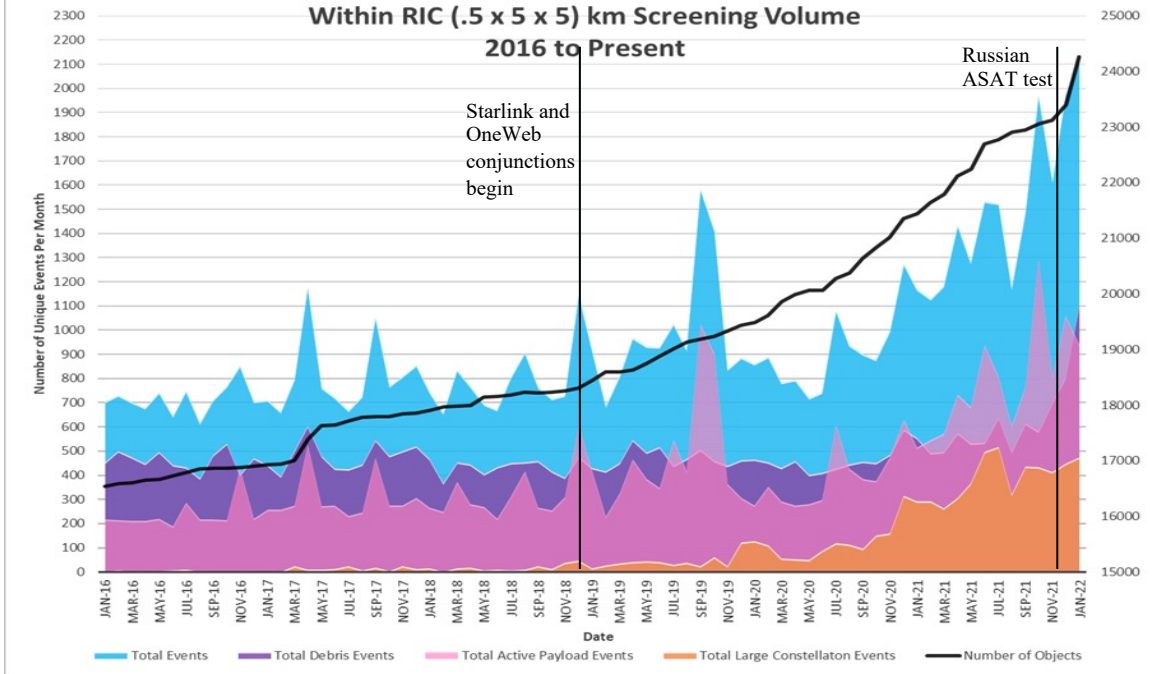


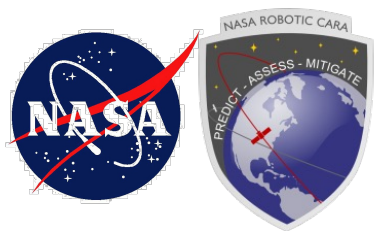
Figure courtesy Aerospace Corporation

Unique Conjunction Event Growth Over Time
Within RIC (.5 x 5 x 5) km Screening Volume
2016 to Present



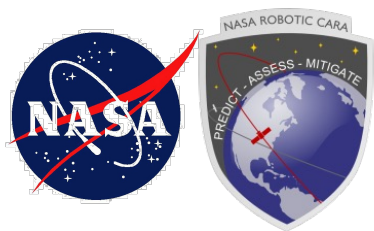
- **Current CA workload is large and continues to grow**

- Across the LEO fleet, NASA CARA sees about 2000 unique conjunctions each month
 - Up 30% since 2018 primarily due to Starlink and OneWeb conjunctions
 - Russian ASAT test in 2021 added 30% more events



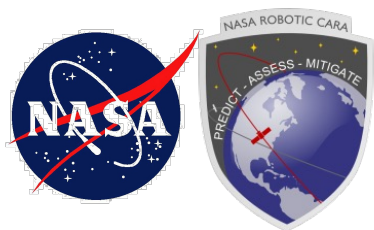
New Space Actors

- **The space environment today is very different from a decade ago and continues to evolve very rapidly**
 - Historically, space operations were domain of large governmental entities
 - Commercial space operations now the predominant paradigm—a different business model and set of concerns from those of government actors
 - CubeSats are cost effective and accessible for everyone, even down to elementary schools
- **Challenge in educating new space actors on best practices and availability of data and tools**
 - DOC is US agency to develop policies for best practices and data sharing
 - Example rule: space “regionalization”
 - Altitude < 350km a “Wild West” region for cubesats with little flight dynamics experience or orbital control
 - Allows inexperienced actors to access space without threatening high-value assets



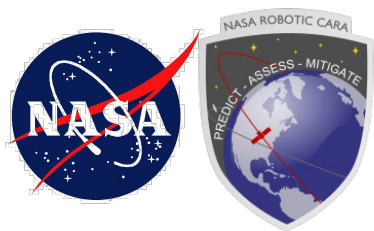
SmallSat Proliferation: Small Doesn't Mean “Safe”

- **In a collision, small satellites can destroy large satellites and create large debris clouds**
- **Small satellites must be tracked in order to prevent collisions**
 - Small satellites harder to track, and some below regular tracking threshold
 - Many small satellite operators do not compute their own ephemeris and rely on TLEs, making SSN tracking essential to their position determination
- **Maneuverable small satellites must have their maneuvers screened**
 - Neighbors unaware of intended trajectory cannot mitigate close approaches
- **In short, it is a fallacy that small, cheap satellites do not require CA**
 - In fact, in many respects more dangerous than traditional satellites



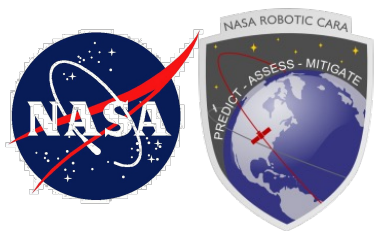
Trending Concern: Importance of Data Sharing

- **Many reasons O/Os can have future positions that tracking networks will not model properly**
 - Planned future impulsive maneuvers
 - Low thrust / electric propulsion, especially over long periods, which is very difficult to solve for with traditional methods
 - Satellites too small to be tracked reliably
- **Missions thus need to share predicted ephemerides to all for CA**
 - Predicted ephemerides are **not** proprietary—they are needed for safety of flight, and the satellite's future position will be openly discoverable anyway
 - Without shared data, other operators have no way to tell where these assets are
 - Sharing should be through a trusted/protected mechanism, like Space-Track.org or SDA
 - Screening authority will need to access these ephemerides to include them in CA screenings



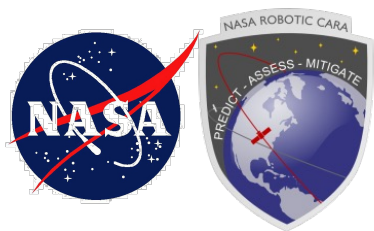
Satellite Autonomous Maneuvering

- **Becoming more common for satellites to employ autonomous maneuvering (especially large constellations)**
 - SpaceX's Starlink current example: ~2000 active satellites operated this way
 - Other, smallsat autonomous constellations planned
- **Maneuvers automatically commanded/executed**
 - Often ground systems do not even know of maneuvers until after execution
- **CA can also be executed autonomously**
 - CDMs for upcoming conjunctions uploaded to spacecraft
 - On-board CA software can determine risk based on spacecraft's latest position information, plan maneuvers to avoid close approaches, and execute them
 - If CDMs generated with sufficiently large screening volume, then autonomous CA likely to be effective against debris



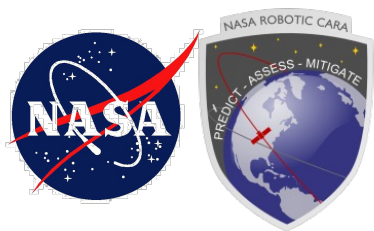
Autonomous Flight Dynamics: Active-vs-Active CA Issue

- **Autonomous systems program maneuvers and perform CA based on CDMs uploaded as frequently as contacts allow**
- **Co-located autonomously-controlled constellations need other solution**
 - Two satellites in conjunction from different constellations may be planning mitigation actions, but neither knows what the other is planning to do
 - Satellites could therefore maneuver into each other
 - Not merely a fanciful situation: in famous Iridium-COSMOS collision, Iridium has stated that their satellite maneuvered into the COSMOS trajectory due to lack of available CA data
 - This situation led the advancement of the CA process to what we know and use today
- **For autonomous CA with other active satellites, latencies in information exchange cause CA problems**
 - Non-autonomous active satellites need to refrain from maneuvers 12-24 hours before close approaches with autonomous satellites
 - Allows sufficient time for submitted ephemeris that includes their maneuver to be screened for CA and these screening results uploaded to autonomous system



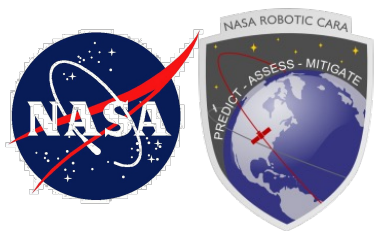
Active-vs-Active CA Issue Potential Solution: “Mother May I” Approach

- **Ground hub established to receive ephemerides from autonomously-controlled constellations**
- **If a satellite wishes to maneuver, assembles proposed maneuver ephemeris and submits to ground node**
- **If ephemeris does not produce any CA issues, ephemeris is “cleared” for use, and message sent to constellation indicating this**
 - Submitting satellite now has a “right” to this ephemeris, and other satellites prevented from (voluntarily) impinging on it
 - But submitting satellite also has an obligation to follow this ephemeris unless they subsequently submit an alternative, which is itself cleared
- **System can also allow the submission of multiple, ranked maneuver ephemerides at the same time**
 - Highest-ranked ephemeris that does not produce CA issues “cleared” for use
- **Approach requires contact times frequent enough to enable communication of plan between spacecraft and ground at appropriate times**



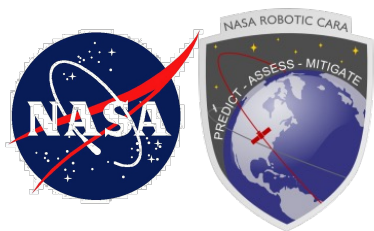
Active-vs-Active CA Issue Potential Solution: Rule-Based Approach

- **Set of rules could be developed that would make clear, in every conjunction, which satellite should perform which actions**
 - Iridium proposed set of such rules in a recent paper
- **If approach possible, could eliminate need for communication approach and system described previously**
- **However, some scenarios may not be sufficiently addressed:**
 - Example: Suppose two autonomous spacecraft each need to perform a maneuver
 - Each schedules one, unaware the other has done so, creating a conjunction
 - Unless the maneuvers are planned well in advance (more than 24 hours, to allow the present system to screen submitted ephems and send back CA results), no way for both satellites to know they are creating a risky conjunction
 - No easy way to resolve who is permitted to maneuver



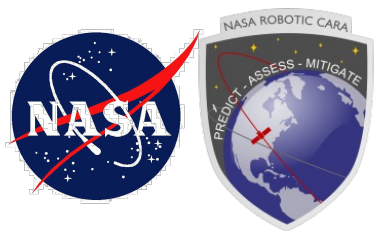
Active-vs-Active CA Issue: Current Resolution Efforts

- **NASA is part of an industry consortium to develop pathfinder solution**
 - NASA experimental autonomous constellation (Starling) will be collocated with Starlink constellation, forcing the issue
 - Consortium among NASA Ames, NASA CIRA, SpaceX, Emergent Technologies, and UT Austin to develop and demonstrate a prototype autonomous CA approach
 - “Mother May I” solution utilized
- **Infrastructure being built out. Ground testing underway**
- **Department of Commerce (DOC) participates in observer status**
 - Designated to assume space traffic management responsibility
 - Successful demonstration of approach expected to lead to embrace by DOC



New Methodologies (1/2)

- **Potential new CA paradigms to handle workload**
 - CA remediation against “grouped” events using an aggregate P_c
 - Station-keeping burn strategy to minimize conjunction risk, without actually remediating individual events unless an extremely high P_c
 - Consideration of consequence in addition to risk to determine which events to remediate—already moving towards implementation at NASA
- **CARA tools are available free to the public as Software Development Kits (SDKs) on the CARA repository (https://github.com/nasa/CARA_Analysis_Tools)**
 - Contain benchmark test cases in addition to Matlab source code.



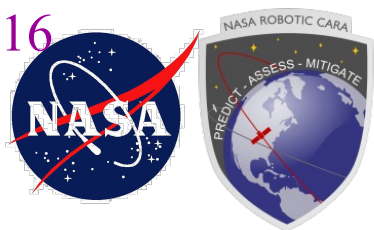
New Methodologies (2/2)

- **Automation/artificial intelligence**

- Investigate methods to automate more of the process while retain key safety elements
- Determine usefulness of machine learning, neural nets, etc. in decision-making
- Enterprise difficult because CA lacks “truth” data—very few collisions actually take place
- NASA initial CA AI / machine learning studies show little improvement

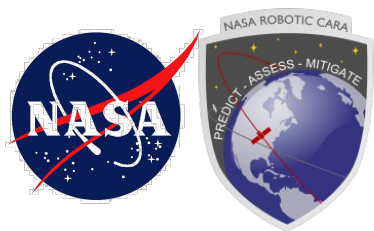
- **Challenges: no truth data make training the system hard**

- Dog-vs-cat ML/AI trained against millions of curated dog/cat photographs
- In CA, only a few verified collisions, and these often lack modern data
- Similar to predicting 1000-year floods: have no modern empirical data



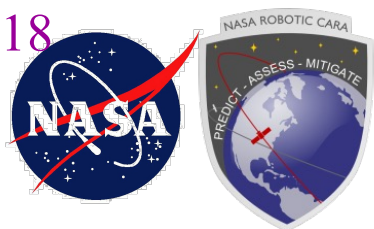
Cis-lunar CA

- **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 many years away
- **NASA Multimission Automated Deepspace Conjunction Assessment Process (MADCAP) provides ephemeris-on-ephemeris screening for missions that utilize DSN**
 - Not Pc based; most operators do not provide covariance
 - Relies on sharing of data; sharing of non-NASA data encouraged

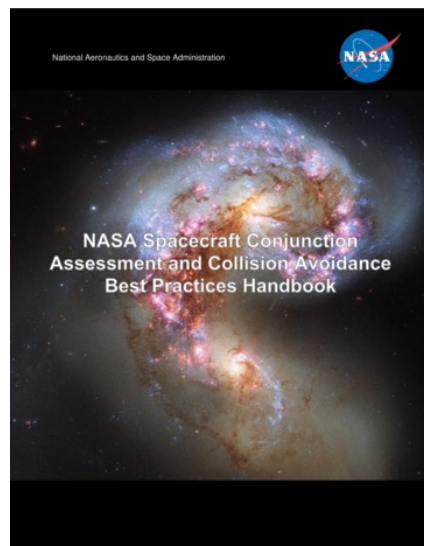


CA Best Practices

- **CA industry is evolving rapidly**
- **Guidelines/standards are needed to enable healthy growth**
 - Safety of Flight best practices should be adapted universally
- **Sources of existing best practices:**
 - Best practices for 18 SDS support are available on [Space-Track.org](https://space-track.org) website
 - NASA published CA best practices Handbook in December 2020; contains analysis describing the technical/scientific foundations of best practices
 - https://nodis3.gsfc.nasa.gov/OCE_docs/OCE_50.pdf
 - Secure World Foundation publishes “Handbook for New Actors in Space”
 - Best practices for satellite operations at [Spacesafety.org](https://spacesafety.org)
 - CONFERS publishes best practices for Proximity ops
- AIAA has a Space Traffic Management working-group to investigate various topics. One is best practices.
 - For information contact Dan Oltrogge / AGI or Moriba Jah / UT Austin



NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook



- Covers the current USG CA process end-to-end, including high-level details of 18 SDS screening process.
- Provides list of best practices with rationale and appendices on methodologies
- 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



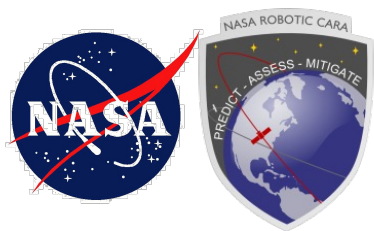
NASA CA Handbook



CARA Tools



NASA CA website



Summary

- **Exciting growth offers opportunities that will change society, but needs to be done safely to ensure that we have continued use of the space environment for future generations**

