National Aeronautics and Space Administration

NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook

Informational Briefing to the Small Satellite Systems Virtual Institute (S3VI)

October 13, 2021

NASA Office of the Chief Engineer
Mission Resilience and Protection Program

Today's Discussion

Context

Process and Risk

Gaps / Opportunities

Key elements of the best practices

Forward work

NASA Guidance Overview for Conjunction Assessment Topics

NID 7120.132
Effective 2020-11-19

Collision Avoidance for Space Environment Protection

Expected CY2022

In progress, replaces the NID

Released December 2020

NASA Spacecraft Conjunction Assessment Best Practices Handbook

Next update no sooner than CY2022

Initial draft early CY2020

NASA-STD-1007 Conjunction Assessment Standard (DRAFT)

Release no sooner than CY2022

NASA-specific

Usable by any space operator

Where Does NASA Fit?

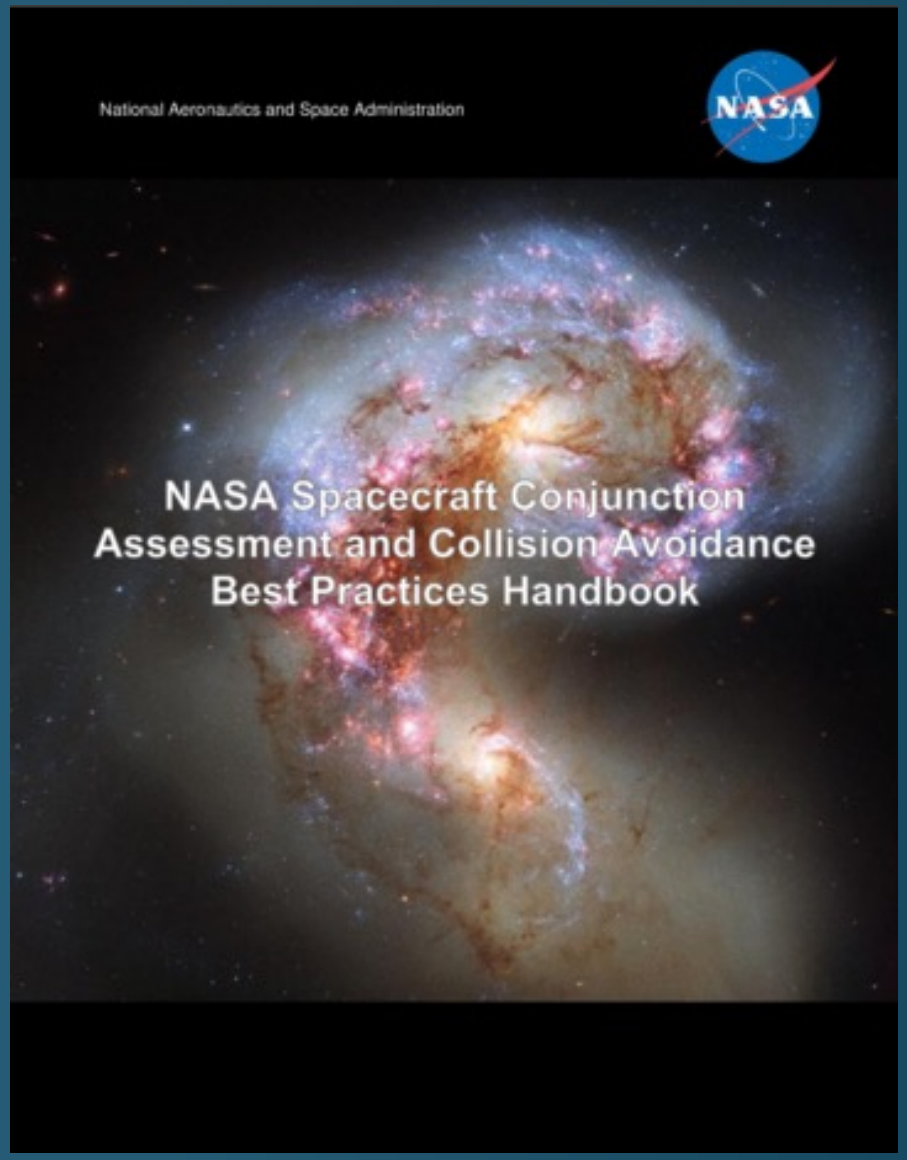
NASA …

- Measures orbital debris and helps develop the technical consensus for adopting debris mitigation measures
- Performs research and development for orbital debris mitigation and conjunction risk assessment
- Generates and shares ephemeris data for NASA missions
- Performs conjunction risk assessment for NASA-sponsored missions, certain others
- Shares knowledge and expertise
- Encourages a robust and diverse commercial space industry

Space Policy Directive-3, the National Space Traffic Management Policy (SPD-3), established a goal to develop safety standards and best practices

- NASA's handbook supports the SPD-3 goals by sharing our current approach

NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook



Addresses general conjunction assessment topics across the mission lifecycle

- Human spaceflight-specific topics, such as rendezvous with the International Space Station, are not fully addressed

Helps space system operators understand existing capabilities and processes

- Includes US Space Command (USSPACECOM) and the US Space Force 18th Space Control Squadron (SPCS)

Offers voluntary best practices for use by any space operator to help protect the space environment

Orbital Debris vs Conjunction Assessment

Orbital Debris Mitigation

Reducing the introduction of new orbital debris into orbit, including through use of shielding and disposal planning.

NASA helps to characterize and model the orbital debris environment, and in developing the technical consensus for adopting mitigation measures.

See also guidance from Inter-Agency Space Debris Coordination Committee (IADC) and United States Government Orbital Debris Mitigation Standard Practices (ODMSP).

Active Debris Removal

Reducing the amount of existing orbital debris from orbit.

NASA conducts research and development of technologies that may support active debris removal.

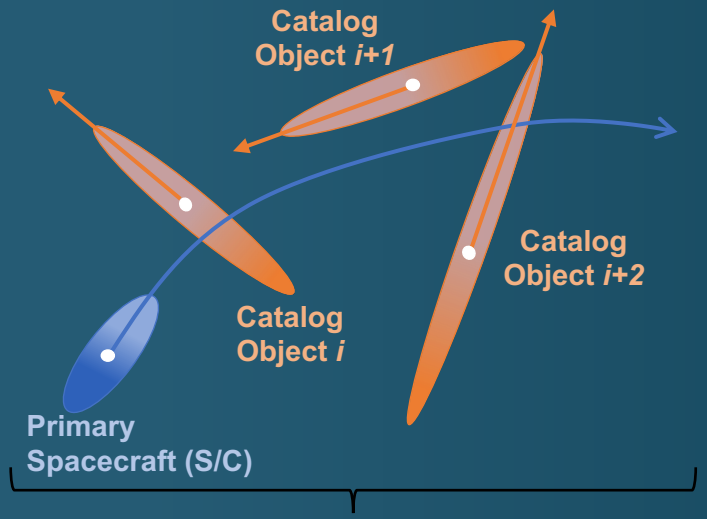
Conjunction Risk Assessment

Evaluating the risk of close approaches between objects, so that high-risk approaches may be mitigated, such as through a maneuver.

NASA performs conjunction risk assessment for its operating missions.

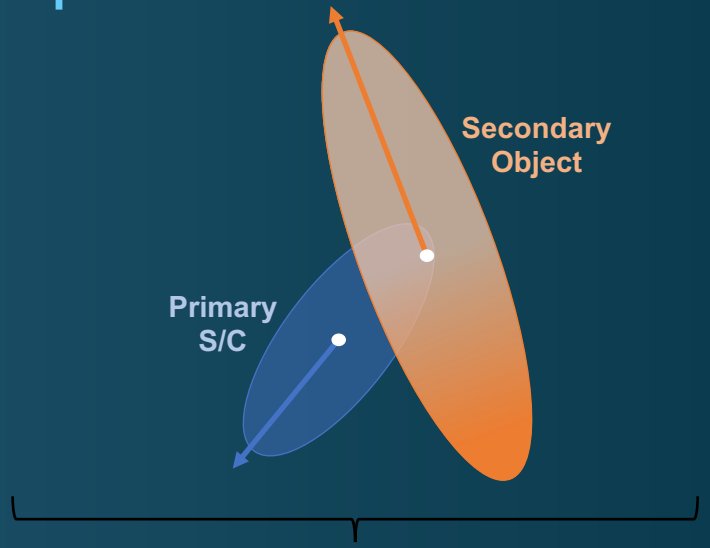
See also the USSPACECOM Spaceflight Safety Handbook For Satellite Operators, and the NASA Handbook.

Conjunction Assessment: Basic Definitions and Responsibilities



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

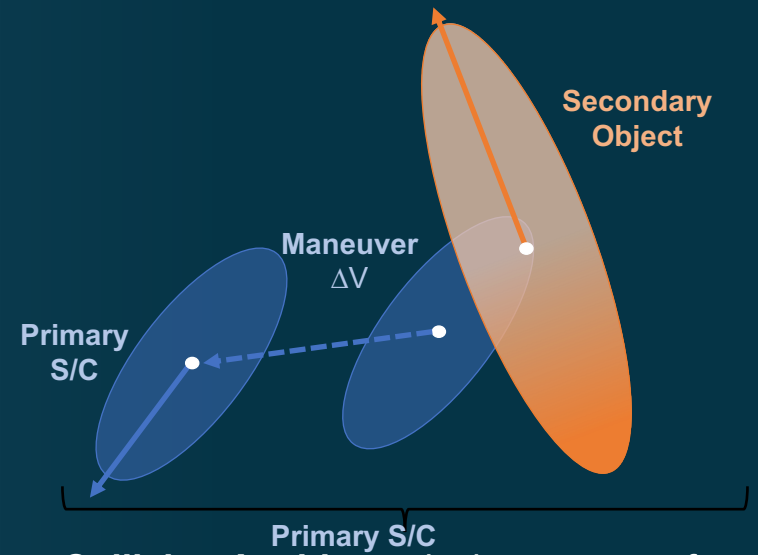
The **18th Space Control Squadron (18 SPCS)** at Vandenberg Space Force Base (VSFB) maintains the high accuracy catalog of space objects. Orbital Safety Analysts (OSAs) at VSFB screen protected assets against the catalog, perform tasking requests, and generate close approach data.



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

The NASA **CARA** program performs risk assessment for all NASA operational non-HSF satellites, and some partner missions.

JSC **Flight Operations Directorate (FOD)** performs risk assessment for all NASA HSF program assets and is the O/O for maneuver decisions and execution.

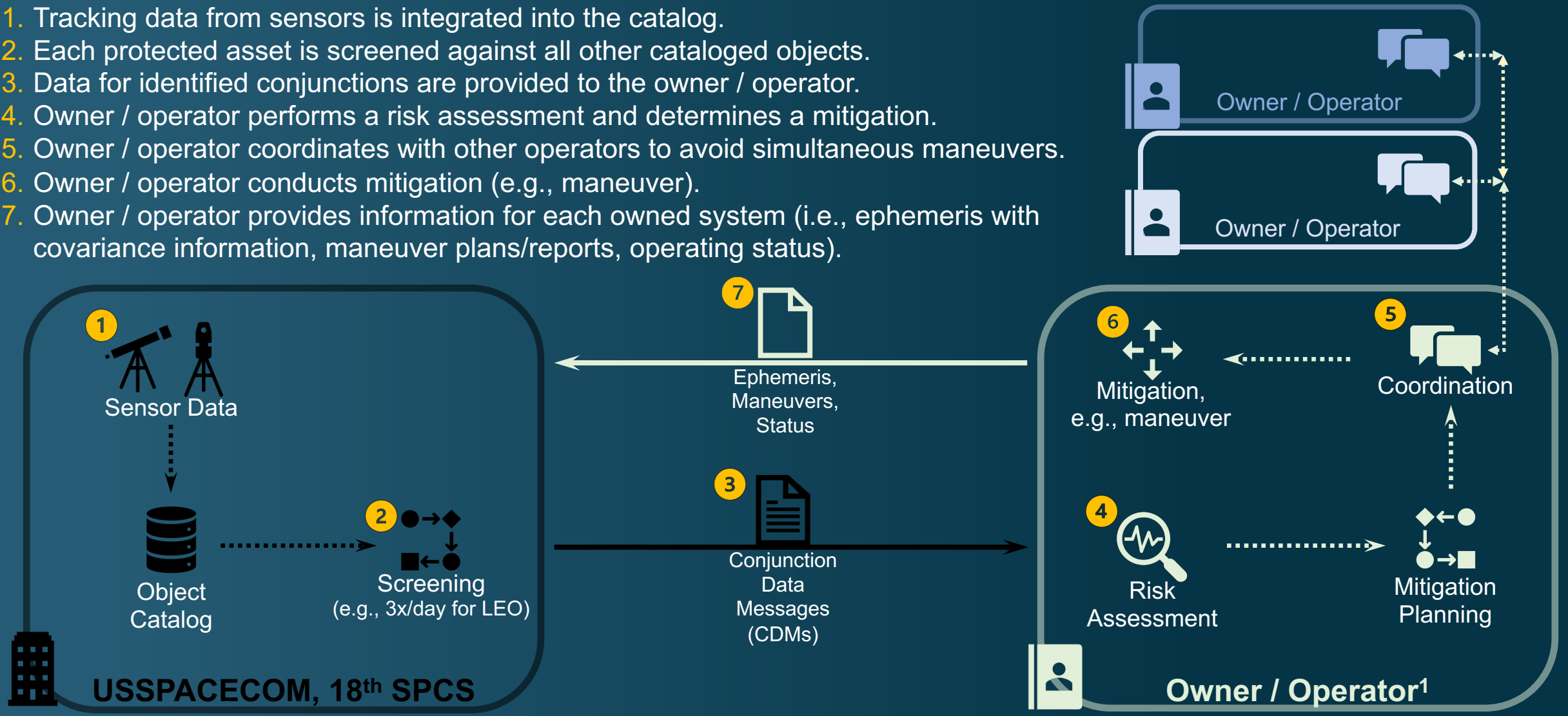


Collision Avoidance is the process of executing mitigative action, typically in the form of an orbital maneuver, to reduce collision risk.

Each satellite **Owner/Operator (O/O)** – mission management, flight dynamics, and flight operations – is responsible for making maneuver decisions and executing the maneuvers.

General Collision Avoidance Flow

1. Tracking data from sensors is integrated into the catalog.
2. Each protected asset is screened against all other cataloged objects.
3. Data for identified conjunctions are provided to the owner / operator.
4. Owner / operator performs a risk assessment and determines a mitigation.
5. Owner / operator coordinates with other operators to avoid simultaneous maneuvers.
6. Owner / operator conducts mitigation (e.g., maneuver).
7. Owner / operator provides information for each owned system (i.e., ephemeris with covariance information, maneuver plans/reports, operating status).



[1] NASA missions have access to internal services for these functions

Components of Conjunction Risk

Uncertainty with respect to the orbital environment

- Natural objects, e.g., micro-meteorites, Near Earth Objects (NEOs)
- Orbital debris, particularly at small sizes (e.g., mm)

Inaccurate measurements and models

- Ephemeris without covariance information (e.g., two-line elements)
- Atmosphere models, thrust models, computation models

Insufficient coordination between operators, avoided by:

- Sharing ephemeris, de-conflicting maneuvers
- Coordinated automation, particularly for maneuvers

Stressors from Scale

Stressor	Risk Implications
Number of discrete owners/operators, often with varying expertise with conjunction assessment practices	Ability for operators to coordinate or implement conjunction mitigations
Launches with large numbers of payloads (50+), and payloads with sub-payloads	Risk to existing systems, including through delayed cataloging of the new objects
Number of systems in popular orbits	Increased rate of conjunctions, maneuvers
Technology adoption, e.g., propulsion, autonomous operations	Inaccurate predictions due to model assumptions or state changes
Trackability with respect to debris, small systems, bulk deployments	Un-detected conjunctions

Gaps / Opportunities

International: space traffic coordination, technical standards

- IADC efforts exist, specific to debris

Space situational awareness data

- Sensor capabilities, integration and fusion, verification and validation

Catalog integration

- Need a common source of truth

Automation

- New capabilities, technical standards, intra-operator coordination
- Intra-operator autonomous conjunction assessment support

Handbook Detail

Chapter 3: History (USSPACECOM services)

Key topics include:

- Make full use of USSPACECOM services
  - Space-Track.org: manage the account, contact information
  - Use screening service to receive notice of identified conjunctions
  - Share ephemeris, Conjunction Data Messages (CDM), and maneuver notifications
- Plan for safety of flight that includes CA screening and risk assessment
- Coordinate large constellation plans with USSPACECOM and NASA during development

Chapter 4: Spacecraft and Constellation Design (planning)

Key topics include:

- Consider final, as well as transit to and from, on-station position
  - Estimate close approaches over lifetime, imputed reliability, fuel needs
  - Transiting spacecraft should yield way to on-station spacecraft
  - Use fastest and safest disposal option available
- Address minimizing of new debris, assess existing debris density estimates
- Consider systematic conjunctions with other active systems, coordinate with the other operators
- Address Launch Collision Avoidance (LCOLA) and associated gap
- Ensure deployed systems are trackable and reliable
- Implement end-to-end capabilities for conjunction assessment and mitigation
  - Generate and share accurate ephemerides, plan potential risk mitigations, assess conjunctions (via CDMs) and risk, validate all tools well in advance of deployment

Chapter 5: Pre-Launch Preparation and Early Launch Activities

Key topics include:

- Coordinate with USSPACECOM regarding launch, deployment planning, and other needs
  - Provide spacecraft and planned operations information, injection vectors, ephemerides
  - Identify advanced CA product needs from USSPACECOM
  - Support the space cataloging process, report any anomalies
- Obtain CA screening services (e.g., via USSPACECOM)
- Coordinate with NASA for large constellations (expertise exchange)

Chapter 6: On-Orbit Collision Avoidance

Key topics include:

- Maintain Space-Track.org information, particularly active and maneuverable status flags
- Regularly share ephemerides (with covariances), maneuver plans, and reports
- Actively support a routine screening process, including for all maneuvers and collision mitigations
- Use Probability of Collision (*Pc*) measure and mitigate high-risk conjunctions
  - Plan mitigating action when *Pc* > 1E-04 (1 in 10,000) or estimated miss distance is less than the hard-body radius (HBR)
  - Mitigate *Pc* by at least 1.5 orders of magnitude below 1.4E-04 (i.e., to below 3.1E-06)
  - For conjunctions, coordinate with the operators of the other object(s)
- Autonomous control requires additional considerations, including:
  - Accurate ground simulation and ground-sourced abort capabilities
- Consider light pollution in material design and orbit selection

Appendix L: Commercial Data in NASA Conjunction Assessment

The following principles are used to guide NASA's approach to use of commercial data:

1. Use raw observation data only, and combine them with Space Surveillance Network (SSN) observations for a single solution.
2. All data must be validated.
3. Cost/benefit analysis must be undertaken before purchasing.

Forward Work

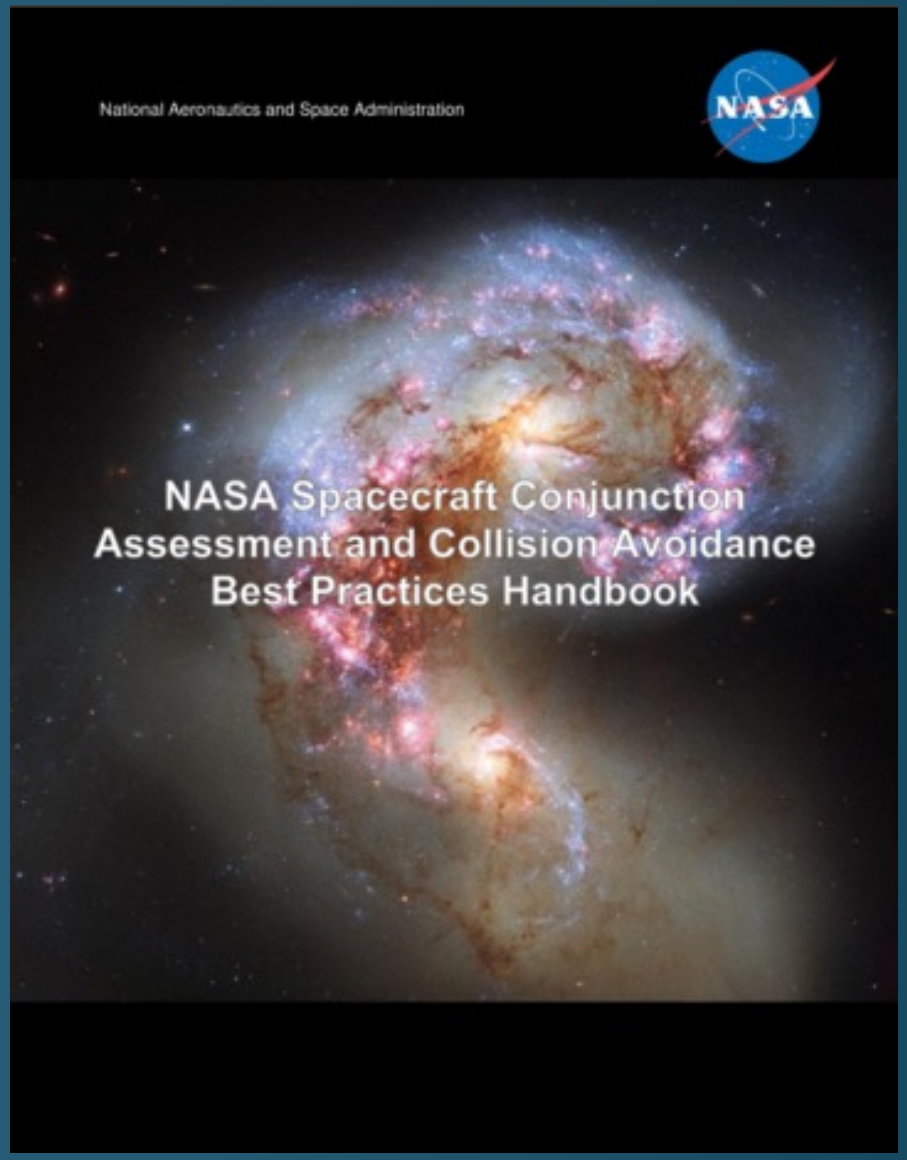
Future versions of the handbook

- Integrate feedback from space operators
- Expand coverage to address emerging areas of interest
- Continue to focus on a safe space environment for all operators

Supporting space traffic management and coordination

- Technical standards
- Model practices

NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook (Links)



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

Backup Slides

References

NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook

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

NASA Examples of Information to Expedite Review of Commercial Operator Applications to Regulatory Agencies

- https://www.nasa.gov/recommendations-commercial-space-operators

NASA Conjunction Assessment Risk Analysis software repository

- https://github.com/nasa/CARA_Analysis_Tools

NASA Orbital Debris Program Office

- https://orbitaldebris.jsc.nasa.gov/

Inter-Agency Space Debris Coordination Committee

- https://www.iadc-home.org/

USSPACECOM Space-Track web site:

- https://www.space-track.org/

USSPACECOM Spaceflight Safety Handbook for Satellite Operators

- https://www.space-track.org/documents/Spaceflight_Safety_Handbook_for_Operators.pdf

US Government Orbital Debris Mitigation Standard Practices (ODMSP)

- https://orbitaldebris.jsc.nasa.gov/library/usg_orbital_debris_mitigation_standard_practices_november_2019.pdf

Handbook Table of Contents

Content developed from inter-agency working group

Document size summary:
- Main document: 40 pages
- Appendices: 117 pages
- 83 best practices

Statistics: Maneuvers per Year, by Orbit Regime, NASA-supported Non-HSF Missions, 2005 – May 2021