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NASA Procedural Requirements

NPR 8079.1

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COMPLIANCE IS MANDATORY FOR NASA EMPLOYEES

NASA Spacecraft Conjunction Analysis and Collision Avoidance for Space Environment Protection

Responsible Office: Office of the Chief Engineer

Table of Contents

Preface

- P.1 Purpose
- P.2 Applicability
- P.3 Authority
- P.4 Applicable Documents and Forms
- P.5 Measurement/Verification
- P.6 Cancellation

Chapter 1. Introduction

- 1.1 Intent to Mitigate Spacecraft Collision Risk
- 1.2 Conjunction Analysis and Mitigation and the Project Life-Cycle
- 1.3 Conjunction Analysis and Mitigation Process Key Documents
- 1.4 Intra- and Interagency Coordination of Collision Avoidance

Chapter 2. Roles and Responsibilities

- 2.1 Office of the NASA Chief Engineer
- 2.2 Mission Directorate Associate Administrators
- 2.3 Project Managers
- 2.4 Conjunction Assessment Risk Analysis Program Manager
- 2.5 JSC Flight Operations Directorate Officers
- 2.6 SOMD Launch Services Office Manager

Chapter 3. Early Phase Planning for the Conjunction Analysis and Mitigation Process and Key Product Requirements

- 3.1 Overview
- 3.2 Orbital Collision Avoidance Plan
- 3.3 Conjunction Assessment Operations Implementation Agreement

Chapter 4. Conjunction Analysis and Mitigation Process Implementation

- 4.1 Overview
- 4.2 Conjunction Assessment Step
- 4.3 Conjunction Risk Assessment Step
- 4.4 Conjunction Mitigation Step

Chapter 5. Technical Requirements

- 5.1 Ephemeris Sharing
- 5.2 Maneuverable Spacecraft
- 5.3 Conjunction Mitigation
- 5.4 Post-Launch Deployments
- 5.5 Advanced Capabilities

Appendix A. Definitions

Appendix B. Acronyms

Appendix C. Compliance Matrix

Appendix D. Orbital Collision Avoidance Plan Template

Appendix E. Conjunction Assessment Operations

Implementation Agreement (CAOIA) Elements

Appendix F. References

Table of Figures

- Figure 1-1 Earth-Orbiting Collision Avoidance Process for a NASA-Owned or -Operated Spacecraft
- Figure 1-2 Conjunction Assessment
- Figure 1-3 Conjunction Risk Assessment
- Figure 1-4 Conjunction Mitigation
- Figure 3-1 Orbital Collision Avoidance Plan Flow
- Figure 4-1 Conjunction Analysis and Mitigation Process Flowchart

List of Tables

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

Table 3-2 Example Conjunction Assessment Activities Throughout an NPR 7120.8 Project Life Cycle

Table 5-1 Ephemeris Specifications

Table C-1 NASA Spacecraft Conjunction Analysis and Collision Avoidance for Space Environment Protection Compliance Matrix

Table D-1. Planning Activities for Deployment Scenarios

Table D-2. Inputs, Analyses, and Context for OCAP Fields

Preface

P.1 Purpose

This NASA Procedural Requirements (NPR) document establishes minimum collision avoidance requirements and associated operational protocols for NASA space flight programs, projects, and spacecraft to protect the space environment by reducing the risk of collision to an acceptable level.

P.2 Applicability

a. This directive is applicable to NASA Headquarters and NASA Centers, including Component Facilities and Technical and Service Support Centers. This directive applies to the Jet Propulsion Laboratory (JPL), a Federally Funded Research and Development Center (FFRDC), other contractors, recipients of grants or cooperative agreements, and parties to other agreements only to the extent specified or referenced in the applicable contract, grant, or agreement.

b. The requirements of this directive apply to NASA programs and projects with spacecraft that are owned, developed, or operated by NASA. For such programs and projects that already exist, the requirements of this directive apply to their current and future life-cycle phases as determined by the responsible Mission Directorate Associate Administrator (MDAA) and concurred with by the NASA Chief Engineer (or as delegated). For other spacecraft, MDAA's share the intent of this directive and associated best practices and seek to understand the partners' operational procedures for conjunction risk assessment.

c. In this directive, all mandatory actions (i.e., requirements) are denoted by statements containing the term "shall." The term "may" denotes a discretionary privilege or permission, "can" denotes statements of possibility or capability, "should" denotes a good practice that is recommended but not required, "will" denotes expected outcome, and "are" or "is" denotes descriptive material.

d. In this directive, all document citations are assumed to be the latest version unless otherwise noted.

P.3 Authority

a. The National Aeronautics and Space Act, 51 United States Code (U.S.C.) § 20113 (a).

b. NASA Policy Directive (NPD) 1000.0, NASA Governance and Strategic Management Handbook.

c. NPD 7120.4, NASA Engineering and Program/Project Management Policy.

P.4 Applicable Documents and Forms

a. NPR 7120.5, NASA Space Flight Program and Project Management Requirements.

b. NPR 7120.8, NASA Research and Technology Program and Project Management Requirements.

P.5 Measurement/Verification

Compliance with the requirements contained within this directive is verified through approval of the Appendix C Compliance Matrix. Compliance may also be verified through life-cycle reviews and other assessments.

P.6 Cancellation

NASA Interim Directive (NID) 7120.132, Collision Avoidance for Space Environment Protection dated November 19, 2020.

Chapter 1. Introduction

1.1 Intent to Mitigate Spacecraft Collision Risk

1.1.1 As more spacecraft are deployed, the space environment becomes increasingly congested. Therefore, it is important for spacecraft operators to coordinate planning and operations to lower the risk of spacecraft collisions, not only to protect the assets involved but also the space environment. A framework of standard practices facilitates appropriate protocols between spacecraft operators.

1.1.2 Current United States (U.S.) and international laws and regulations affect many elements of a NASA space flight project including launch and return to Earth, operations, communications, use of certain sensors or technologies, disposal, and demise. Additional legal or regulatory requirements are expected, particularly in the areas pertinent to this directive. NASA project managers may need to demonstrate compliance with such laws and regulations and to provide direction to partners or service providers. In the event of a conflict with this directive, laws or regulations take precedence.

1.1.3 NASA's interests are best served by proactively implementing protocols and best practices to reduce collision risk. NASA supports other Federal agencies in their development of regulations and policies for protecting the space environment. NASA actively participates in raising awareness of space environment concerns, mentoring spacecraft operators in establishing effective practices, and developing baselines, standards, and best practices.

1.1.4 This directive establishes minimum orbit and trajectory protocols and associated operational requirements for NASA to protect the space environment and manage the risk of collision between a NASA-owned or -operated spacecraft and other man-made objects. Some of these measures are implemented during conceptual and design phases while others can only be fully implemented during operations.

1.1.5 For conjunction assessment and mitigation, the focus of applicability is spacecraft operations between separation from the launch vehicle (or other deployment) and spacecraft disposal. This directive applies to space flight programs and projects that:

- a. Operate spacecraft in any Earth orbit that exceeds 130 km (~80 miles) in altitude, including for short timeframes such as phasing loop orbits.
- b. Operate spacecraft in orbit about the Moon, Mars, or any other solar system central body orbited by more than one spacecraft.
- c. Operate spacecraft in orbit about a Sun-Earth or Earth-Moon Lagrange point orbited by more than one spacecraft.
- d. Perform a fly-by of Earth or any natural body orbited by other spacecraft.

1.1.6 To avoid collisions, predicted trajectory data are collected and actively processed to continuously assess potential close approaches between space objects. Spacecraft, subsidiary deployed objects, and jettisoned objects are tracked, and to this end, program and project managers are responsible for making their products trackable. (See Section 3.1.2.)

1.1.7 To quantify the likelihood of a collision, a conjunction risk assessment considers uncertainty from many sources, including environmental conditions such as upper atmospheric drag and

available sensor data quality. Spacecraft operators use the assessment to determine whether to initiate mitigating actions such as a maneuver. Mature practices in this area and active coordination among independent spacecraft operators result in a safer space environment for all operators.

1.1.8 An example of an Earth-orbiting collision avoidance process for a NASA-owned or -operated spacecraft is depicted in Figure 1-1.

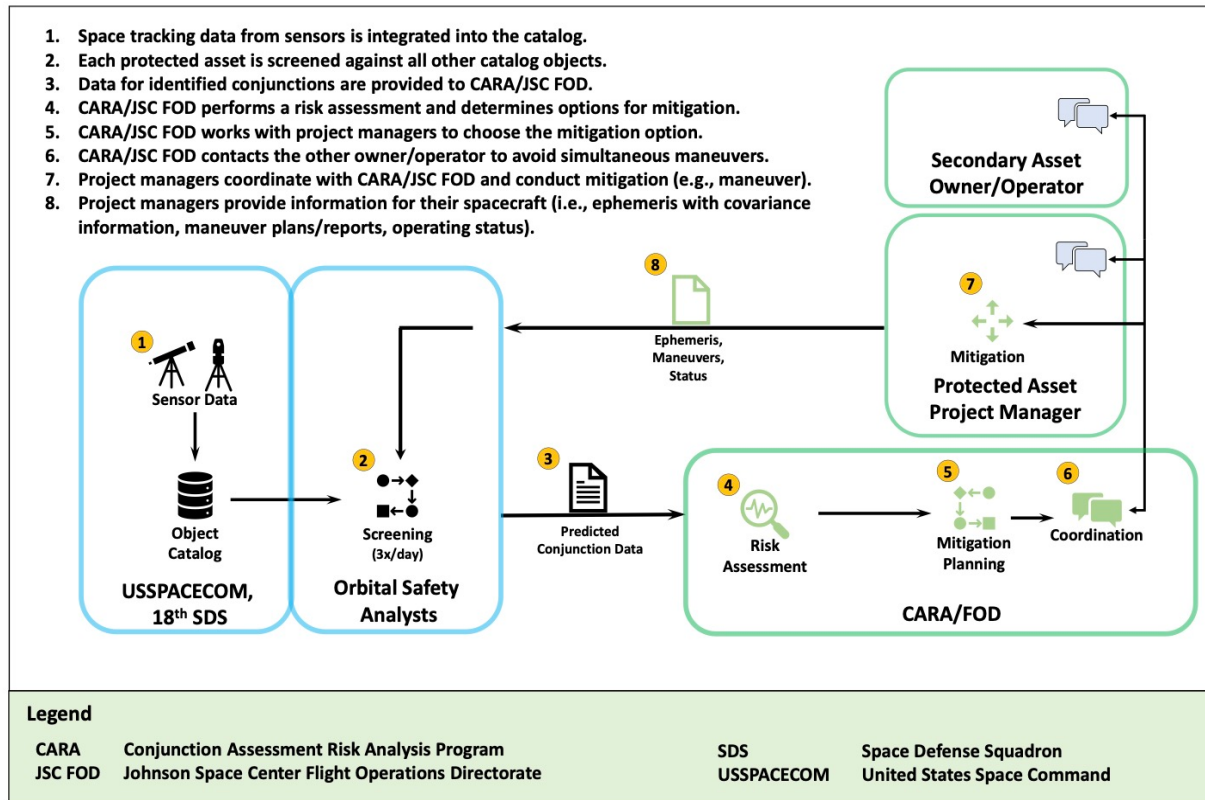


Figure 1-1 Earth-Orbiting Collision Avoidance Process for a NASA-Owned or -Operated Spacecraft

1.2 Conjunction Analysis and Mitigation and the Project Life-Cycle

1.2.1 Conjunction analysis and mitigation activities are performed throughout the project life-cycle. In the design phase, project managers pay attention to the requirements in this directive for mitigating the potential for collisions to prevent costly redesigns later or unnecessary operational challenges after launch. Reducing the potential for spacecraft collisions continues with on-going monitoring and risk assessments after launch.

1.2.2 Early Phase Planning, Development, and Testing

During concept development, project managers consider how to make their spacecraft trackable, which orbits or trajectories will minimize the likelihood of collisions, and whether the spacecraft needs maneuverability to avoid potential collisions. Conjunction analysis and mitigation capabilities depend on spacecraft architecture and design. As designs are developed and reviewed, project teams consult with Agency subject matter experts available in the NASA Conjunction Assessment Risk

Analysis (CARA) Program, the Johnson Space Center (JSC) Flight Operations Directorate (FOD), and the Space Operations Mission Directorate (SOMD) Launch Services Office (LSO) on the capabilities needed for spacecraft tracking and collision mitigation. Tracking and mitigation capabilities can be tested, verified, and validated during the later stages of development. (See Chapter 3 of this document for additional detail on pre-launch activities and key products.)

1.2.3 On-Orbit Conjunction Analysis and Mitigation Process

1.2.3.1 After launch, NASA implements a three-step conjunction analysis and mitigation process: conjunction assessment, conjunction risk assessment, and conjunction mitigation. (See Chapter 4 of this document for additional detail on the three steps of the conjunction analysis and mitigation process.)

a. Conjunction assessment (otherwise referred to as "screening") compares trajectory data from the "protected asset" (otherwise referred to as the "primary object") against the trajectories of the objects in the applicable database.

(1) For Earth orbiting objects, screening is performed against the space object catalog maintained by the United States Space Command (USSPACECOM) to predict when a close approach will occur within a volume of space called a "safety volume" placed about the asset. This catalog includes information about international and commercial operational spacecraft as well as all trackable debris. (See Figure 1-2 for an example of the conjunction geometry for a near Earth-orbiting spacecraft with covariances indicated as ellipses.)

(2) For non-Earth orbiting objects, the ephemeris of the protected asset is only screened against other provided ephemerides.

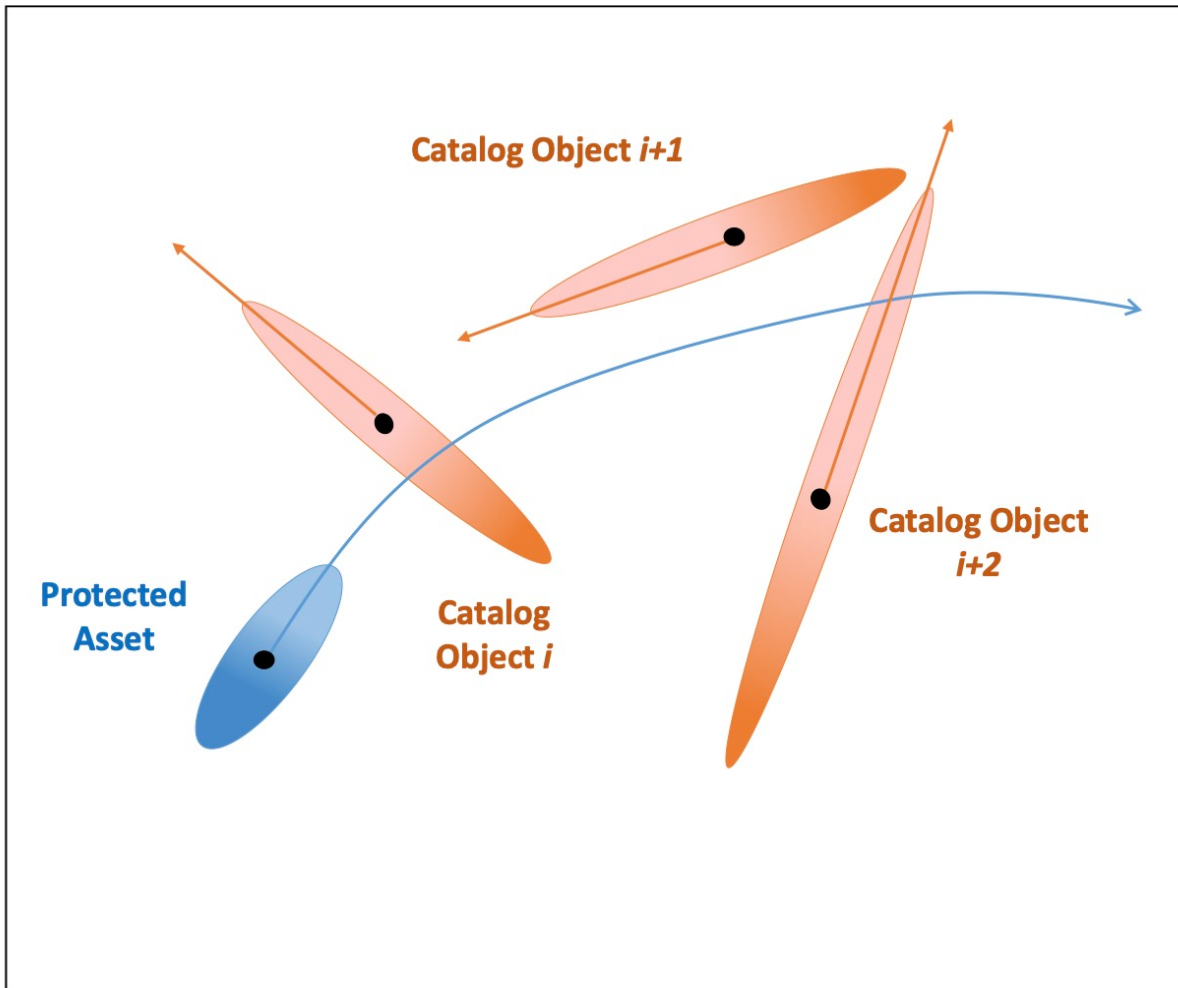


Figure 1-2 Conjunction Assessment

b. Conjunction (i.e., "close approach") risk assessment determines the likelihood of two space objects colliding and the expected consequence if they collide in terms of lost spacecraft and expected debris production. (See Figure 1-3.)

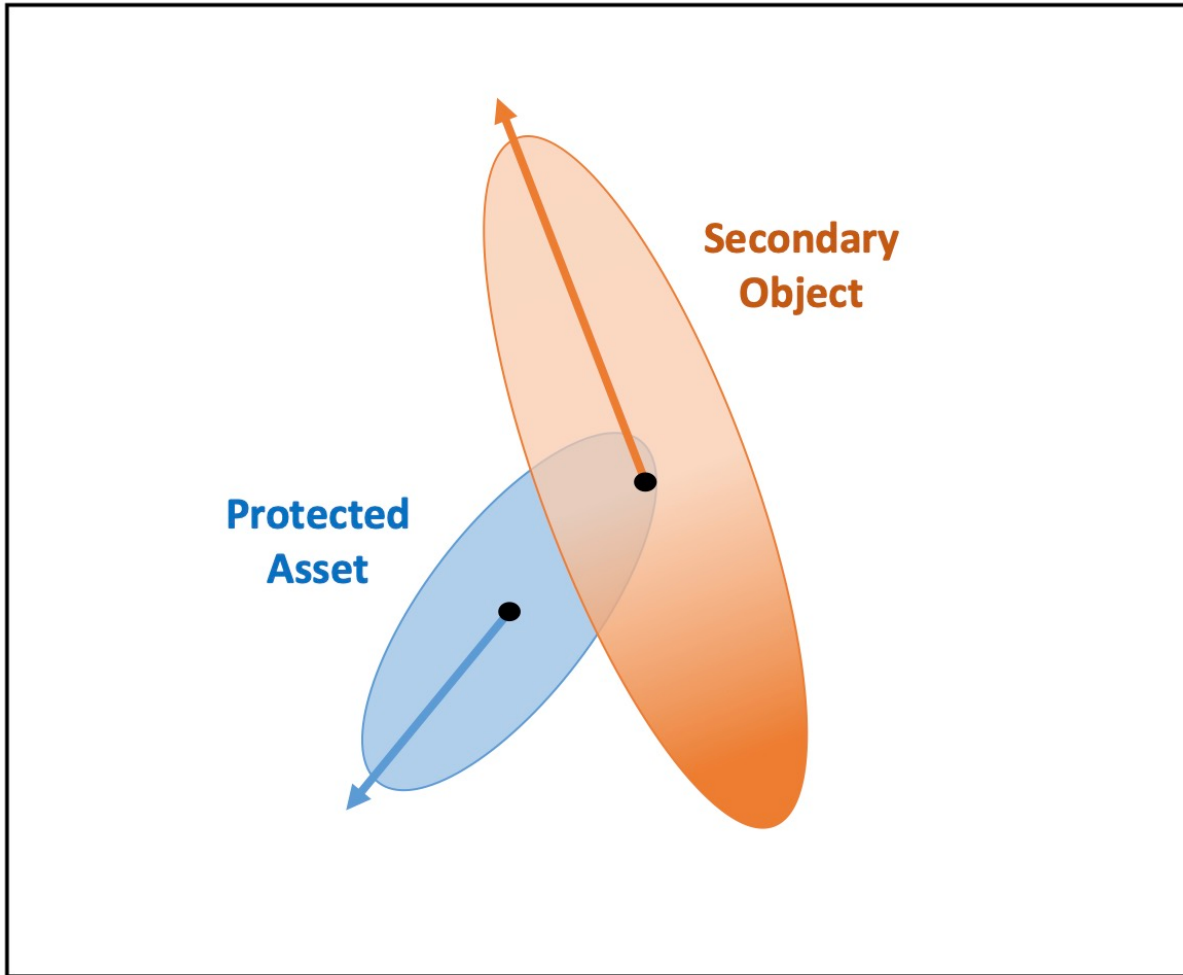


Figure 1-3 Conjunction Risk Assessment

c. Conjunction mitigation remediates conjunction risk. Potential actions include changes to the trajectory such as those resulting from a propulsive maneuver (Figure 1-4); an attitude adjustment (e.g., for differential drag or to minimize frontal area); or providing ephemeris data to the owner/operator(s) (O/O) of the secondary (other) object in the close-approach event to enable that spacecraft to plan and execute an avoidance maneuver.

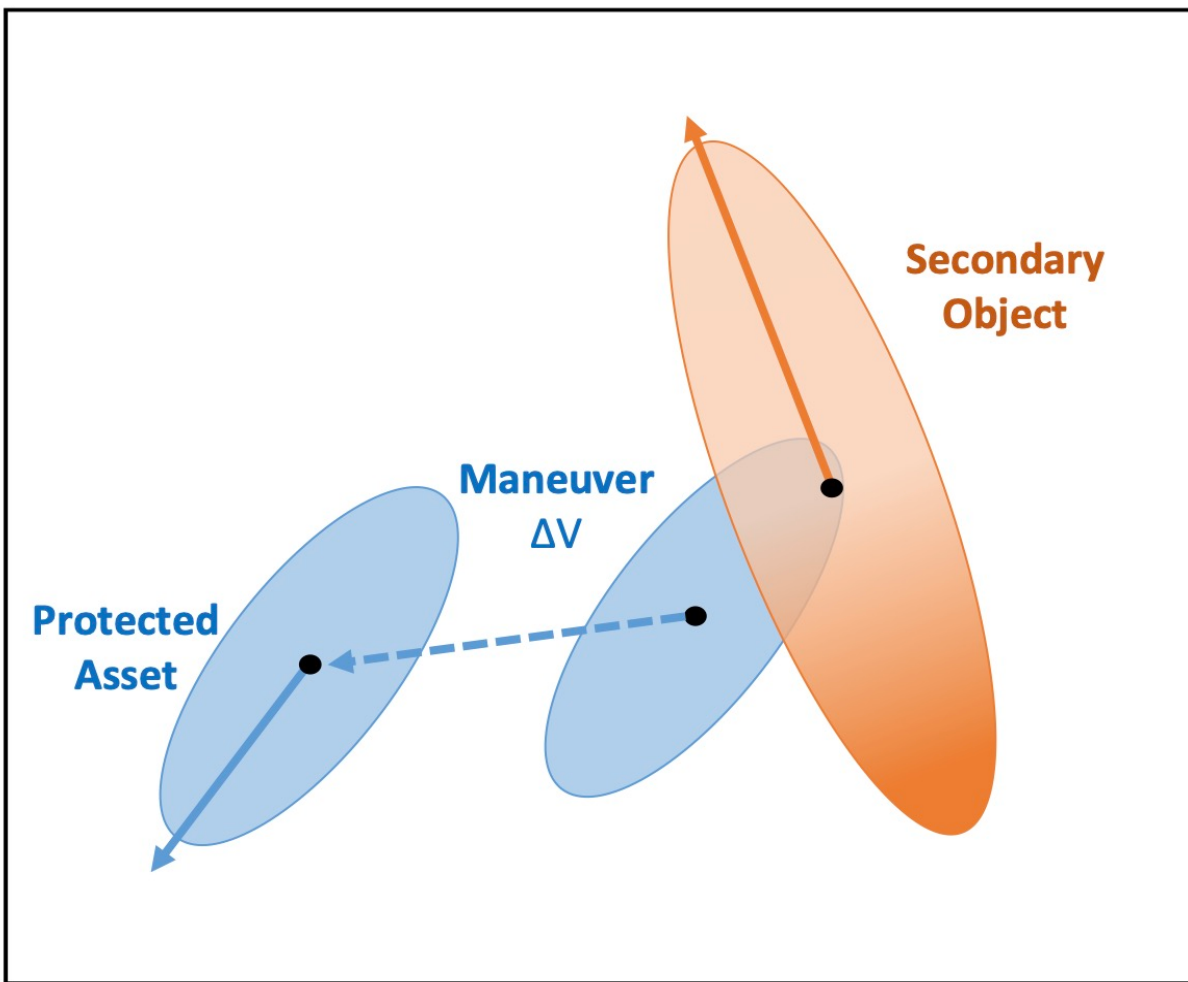


Figure 1-4 Conjunction Mitigation

1.2.3.2 Each spacecraft is independently considered in the on-orbit conjunction analysis and mitigation process. When two NASA spacecraft experience a conjunction with each other, each will receive a separate analysis identifying them as the protected asset. In some cases, a non-NASA spacecraft may be analyzed as the primary or protected asset and the NASA asset is the secondary object.

1.3 Conjunction Analysis and Mitigation Process Key Documents

1.3.1 This directive requires two key products to support the conjunction analysis and mitigation process:

- a. The Orbital Collision Avoidance Plan (OCAP) documents the results of study and analysis tasks and design considerations. The project manager implements this plan while preparing for operations. (See Chapter 3 and Appendix D.)
- b. The Conjunction Assessment Operations Implementation Agreement (CAOIA) documents specific operational processes the project implements to protect the spacecraft and space environment. (See Chapter 3.)

1.3.2 Programs and projects should reach out to CARA or JSC FOD as soon as possible (after

approval and prior to Mission Concept Review (MCR)) to begin working on the draft OCAP and CAOIA.

1.4 Intra- and Interagency Coordination of Collision Avoidance

1.4.1 Overview

1.4.1.1 Two groups at NASA coordinate close-approach topics for NASA space flight missions: CARA for non-human space flight (non-HSF) missions and JSC FOD for human space flight (HSF) missions with or without crew. For data and support required for conjunction assessment and risk analysis, NASA uses CARA and JSC FOD (specifically at JSC FOD, the trajectory operations officer (TOPO) and flight dynamics officer (FDO) positions) as the exclusive interfaces to the U.S. Space Force's 18th Space Defense Squadron (18 SDS) and USSPACECOM.

1.4.1.2 In addition, LSO supports conjunction mitigation by managing review of license requests and ensuring flight safety. LSO communicates NASA's interests and concerns to regulating agencies and Agency partners in its capacity as NASA's representative to the Commercial Space Transportation Interagency Group, which was established pursuant to Executive Order 12465, Commercial Expendable Launch Vehicle Activities. In collaboration with the NASA Office of International and Interagency Relations (OIIR), LSO also coordinates communication of rules, regulations, and requests for license review through the NASA community for awareness and comment.

1.4.1.3 For Earth-orbiting spacecraft, collision avoidance relies on data from several sources. When data for conjunction assessment and space situational awareness (SSA)-related communication need to be obtained from the U.S. Department of Defense (DOD), orbital data request (ODR) forms are submitted to 18 SDS. The current version of the ODR forms can be obtained from CARA or JSC FOD. For NASA space flight missions, these forms need to be submitted to 18 SDS by CARA or JSC FOD to comply with the official Memorandum of Agreement (MOA) between DOD and NASA, which specifically restricts access. Managing the interface with DOD requires personnel trained and familiar with DOD's specific handling and data schemata to avoid data handling errors.

1.4.1.4 For non-Earth orbiting spacecraft (currently Moon, Mars, or Sun/Earth Lagrange points 1 [L1] or 2 [L2]), collision avoidance relies primarily on spacecraft ephemerides prepared by spacecraft navigation teams using a tracking network. These ephemerides are generally accurate for conjunction assessment for a few weeks. Thus, a regular ephemeris update process needs to be negotiated between the project and the project's tracking network. In some cases, particularly those that involve a non-NASA U.S. Government or foreign government tracking network, the NASA OIIR may need to facilitate the periodic ephemeris exchange process.

1.4.2 NASA's Conjunction Assessment Risk Analysis Program

1.4.2.1 CARA is an Agency-level resource that provides support to all NASA non-HSF missions. CARA protects the orbital environment from collision between NASA non-HSF missions and other tracked on-orbit objects.

1.4.2.2 CARA routinely collects predicted orbital information from NASA space flight projects, passes it on to 18 SDS for screening, analyzes the screening results to determine the risk posed by predicted close approaches, and works with NASA space flight projects to determine an appropriate mitigation strategy for the close approach risk.

1.4.2.3 CARA is the sole entity with authority to submit ODRs to DOD on behalf of NASA non-HSF missions both to ensure compliance with the NASA-DOD MOA and to permit standardization of requests across NASA.

1.4.3 JSC Flight Operations Directorate

1.4.3.1 JSC FOD provides conjunction assessment support to NASA HSF missions through two console positions (TOPO and FDO) staffed by SOMD. These positions assist NASA HSF project managers in monitoring and identifying potential conjunctions and developing possible maneuvers to avoid conjunctions.

1.4.3.2 Because the conjunction assessment support is integrated with the space flight mission operations for HSF, the process is documented as part of policies and procedures for HSF programs and projects. JSC FOD will implement the operational requirements found in chapters 4 and 5 of this directive by capturing the requirements in HSF mission flight rules or jettison policy documentation.

1.4.3.3 JSC FOD is the sole entity with authority to submit ODRs to DOD on behalf of NASA HSF missions both to ensure compliance with the NASA-DOD MOA and to permit standardization of requests across NASA.

1.4.4 NASA SOMD Launch Services Office

1.4.4.1 The LSO representative reviews launch license requests (i.e., for a launch license, reentry license, experimental permit, payload review, launch operator license, or launch site operator license) that have been submitted to LSO by the Federal Aviation Administration (FAA), the Federal Communications Commission (FCC), or the National Oceanic and Atmospheric Administration (NOAA).

1.4.4.2 Based on the information documented in the launch license request, the LSO representative forwards the request to appropriate contacts within NASA to determine whether there is risk to NASA asset health or safety.

1.4.4.3 The LSO representative consults NASA organizations including CARA and JSC FOD, the Office of Safety and Mission Assurance (OSMA), the Science Mission Directorate (SMD), and the International Space Station (ISS) Program to capture license review feedback.

1.4.4.4 LSO provides the NASA responses, including questions and concerns, back to the requesting agency and coordinates any related discussions. If major concerns are identified, LSO works to connect the NASA technical team with the license applicant to aid in a resolution.

Chapter 2. Roles and Responsibilities

2.1 Office of the NASA Chief Engineer

For the requirements in this directive, the NASA Chief Engineer resolves issues that may occur between CARA or JSC FOD and MDAAs or space flight program or project managers.

2.2 Mission Directorate Associate Administrators

2.2.1 MDAAs (or as delegated to the program or project manager) shall levy the requirements from this directive in solicitations that are intended to result in a NASA-owned or -operated spacecraft and allocate the requirements to spacecraft and supporting ground system element providers.

2.2.2 MDAAs consider including these requirements in other types of NASA agreements or awards associated with non-NASA-owned and -operated spacecraft. Considering the protection of the space environment, MDAAs weigh the inclusion of these requirements in balance with supporting the goals of the agreement or award.

2.2.3 MDAAs are encouraged to engage with partners to share the intent of the requirements in this directive and the best practices elucidated in the NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook (hereafter referred to as the "CA2 Handbook"). (See the CA2 Handbook on the Office of Chief Engineer (OCE) tab in the NASA Online Directives Information System (NODIS) at https://nodis3.gsfc.nasa.gov/OCE_docs/OCE_51.pdf.)

2.2.4 In coordination with CARA or JSC FOD, MDAAs engage with partners to understand the partner's operational procedures for conjunction risk assessment.

2.2.5 MDAAs provide, as soon as available, pre-launch predicted trajectory data from the launch provider for all objects on the launch stack to CARA or JSC FOD for colocation analysis.

2.3 Project Managers

2.3.1 This directive assigns responsibilities to project managers. These responsibilities also apply to the equivalent of the project manager in operations, which may be called the "spacecraft operations manager" or other titles. Under special circumstances, the program manager may fulfill the role of the project manager.

2.3.2 Project managers are responsible for developing an OCAP and obtaining concurrence from CARA or JSC FOD for each spacecraft under their authority. (See Chapter 3.)

2.3.3 For non-HSF missions, project managers are also responsible for developing a CAOIA and obtaining approval from CARA for each spacecraft under their authority. (See Chapter 3.) HSF missions typically do not develop a CAOIA, but project managers should consult with JSC FOD on whether a CAOIA is required.

2.3.4 Project managers identify the governing office of record and records management plan to determine the records retention requirements of the OCAP and CAOIA consistent with other project

management documents. (Refer to NASA Records Retention Schedules (NRRS) 1441.1, which can be found at: https://nodis3.gsfc.nasa.gov/NPR_attachments/NRRS_1441.1.pdf)

2.3.5 Project managers are responsible for mitigating risks to their spacecraft, mitigating conjunctions, and maintaining a sustainable space environment.

2.3.6 If additional SSA data are required (from USSPACECOM), the project manager coordinates the request through CARA or JSC FOD, which provides the current USSPACECOM ODR form. The final ODR is submitted by CARA or JSC FOD.

2.4 Conjunction Assessment Risk Analysis Program Manager

2.4.1 The CARA program manager provides consulting support to space flight project managers in the design phase to provide expertise and assistance in meeting the requirements of this directive.

2.4.2 The CARA program manager will:

- a. Develop, implement, and maintain a conjunction prediction and risk assessment process that identifies high-risk conjunctions and evaluates potential mitigation options for suitability to mitigate risk to the orbital environment.
- b. For each conjunction determined to be of sufficient risk and actionability to mitigate, review the project's choice of collision risk mitigation strategy based on a technical assessment of the residual conjunction risk and provide results to the project manager.
- c. Monitor the technical consistency and validity of close-approach prediction and evaluation practices used by NASA.
- d. Ensure screening of available near-Earth object (NEO) ephemerides against protected assets.
- e. Support the project manager with data and analysis on design options to enable the spacecraft and any subsidiary deployed objects and jettisoned objects to be trackable.
- f. Share ephemerides in CARA's possession with non-NASA organizations as deemed necessary for space safety.
- g. Monitor compliance with the practices documented in the OCAP and/or CAOIA.
- h. Serve as the single point of contact between NASA and DOD (e.g., 18 SDS and USSPACECOM) for SSA data and support required for conjunction assessment and risk analysis of non-HSF missions. CARA uses this interface to support the project manager as documented in the CAOIA.
- i. Evaluate and approve the relevance, utility, and validity of commercial conjunction assessment data and commercial or governmental tools prior to their use in support of NASA non-HSF missions.
- j. Direct research and development to improve conjunction-related risk evaluation and decision-making support.
- k. In support of LSO's license review process, evaluate payload and launch license submissions to determine the conjunction risk to NASA spacecraft of the license request.

2.4.3 CARA routinely coordinates with JSC FOD regarding collision avoidance topics.

2.4.4 The CARA program manager evaluates and reports to OCE risks to the sustainability of the space environment with respect to conjunction assessment topics. This includes monitoring project compliance with the OCAP and CAOIA, the effects of project decisions, the risks posed by commercial and large constellation launches, emergent issues, and other operator actions that may increase risks.

2.5 JSC Flight Operations Directorate Officers

2.5.1 The JSC FOD, supported by console officers (TOPO and FDO), provides expertise and assistance in meeting the requirements of this directive. JSC FOD consults with space flight project managers in the design phase and supports ongoing mission operations.

2.5.2 JSC FOD will:

- a. Develop, implement, and maintain a conjunction risk assessment and evaluation process that identifies high-risk conjunctions, certify that the input data for such conjunctions are suitably accurate to support conjunction risk assessment, and evaluate potential mitigation options to determine their suitability to mitigate risk to the orbital environment.
- b. Appropriately notify and/or communicate plans for addressing conjunctions and concerns applicable to HSF to appropriate program and mission directorate personnel.
- c. Determine whether commercial launches pose a collocation or transit threat to NASA HSF missions, engaging commercial providers and informing OCE and affected space flight missions appropriately.
- d. Support the project manager with data and analysis on design options to enable the spacecraft and any subsidiary deployed objects and jettisoned objects to be trackable.
- e. Share ephemerides in JSC FOD's possession with non-NASA organizations as deemed necessary for space safety.
- f. Serve as the single point of contact between NASA and DOD (e.g., 18 SDS and USSPACECOM) for SSA data and support required for conjunction assessment and risk analysis of NASA HSF missions. JSC FOD uses this interface to support the project manager.
- g. Evaluate and approve the relevance, utility, and validity of commercial conjunction assessment data and commercial or governmental tools prior to their use in support of NASA HSF space flight missions.

2.5.3 JSC FOD routinely coordinates with CARA regarding collision avoidance topics.

2.5.4 JSC FOD reviews and concurs on the OCAP for HSF-related missions and provides feedback to the project manager regarding further trade analysis or risk mitigation considerations, if needed.

2.6 SOMD Launch Services Office Manager

2.6.1 The LSO manager shares orbital flight safety preferences and recommendations, including collision avoidance best practices and the CA2 Handbook, with NASA external customers procuring launch services, when appropriate.

2.6.2 When NASA receives a launch license request from another governing agency for review, the LSO manager assesses the request in coordination with NASA stakeholders for compliance with the CA2 Handbook and provides feedback to the governing license authority. LSO is not the sole decision point but serves as a facilitator between NASA and interagency interests.

Chapter 3. Early Phase Planning for the Conjunction Analysis and Mitigation Process and Key Product Requirements

3.1 Overview

3.1.1 The process for collision avoidance spans the program or project life-cycle involving key design choices, conjunction risk analysis, and operational mitigation. Early attention to the requirements in this directive can prevent costly redesigns later or unnecessary operational challenges.

3.1.2 The project manager shall ensure the spacecraft can be tracked from deployment until demise. Trackable spacecraft are essential for collision avoidance, including the time between disposal and demise. Trackability is analyzed by CARA or JSC FOD as part of the OCAP development. Trackability can be achieved through a variety of means depending on the spacecraft design, orbits, and available technical capabilities. (See the CA2 Handbook section on trackability.)

3.1.3 During early phase planning as project designs and the OCAP are developed, questions about orbital or trajectory conjunction risks are discussed with CARA (for non-HSF missions) or JSC FOD (for HSF missions). Involvement of CARA or JSC FOD early in the life-cycle establishes a relationship and allows for early advice and support for orbital or trajectory trade studies. CARA and JSC FOD can provide analytical support and suggestions on orbits to avoid or mitigation strategies to use for specific space flight mission planning scenarios. In the design and development phases, the project manager ensures that the spacecraft and ground systems include the capabilities necessary for operations.

3.1.4 As the designs progress to a final state, CARA or JSC FOD continues to provide support and document review to ensure all aspects of collision avoidance capabilities have been addressed. CARA also provides advice and support as the project begins development of the CAOIA, which will be baselined prior to flight. The CAOIA documents specific operational implementation processes.

3.1.5 Project managers ensure that the spacecraft, mission, and trajectory designs reduce the risk of collision as documented in the OCAP. Launch protection of crewed assets includes the gap (called the collision on launch assessment (COLA) gap) between the end of the time interval covered by standard launch collision avoidance screening and the point at which either the spacecraft moves beyond the risk of an Earth-orbit conjunction or the spacecraft is incorporated into the 18 SDS spacecraft catalog. Non-HSF missions perform COLA gap analysis only to protect crewed missions.

3.1.6 Table 3-1 shows the assessment and mitigation activities mapped against the life-cycle phases in NPR 7120.5, NASA Space Flight Program and Project Management Requirements. Table 3-2 shows the activities mapped against the life-cycle phases in NPR 7120.8, NASA Research and Technology Program and Project Management Requirements. The tables also show where the key OCAP and CAOIA products are provided in the life-cycles.

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

Life-Cycle

Life-Cycle Phase	Pre-Formulation	Formulation			Implementation							
7120.5 Life-Cycle Gates	MCR	SRR	SDR	PDR	CDR	SIR	ORR	FRR	PLAR	CERR	DR	DRR
	Notes: ① Project provides initial inputs for OCAP ② Iteration of OCAP content with CARA or JSC FOD ③ Achieve OCAP concurrence (Baseline)				Notes: ④ Project begins CAOIA development ⑤ Iteration of CAOIA content with CARA or JSC FOD ⑥ Achieve CAOIA concurrence (Final)				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	<ul style="list-style-type: none"> As concepts develop, project manager coordinates with CARA (non-HSF) or JSC FOD (HSF) for orbit selection options 	<ul style="list-style-type: none"> Project manager demonstrates application of this NPR Project manager provides initial OCAP inputs to CARA/JSC FOD review CARA/JSC FOD begins OCAP analyses 	<ul style="list-style-type: none"> Project manager baselines OCAP and provides OCAP to CARA/JSC FOD for review and concurrence and subsequent final approval by the program manager 	<ul style="list-style-type: none"> 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 	<ul style="list-style-type: none"> 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 	<ul style="list-style-type: none"> 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 	<ul style="list-style-type: none"> CARA/JSC FOD monitors disposal efforts for issues affecting conjunction assessment 					
Legend	CARA Conjunction Assessment Risk Analysis CAOIA Conjunction Assessment Operations Implementation Agreement CERR Critical Events Readiness Review CDR Critical Design Review DOD Department of Defense DR Decommissioning Review				DRR Disposal Readiness Review FOD Flight Operations Directorate FRR Flight Readiness Review HSF Human Space Flight MCR Mission Concept Review OCAP Orbital Collision Avoidance Plan ODR Orbital Data Request	ORR Operational Readiness Review PDR Preliminary Design Review PLAR Post-Launch Assessment Review SDR System Definition Review SIR System Integration Review SRR System Requirements Review						

Note: Section 3.2.7 provides more information on OCAP delivery.

Table 3-2 Example Conjunction Assessment Life-Cycle Activities Throughout an NPR 7120.8 Project Life-Cycle

Life-Cycle Phase	Pre-Formulation	Formulation		Implementation						
7120.8 Life-Cycle Gates	ATP	Project Approval		CA	(as needed)			CA	Closeout	
	Notes: ① Project provides initial inputs for OCAP ② Iteration of OCAP content with CARA or JSC FOD ③ Achieve OCAP concurrence (Baseline)		Notes: ④ Project begins CAOIA development ⑤ Iteration of CAOIA content with CARA or JSC FOD ⑥ Achieve CAOIA concurrence (Final)					Update as needed		
Conjunction Assessment Products		Preliminary OCAP (recommended)	Baseline OCAP (required)	Initial CAOIA (recommended)	Final CAOIA (required)	Update CAOIA (as needed)				
NPR-Related Activities	<ul style="list-style-type: none"> As concepts develop, project manager coordinates with CARA (non-HSF) or JSC FOD (HSF) for orbit selection options 	<ul style="list-style-type: none"> 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 		<ul style="list-style-type: none"> 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 	<ul style="list-style-type: none"> 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 	<ul style="list-style-type: none"> CARA/JSC FOD monitors disposal efforts for issues affecting conjunction assessment 				
Legend	ATP Authority to Proceed into Formulation CA Continuation Assessment CARA Conjunction Assessment Risk Analysis CAOIA Conjunction Assessment Operations Implementation Agreement DOD Department of Defense			FOD Flight Operations Directorate HSF Human Space Flight JSC Johnson Space Center ODR Orbital Data Request OCAP Orbital Collision Avoidance Plan						

Note: Section 3.2.7 provides more information on OCAP delivery.

3.2 Orbital Collision Avoidance Plan

3.2.1 Project managers shall provide input to and work iteratively with CARA or JSC FOD to develop an OCAP that documents how the project will incorporate the capacity to meet the requirements of this directive into the design and operation of each spacecraft under their authority. The OCAP also includes design considerations for launch and deployment. CARA or JSC FOD reviews the completed OCAP and provides concurrence on the chosen implementation. The OCAP template containing the required elements is provided in Appendix D. NASA programs may develop OCAPs to cover multiple comparable spacecraft with mission-unique characteristics captured in separate appendices approved by CARA or JSC FOD.

3.2.2 The project manager provides the initial inputs shortly after approval for Formulation as shown in Figure 3-1 and as indicated in the instructions of Appendix D (template sections 1.0 and 2.0). CARA or JSC FOD responds with their analysis results, which are input into the analyses sections of the template. The results of the analyses are discussed between the project and CARA or JSC FOD. The resulting project decisions may be used to inform the design and operations of the spacecraft. The chosen course of action and rationale is then also documented in the OCAP. This process captures all the pertinent information, analyses, and plans in one document.

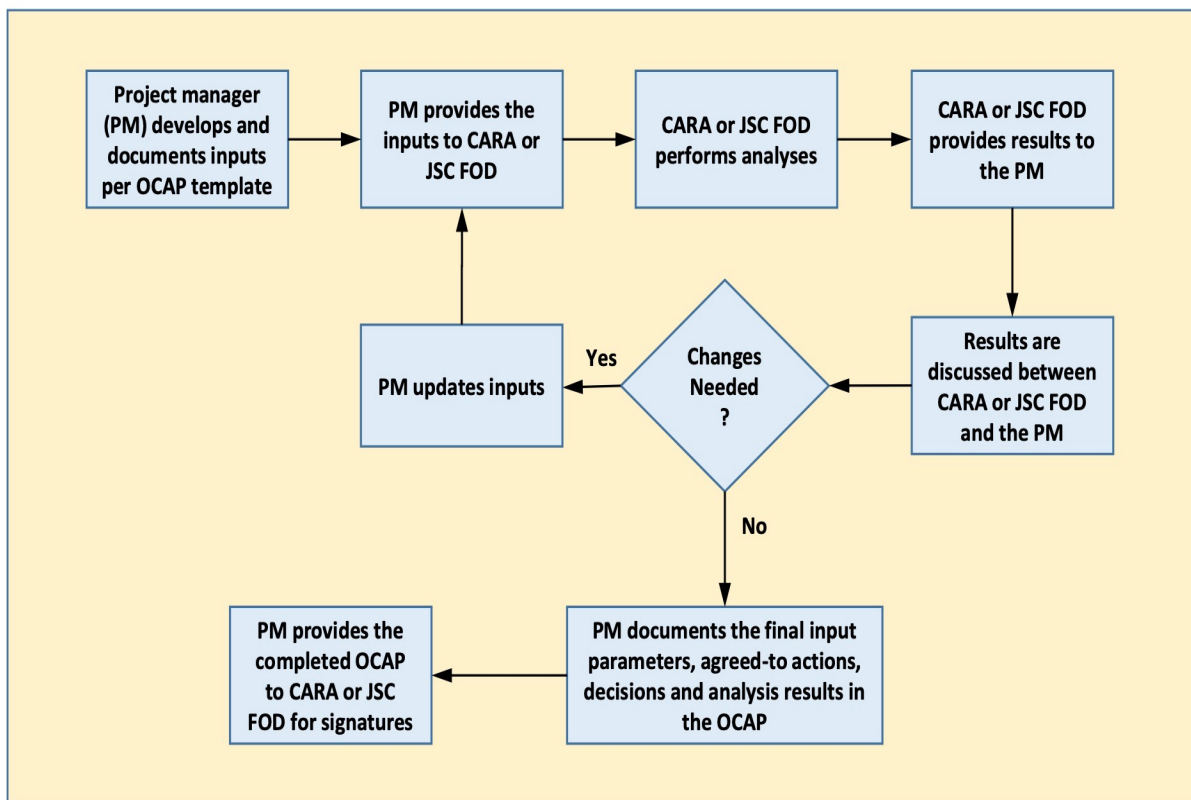


Figure 3-1

Orbital Collision Avoidance Plan Flow

3.2.3 The OCAP includes the information needed to review all phases of a space flight mission, providing for conjunction assessment and mitigation operations performed by the project manager or spacecraft owner. As a planning document, the OCAP has a broader applicability than solely the on-orbit conjunction assessment processes.

3.2.4 The OCAP includes as an attachment the Compliance Matrix that documents the project's acceptance or tailoring of the requirements of this NPR. The required Compliance Matrix is provided in Appendix C.

3.2.5 Per NPD 1000.0, NASA Governance and Strategic Management Handbook, tailoring is both accepted and expected. The Compliance Matrix documents the agreed-to tailoring of the requirements.

3.2.6 The information requested in the OCAP is illustrated in the plan template provided in Appendix D. The project manager obtains the latest version of the template from CARA or JSC FOD.

3.2.7 To secure concurrence for the OCAP from JSC FOD or CARA, project managers submit the OCAP to JSC FOD for HSF-related missions or to CARA for all other space flight missions. Project managers baseline the OCAP prior to proceeding into the Implementation Phase, or as otherwise negotiated with JSC FOD or CARA. When agreed to with JSC FOD or CARA, certain data values that are unknown at baseline (i.e., to-be-determined (TBD) and to-be-resolved (TBR) elements) may be filled in without additional approvals. JSC FOD and CARA provide feedback to the project manager within 30 days regarding further trade analysis or risk mitigation considerations if needed for concurrence. Program managers provide the final approval for the OCAP.

3.2.8 As changes occur, the project manager keeps the OCAP updated. The latest OCAP is made available for reviews and decision points. In general, the OCAP does not need to be updated after the CAOIA has been baselined.

3.3 Conjunction Assessment Operations Implementation Agreement

3.3.1 The CAOIA documents the operational processes that the project implements to protect the space environment. For non-HSF-related missions, project managers implement the operational requirements specified in this NPR. For HSF-related missions, project managers implement the minimum operational requirements specified in this NPR with additional requirements specific to HSF projects established with JSC FOD in operational interface procedures, flight rules, and program jettison policies.

3.3.2 For HSF-related missions, project managers shall discuss with JSC FOD whether an agreement is needed (i.e., the CAOIA) that documents the conjunction assessment screening, conjunction risk assessment, conjunction mitigation steps, flight dynamics operations concept (including maneuvers), and the communication and coordination process between the project manager and JSC FOD.

3.3.3 For non-HSF-related missions, project managers shall establish with CARA an agreement (i.e., the CAOIA) that documents the conjunction assessment screening, conjunction risk assessment, conjunction mitigation steps, flight dynamics operations concept (including maneuvers), and the communication and coordination process between the project manager and CARA. Project managers are encouraged to engage with CARA early in the Implementation Phase to develop the CAOIA. Project managers obtain the most recent template for the CAOIA from CARA. (See Appendix E for a sample CAOIA table of contents. Operational requirements are detailed in chapters 4 and 5 of this directive.)

3.3.3.1 For projects governed by NPR 7120.5, the CAOIA is finalized by the Operational Readiness Review (ORR).

3.3.3.2 For projects governed by NPR 7120.8, the CAOIA is finalized by an appropriate pre-launch review such as a Continuation Assessment or Periodic Project Review as determined by the program manager.

3.3.4 When changes are needed to the flight dynamics operations concept (including maneuvers) captured in the approved CAOIA, the project manager shall provide updated information (e.g., orbital parameters or trajectory ephemeris) to CARA or JSC FOD 30 days prior to implementing the changes.

3.3.4.1 This requirement does not apply to routine maintenance and other maneuvers that are already captured in the CAOIA.

3.3.4.2 Thirty days is needed for CARA or JSC FOD to analyze the spacecraft trajectory for potential colocation or systematic conjunctions with other on-orbit assets. When negotiated prior to the 30-day cutoff, a shorter analysis period may be possible.

Chapter 4. Conjunction Analysis and Mitigation Process Implementation

4.1 Overview

4.1.1 A program or project transitioning from development to operations implements a conjunction analysis and mitigation process to maintain safe transit in space. Figure 4-1 illustrates activities and decision points throughout this regularly iterated process. These activities apply to the equivalent of the project manager in operations, which may be called the "spacecraft operations manager," "spacecraft owner," "spacecraft operator," or other titles.

4.1.2 The CAOIA, which is agreed to between the project and CARA, documents the specific implementation of the conjunction assessment and mitigation process.

4.2 Conjunction Assessment Step

4.2.1 The first step of the conjunction analysis and mitigation process entails routinely collecting ephemeris-with-covariance information from spacecraft O/Os. The O/O of the protected asset submits an ephemeris with covariance predicting its planned trajectory (including any maneuvers) and expected maneuver execution error to CARA or JSC FOD for screening to predict any close approaches.

4.2.2 Process for Earth-Orbiting Spacecraft

4.2.2.1 Orbital safety analysts (OSAs) screen the predicted ephemeris against the predicted positions of all the objects in the resident space object (RSO) catalog maintained by USSPACECOM. The protected asset with its chosen safety volume is then flown along its trajectory. Any RSO that passes through the safety volume is identified as a "secondary object" and is a predicted future close-approach event.

4.2.2.2 OSAs also have a predicted ephemeris with covariance for the protected asset created from "non-cooperative tracking data," that is, tracking data from independent sensors. That ephemeris is also screened against the catalog.

4.2.2.3 The results of both screenings are sent back to CARA or JSC FOD for risk assessment.

4.2.3 Process for Non-Earth-Orbiting Spacecraft

4.2.3.1 For non-Earth-orbiting spacecraft, collision avoidance relies on O/O ephemeris files for the spacecraft orbiting a body or point or on a non-orbital trajectory. Data that can be used to non-cooperatively predict conjunctions between spacecraft in orbit regimes outside of Earth orbit are not currently available.

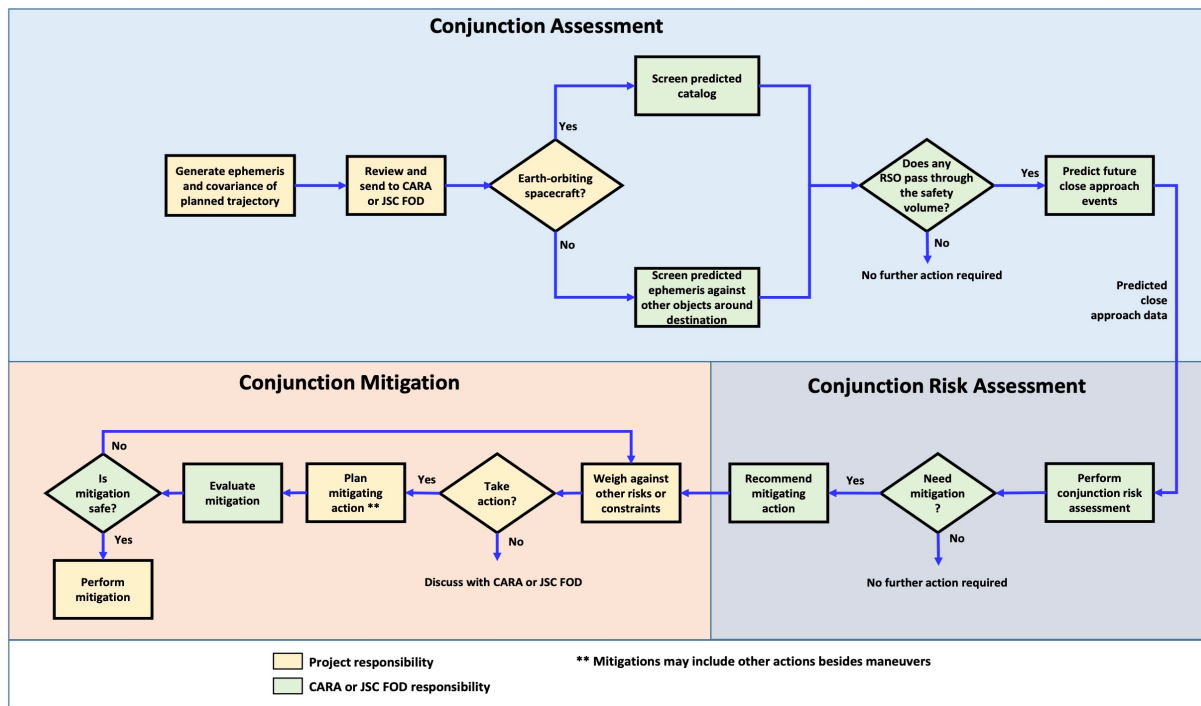


Figure 4-1 Conjunction Analysis and Mitigation Process Flowchart

4.2.3.2 The predicted ephemeris is screened against all other ephemerides available to NASA for spacecraft in the same orbit regime.

4.2.3.3 The results of the screenings are sent to the project manager for decision making.

4.2.4 For both Earth-orbiting and non-Earth-orbiting spacecraft, ephemerides with covariance are produced and furnished to CARA or JSC FOD throughout the spacecraft's active orbital life in accordance with the specifications provided in Section 5.1.1 of this NPR. Ephemeris data for subsidiary deployed child payloads throughout their active life are also provided to CARA or JSC FOD. Spacecraft and intentionally generated orbital debris (e.g., jettisoned objects and trash) that are below normal detectability thresholds may need enhancements to enable ephemeris data to be generated using non-cooperative tracking. (See CA2 Handbook section on trackability.) These ephemerides model any planned maneuvers. For non-maneuverable spacecraft, ephemerides may not be necessary as determined during OCAP preparation, provided the spacecraft is trackable non-cooperatively.

4.2.4.1 Project managers shall provide launch-related information to CARA or JSC FOD as soon as it is available. This information facilitates rapid cataloging and identification of launch-related objects and includes injection vectors and initial ephemerides based on the launch vehicle separation vector for deployed objects under the purview of the project manager. (See the CA2 Handbook, Section 6.1.)

4.2.4.2 Project managers shall provide updated predicted ephemerides for each spacecraft under their authority as soon as communications are established and sufficient tracking data are received from the payload(s) to update the separation ephemerides.

4.2.5 For planned maneuvers included in the routine ephemerides described in Section 4.2.4, the project manager provides an updated ephemeris with covariance as soon as possible after the time of these planned maneuvers. This delivery is in addition to the routine delivery described in Section

4.2.1 and in Section 5.1.1 of this NPR. For Earth-orbiting missions, the routine ephemeris delivery is usually sufficient.

4.3 Conjunction Risk Assessment Step

4.3.1 CARA or JSC FOD processes the predicted close-approach data using a combination of automated and manual methods. To determine whether the predicted event poses a high risk to the protected assets, analysts compute appropriate collision likelihood and consequence parameters, examine the conjunction geometry, and for Earth-orbiting spacecraft, assess whether the orbit determination solution for the other object is sufficient to serve as a basis for conjunction risk assessment. CARA or JSC FOD then makes a recommendation on whether the event should be mitigated for flight safety.

4.3.1.1 The CARA program manager determines which spacecraft conjunctions constitute high collision risks to the space environment based on conjunction assessment-related criteria and advises the project manager on appropriate mitigation actions.

4.3.1.2 The CARA program manager determines whether the orbit determination data for a conjunction event allow sufficient fidelity for use by the project to plan and execute a mitigating action.

4.3.2 If adequate mitigating action cannot be taken for a close approach due to extenuating circumstances, the CARA program manager and JSC FOD communicate information regarding the residual risk to OCE.

4.4 Conjunction Mitigation Step

4.4.1 Project managers weigh CARA or JSC FOD's recommendation against any other constraints or risks to determine whether to take mitigating action, considering risks to their spacecraft and sustaining a safe space environment.

4.4.2 Project managers take mitigating action or notify CARA or JSC FOD that no mitigation will occur. If the decision is to mitigate, project managers plan mitigation for conjunctions at the mitigation threshold (i.e., baseline criteria for mitigating an identified conjunction) documented in the CAOIA.

4.4.3 Ephemerides for the planned conjunction mitigations are provided to CARA or JSC FOD for screening to ensure the action is safe; specifically, that it mitigates the conjunction and does not introduce new risk.

4.4.4 For systematic conjunction situations identified through the analysis described in Appendix D.4, Section 2.2.1, project managers develop and implement a process with the other operator(s) to routinely coordinate maneuver plans and optimize relative spacing during operations. (See the CA2 Handbook, Section 4.2.)

4.4.5 Prior to finalizing their ascent plan and disposal plan, project managers shall coordinate with JSC FOD to identify and mitigate persistent or problematic orbital crossings with HSF missions (including the ISS). For non-HSF projects, CARA can provide a JSC FOD point of contact. (See the CA2 Handbook, Section 4.3.)

Chapter 5. Technical Requirements

This chapter captures the baseline technical requirements that the project manager meets. An approved CAOIA is sufficient to document deviations from this baseline.

Note: The requirements in this chapter may be captured in a NASA technical standard; when it becomes available the NPR may be adjusted accordingly.

5.1 Ephemeris Sharing

5.1.1 The specifications shown in Table 5-1 apply to ephemeris production as documented in the CAOIA. (Additional ephemeris quality context is provided in the CA² Handbook, Section 6.1.)

Table 5-1 Ephemeris Specifications

Parameter	Low-Earth Orbit	Other Earth Orbits	Non-Earth Orbits
Predictive duration	7 days (or full spacecraft lifetime if less than 7 days)	14 days	The conjunction assessment screening interval for the mission's orbit regime. Typically, 14-21 days.
Delivery frequency	Daily	Twice weekly	At least weekly
Ephemeris point spacing	~ 1/100th of an orbit in either time or true anomaly. ¹		
Covariance at each ephemeris point	The covariance consists of at least the six spacecraft state parameters. This covariance should be at least as statistically representative of the spacecraft's state position error histories as the DOD precision catalog covariances are for well-tracked objects in similar orbits ²		
Maneuvers	All known maneuvers within the ephemeris file span including maneuver execution error in the appropriate ephemeris covariances.		
Format	CCSDS standard OEM Format ³	CCSDS standard OEM Format ³	CCSDS standard OEM Format ³ or SPK Type 13 ⁴

Notes:

¹Spacecraft with extremely long period orbits and/or highly eccentric orbits may require more specialized approaches.

²Covariance realism software exists as open-source code on the CARA software repository.

³The definition for the standard on the Orbit Ephemeris Message (OEM) is in the Consultative Committee for Space Data Systems (CCSDS) standard CCSDS 502.0-B-2, "Orbit Data Messages," Section 5. <https://public.ccsds.org/Pubs/502x0b2c1e2.pdf>

⁴The Spacecraft and Planet Kernel (SPK) file format types are described in the JPL SPICE Toolkit at https://naif.jpl.nasa.gov/pub/naif/toolkit_docs/FORTRAN/req/spk.html#Supported%20Data%20Types

5.2 Maneuverable Spacecraft

5.2.1 The project manager shall coordinate all maneuver efforts with CARA or JSC FOD. This typically includes the following:

- a. Providing maneuver notifications to CARA or JSC FOD in the CCSDS Orbit Parameter Message (OPM) format. (See CA2 Handbook, Section 6.1 and CCSDS standard 502.0-B-2, Section 3, at <https://public.ccsds.org/Pubs/502x0b2c1e2.pdf>.)
- b. Submitting proposed maneuver plans in the form of ephemerides with covariance to CARA or JSC FOD at least 24 hours in advance of intended execution to allow for conjunction assessment screening. Conformity with this timeline may require out-of-cycle ephemeris production and submission. CARA and JSC FOD will screen the proposed maneuver ephemerides against other objects and notify the project of the results.
- c. Contacting CARA or JSC FOD and negotiating a contingency approach for emergency situations that do not allow notification 24 hours in advance.
- d. Taking responsibility for all mitigating actions required for close approaches with existing on-orbit active spacecraft during project transit to and from the final on-orbit location (transiting spacecraft yield right-of-way to on-station objects). (See the CA2 Handbook, Section 4.3.)

5.2.2 For maneuverable spacecraft, the project manager shall promptly inform CARA or JSC FOD of all anomalies that either affect the ability to perform conjunction mitigation or compromise agreements documented in the CAOIA. This typically includes reporting anomalies that affect a non-HSF mission's ability to maneuver to mitigate conjunctions (e.g., spacecraft in safe hold mode, thruster anomalies). JSC FOD will maintain knowledge of an HSF-related mission's ability to maneuver in accordance with JSC FOD's standard reporting protocols.

5.3 Conjunction Mitigation

5.3.1 Conjunction mitigation maneuvers follow a basic process:

- a. CARA informs the project of high-risk conjunctions for which mitigation planning is appropriate. (See sections 4.3 and 4.4.) Typical mitigation scenarios and associated spacecraft capabilities are documented in the CAOIA. Low-risk conjunctions require no further action.
- b. When the project manager generates a plan for conjunction mitigation, the project manager ensures that ephemerides with covariance, both with and without maneuvers, are provided to CARA for screening and risk assessment. The CAOIA documents the specific information and schedule exchanges between CARA and the project manager.
- c. Based on the screening, CARA makes recommendations on the need to mitigate from a space environment safety perspective.
- d. The project manager makes the conjunction mitigation decision.

5.3.2 For making decisions about mitigating conjunctions in Earth orbit, the project manager considers the following elements:

- a. The baseline decision threshold (i.e., the mitigation threshold) for close-approach events is, at the mitigation commitment point, either a probability of collision (P_c) value in excess of $1E-04$ (1 in 10,000) or a Euclidean miss distance less than the conjunction's combined hard-body radius (HBR).
- b. The conjunction mitigation action reduces the P_c by at least 1.5 orders of magnitude below the mitigation

threshold (e.g., 3E-06 for a mitigation threshold of 1E-04). (See the CA2 Handbook, Section 6.4.)

c. Deliberately engineered spacecraft close approaches require mission-specific safety-of-flight procedures resulting from intra-mission coordination and planning. Examples include proximity operations, on-orbit servicing activities, rendezvous, or operations of multiple spacecraft managed by one flight operations team that controls their relative positions.

5.3.3 For making decisions about mitigating conjunctions for non-Earth-orbiting spacecraft, the project manager considers the following elements:

- a. Uncertainties with the spacecraft-specific orbit determination processes.
- b. Defined thresholds for orbit crossing distance and timing.
- c. Time required for planning and execution of mitigation maneuvers.

5.4 Post-Launch Deployments

Project managers of spacecraft deploying or jettisoning objects provide predicted ephemerides with covariance for the trajectory of the deployed objects 24 hours or as early as possible prior to the deployment time. This allows for screening the ephemerides and performing risk assessment to determine the safety of the trajectories of the deployed objects.

5.5 Advanced Capabilities

5.5.1 For spacecraft using non-instantaneous propulsion (e.g., hydro, electric, solar sail), differential drag, or novel propulsion capabilities, project managers should coordinate with CARA or JSC FOD to allow time to determine how to support these spacecraft-specific capabilities.

5.5.2 For spacecraft using autonomous maneuvering, the project manager implements a conjunction assessment and mitigation process as documented in the CAOIA. This process typically includes the following:

- a. Using an emulation capability that reasonably predicts the behavior of the autonomous control system to generate predicted ephemerides with covariance according to the requirements of Section 5.1 of this NPR.
- b. Complying with Section 5.2.2 for all autonomously planned maneuvers.
- c. Having and, if required, using a capability to halt expected autonomously planned maneuvers for safety-of-flight reasons.
- d. Notifying CARA or JSC FOD of all maneuvers initiated autonomously. (See the CA2 Handbook, Section 6.5.)

Appendix A. Definitions

Ascent plan. An ephemeris file or set of files and associated maneuver plan that represent the predicted flight trajectory (including all modeled maneuvers) that a spacecraft will execute to move from its injection orbit to its final spacecraft orbit. The ascent plan should be updated in real time as flown to incorporate any changes to the plan.

Baseline. In the context of this NPR, baseline indicates putting the product under configuration control so that changes can be tracked, approved, and communicated to stakeholders and the team. Updates to baselined documents require the same formal approval process as the original baseline.

Collision avoidance. The planning and execution of risk mitigation strategies to avoid a collision between two space objects. (See also conjunction mitigation.)

Conjunction. A close approach between two objects that is predicted to occur because the secondary object passes within a chosen geometric or statistical safety volume about the protected asset (also called "primary object").

Conjunction analysis. The process of predicting a close-approach event by screening the ephemeris of the protected asset against the space object catalog (i.e., conjunction assessment) and then analyzing the event to determine the associated threat to the asset (risk assessment).

Conjunction assessment. The identification of close approaches using ephemeris screening against a catalog of resident space objects.

Conjunction Assessment Operations Implementation Agreement. An agreement between the project manager and CARA that documents the implementation of the operational requirements specified in this NPR for each non-HSF spacecraft under the project manager's authority.

Conjunction mitigation. An action taken to remediate conjunction risk, including a propulsive maneuver, an attitude adjustment (e.g., for differential drag or to minimize frontal area), or providing ephemeris data to secondary owner/operators so that they can perform an avoidance maneuver.

Conjunction risk assessment. The process of assessing a conjunction (predicted close approach) to determine the likelihood of two space objects colliding and to determine the expected consequence if they collide in terms of spacecraft inoperability and expected debris production.

Colocation. Being in the vicinity of another operational spacecraft close enough that systematic conjunctions occur.

Covariance. Characterization of uncertainty components and their interactions surrounding a space object's estimated state at a given time.

Crewed asset. Spacecraft that hosts or transports humans.

Demise. When a spacecraft is no longer in space such as a complete burn up on reentry. Spacecraft passivation and migration to disposal orbits occur prior to demise.

Disposal. An end-of-mission process involving a spacecraft's passivation and reentry into the atmosphere for its ultimate demise or its movement (if necessary) to an orbit or trajectory considered acceptable for orbital debris limitation. For purposes of this NPR, "disposal" includes the

reorbiting or deorbiting of a spacecraft at the end of mission. Disposal occurs prior to spacecraft demise.

Disposal plan. An ephemeris file or set of files and associated maneuver plan that represent the predicted flight trajectory (including all modeled maneuvers) that a spacecraft will execute to move from its operating orbit to its disposal orbit. The disposal plan should be updated in real time as flown to incorporate any changes to the plan.

Ephemeris. (plural: ephemerides) A file containing a time-ordered set of position and velocity measurements describing an object's predicted trajectory.

Hard-body radius. The radius of a circle equal to the sum of the circumscribing radii of both the protected plus the secondary spacecraft.

Highly elliptic orbit. An orbit having an eccentricity greater than 0.25 and less than 1.00. Eccentricity is a measure of how an orbit deviates from circular. A perfectly circular orbit has an eccentricity of zero; higher numbers indicate more elliptical orbits.

Low-Earth orbit. An orbit with an orbital period less than 225 minutes and an eccentricity less than 0.25.

Maneuver. Any action that changes a trajectory in a non-Keplerian fashion, i.e., in a way that cannot be modeled non-cooperatively.

Maneuver plan. The specific parameters that represent a planned spacecraft maneuver, including execution time, burn duration, and delta-v. The position and velocity of a single object at a specified epoch is specified in an Orbit Parameter Message (OPM). The industry message standard for communicating maneuver plans is the Consultative Committee for Space Data Systems (CCSDS) standard CCSDS 502.0-B-2, "Orbit Data Messages," Section 3 located at <https://public.ccsds.org/Pubs/502x0b2c1e2.pdf>.

Maneuverable spacecraft. A spacecraft that has capability permitting the manipulation of the spacecraft's trajectory in a non-Keplerian fashion.

NASA-owned or -operated spacecraft. A spacecraft owned, developed, or operated by NASA or operated principally for NASA.

Near-Earth object. A comet or asteroid whose orbit enters Earth's neighborhood, where it may present a hazard.

Non-cooperative tracking data. Data obtained describing the location of space objects that do not themselves actively provide location data. For example, a piece of orbital debris that has no transponder could not provide ephemeris data. Other examples include natural objects such as asteroids, and spacecraft belonging to operators who do not choose to share an ephemeris for their spacecraft.

Non-human space flight mission. A NASA space flight mission that is not related to human space flight, i.e., non-HSF. These space flight missions are supported by the CARA Program.

Orbital Collision Avoidance Plan. **The early life-cycle planning document demonstrating to CARA or JSC FOD that the design considerations and preparation for operations of the space flight mission meet the intent of this directive.**

Orbital debris. In this NPR, orbital debris is defined as any object placed in space by humans that no longer serves any useful function. Objects range from spacecraft to spent launch vehicle stages to components and include materials, fragments, trash, or other objects that are intentionally or inadvertently cast off or generated. (Derived from NPR 8715.6.)

Payload. A specific complement of instruments, sensors, equipment, and support hardware carried into space to accomplish a mission or a discrete activity in outer space. Personnel are not considered a payload or a part of a payload. (See also "primary payload" and "secondary payload.")

Preliminary. The documentation of information as it stabilizes but before it goes under configuration control. It is the initial development leading to a baseline. Some products will remain in a preliminary state for multiple reviews. The initial preliminary version is likely to be updated at a subsequent review but remains preliminary until baselined. (From NPR 7120.5 Appendix I.)

Primary payload. A payload for which a launch vehicle is procured. A primary payload typically defines the orbital placement/trajectory, flight design, critical path of the mission integration including launch preparation process, and mission operations. The primary payload's organization funds the launch service. (See also "payload" and "secondary payload.")

Protected asset. The asset of focus (also called "primary object") for which risk assessments of potential collisions are being performed and collision avoidance mitigation activities are being considered and possibly performed.

Resident space object. An artificial object that orbits Earth.

Rideshare. Accommodation opportunities for secondary payloads on a launch vehicle. Sharing access to space is possible when a launch configuration has excess performance that can be shared between primary payloads and compatible secondary payloads.

Safety volume. A volume defined around a protected asset as a zone for predicting close approaches with a "secondary" space object entering that volume.

Secondary object. Any cataloged object residing in space that passes through the safety volume of a protected (i.e., primary) asset when the protected asset with its safety volume is flown along its trajectory. The resident space object is identified as a "secondary object" and is the conjuncting object in a predicted future close-approach event. The secondary object may be an operated spacecraft.

Secondary owner/operator. **The owner/operator of a "secondary object" (i.e., a predicted future close-approach event) identified when a protected asset with its safety volume is flown along its trajectory. (See "secondary object" above.)**

Secondary payload. A payload that is manifested subordinate to a primary or co-manifested payload and is, therefore, subordinate in launch date and orbit selection. (See also "payload," "primary payload," and "rideshare.")

Space situational awareness. The knowledge and characterization of space objects and their operational environment to support safe, stable, and sustainable space activities. (From Space Policy Directive-3.)

Space surveillance network. A network of radar and optical sensors used by DOD to track space objects. Tracking data are used to perform orbit determination and maintain the space object catalog.

Spacecraft and Planet Kernel. A file format that allows ephemerides for any collection of solar system bodies (spacecraft, planet, satellite, comet, or asteroid) to be combined under a common file format and accessed by a common set of functions. (Derived from SPK Required Reading at https://naif.jpl.nasa.gov/pub/naif/toolkit_docs/C/req/spk.html.)

Systematic conjunction. A situation in which two space objects repeatedly experience close approaches with each other due to their similar orbits.

Tailoring. The process used to adjust or seek relief from a prescribed requirement to accommodate the needs of a specific task or activity (e.g., program or project).

Trajectory plan changes. Any adjustments to orbit parameters or the trajectory occurring between launch and end of mission.

Update. Applied to products that are expected to evolve as the formulation and implementation processes evolve. Only expected updates are indicated. However, any document may be updated as needed. Updates to baselined documents require the same formal approval process as the original baseline. (From NPR 7120.5, Appendix I.)

Appendix B. Acronyms

CA2	Conjunction Assessment and Collision Avoidance
CAOIA	Conjunction Assessment Operations Implementation Agreement
CARA	Conjunction Assessment Risk Analysis
CCSDS	Consultative Committee for Space Data Systems
COLA	Collision on Launch Assessment
DOD	Department Of Defense
FDO	(JSC FOD) Flight Dynamics Officer
FOD	(JSC) Flight Operations Directorate
GPS	Global Positioning System
HBR	Hard-body radius
HSF	Human space flight
ISS	International Space Station
JPL	Jet Propulsion Laboratory
JSC	(NASA) Johnson Space Center
LEO	Low-Earth orbit
LSO	(NASA SOMD) Launch Services Office
MDAA	Mission Directorate Associate Administrator
MOA	Memorandum of Agreement
NID	NASA Interim Directive
NODIS	NASA Online Directives Information System
NPD	NASA Policy Directive
NPR	NASA Procedural Requirements
NRRS	NASA Records Retention Schedules
OCAP	Orbital Collision Avoidance Plan
OCE	(NASA) Office of the Chief Engineer
ODR	Orbital Data Request
OEM	Orbit Ephemeris Message
OIIR	(NASA) Office of International and Interagency Relations
O/O	Owner/operator
OPM	Orbit Parameter Message

OSA	Orbital Safety Analyst
PDR	Preliminary Design Review
RSO	Resident Space Object
SDS	(U.S. Space Force) Space Defense Squadron
SOMD	Space Operations Mission Directorate
SSA	Space situational awareness
SSN	(U.S.) space surveillance network
TOPO	(JSC FOD) Trajectory Operations Officer
U.S.	United States
U.S.C.	United States Code
USSPACECOM	U.S. Space Command

Appendix C. Compliance Matrix

The Compliance Matrix in Table C-1 documents the project's compliance with the requirements of this NPR or how the project is tailoring the requirements. The project manager fills out the Compliance Matrix and attaches the completed matrix to the OCAP when the OCAP is submitted for approval signatures.

For tailoring the NPR requirements, the project manager fills out the Compliance Matrix, obtains signatures for tailored requirements (see description below), and attaches the completed matrix to the OCAP when the OCAP is submitted for approval signatures. (See Tailoring in Section 3.5.3 of NPD 1000.0.)

Columns 1 and 2 identify the requirement.

Column 3 designates the organization responsible for maintaining the requirement for the Agency. The head of OCE has the authority to approve tailoring unless this authority has been delegated.

Column 4 designates the person to whom the requirement applies. "PM" stands for project manager in this table.

Column 5 is filled in by the project to identify their approach to the requirement. The program/project inserts an "FC" if they intend to be fully compliant with the requirement, a "T" for "tailored" if they are seeking relief (waiver) from the requirement, or "NA" for a requirement that is "not applicable." If the project plans on being fully compliant ("FC"), the remaining columns are left blank.

Column 6 is used to provide a justification. If the project believes the requirement to be "NA," the rationale is described in the "Justification" column. If the project is seeking a waiver ("T"), the rationale is summarized in the "Justification" column.

Column 7 contains the name, title, and signature of the requirement owner or delegate to indicate that approval for a "T" or "NA" in Column 6 has been obtained from the organization responsible for the requirement.

Table C-1 NASA Spacecraft Conjunction Analysis and Collision Avoidance for Space Environment Protection Compliance Matrix

Para #	Requirement Statement	Req Owner	Applic-able to	Compliance (FC, T, NA)	Justification	Approval
	MDAAs (or as delegated to the program or project manager) shall levy the requirements from this directive in solicitations that					

2.2.1	are intended to result in a NASA-owned or -operated spacecraft and allocate the requirements to spacecraft and supporting ground system element providers.	OCE	MDAA			
.1.2	The project manager shall ensure the spacecraft can be tracked from deployment until demise.	OCE	PM			
3.2.1	Project managers shall provide input to and work iteratively with CARA or JSC FOD to develop an OCAP that documents how the project will incorporate the capacity to meet the requirements of this directive into the design and operation of each spacecraft under their authority.	OCE	PM			
	For HSF-related missions, project managers shall discuss with JSC FOD whether an					

<p>3.3.2</p>	<p>needed (i.e., the CAOIA) that documents the conjunction assessment screening, conjunction risk assessment, conjunction mitigation steps, flight dynamics operations concept (including maneuvers), and the communication and coordination process between the project manager and CARA .</p>	<p>OCE (Delegated to CARA)</p>				
<p>3.3.3</p>	<p>For non-HSF-related missions, project managers shall establish with CARA an agreement (i.e., the CAOIA) that documents the conjunction assessment screening, conjunction risk assessment, conjunction mitigation steps, flight dynamics operations concept (including maneuvers), and the communication</p>	<p>OCE (Delegated to CARA)</p>	<p>PM</p>			

	and coordination process between the project manager and CARA.					
3.3.4	When changes to the flight dynamics operations concept (including maneuvers) are needed that are not already captured in the approved CAOIA, the project manager shall provide the updated information (e.g., orbital parameter or trajectory) to CARA or JSC FOD 30 days prior to implementing the changes.	OCE (Delegated to CARA)	PM			
4.2.4.1	Project managers shall provide launch-related information to CARA or JSC FOD as soon as it is available.	OCE (Delegated to CARA or JSC FOD)	PM			
	Project managers shall provide updated predicted ephemerides for each spacecraft					

4.2.4.2	authority as soon as communications are established and sufficient tracking data are received from the payload(s) to update the separation ephemerides.	OCE (Delegated to CARA or JSC FOD)	PM			
4.4.5	Prior to finalizing their ascent plan and disposal plan, project managers shall coordinate with JSC FOD to identify and mitigate persistent or problematic orbital crossings with HSF missions (including the ISS).	OCE (Delegated to JSC FOD)	PM			
5.2.1	The project manager shall coordinate all maneuver efforts with CARA or JSC FOD.	OCE (Delegated to CARA or JSC FOD)	PM			
	For maneuverable spacecraft, the project manager shall promptly inform CARA or JSC FOD of all anomalies	OCE (Delegated				

	the ability to perform conjunction mitigation or compromise agreements documented in the CAOIA.	or JSC FOD)				
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Appendix D. Orbital Collision Avoidance Plan Template

D.1. The Orbital Collision Avoidance Plan (OCAP) is an implementation plan that describes how the design and planned operations of the space flight mission meet the intent of the NPR to protect the spacecraft asset and the space environment. The OCAP documents the structured study of aspects of mission design that affect close approach prediction and mitigation during mission operations. Its purpose is to ensure that all needed functionality is in place when the mission is put into operation. The project manager develops the OCAP for each project. An OCAP can cover multiple spacecraft if they are sufficiently similar.

D.2. The OCAP includes the results of study and analysis and the related design and operations considerations. The OCAP is developed iteratively between the project and the NASA Conjunction Assessment Risk Analysis (CARA) Program or the Johnson Space Center (JSC) Flight Operations Directorate (FOD). The project manager provides the initial inputs detailed below. CARA or JSC FOD responds with their analysis results, which provide the basis for discussion and decisions on the course of action for implementing the requirements of this NPR. Selected aspects of mission design need to be discussed and agreed upon between the project manager and CARA or JSC FOD early to avoid costly delays close to mission launch. The project manager documents the results of that discussion and iterative process and the resulting decisions in the OCAP and submits it to CARA or JSC FOD for review and approval. The completed NPR Compliance Matrix from Appendix C is attached when the OCAP is submitted.

D.3. The approval signature of the program manager and the concurrence of the CARA program manager or the JSC FOD interagency operations liaison indicates that the implementation chosen by the project either meets the NPR requirements or the requested tailoring is acceptable. Signature on the OCAP also indicates approval of the requested tailoring in the attached Compliance Matrix.

D.4. The project manager completes approval and baselines the OCAP prior to proceeding into the Implementation Phase. As changes occur, the project manager keeps the OCAP updated and notifies CARA or JSC FOD, who will assess the need to perform OCAP analyses again. In general, for projects that develop a CAOIA, the OCAP does not need to be updated after the CAOIA has been baselined.

D.5. Below are the required fields for the OCAP. If a section is not relevant or not applicable to a particular project, the project manager states that in the appropriate section and provides a rationale. For any section of the OCAP, backup information already documented in an alternate form (e.g., a previously approved OCAP from a comparable mission, a local procedure, or other configuration-controlled document) can be referenced. The project manager ensures that CARA or JSC FOD has access to the alternate form.

D.6 Orbital Collision Avoidance Plan Template

***[Project Name]* Orbital Collision Avoidance Plan**

Approval

Name
Program Manager

Date

Concurrence

Name
JSC FOD Interagency Operations Liaison
or CARA Program Manager

Date

Originator

Name
Project Manager

Date

Table of Contents

1.0 PROJECT OVERVIEW

2.0 SPACECRAFT DESIGN**3.0 ORBIT SELECTION AND PLACEMENT**

3.1 Spacecraft Colocation Analysis

3.2 Spacecraft Transit Burden

3.3 Close Approach Event Density

4.0 DEPLOYMENT, IMPROVING CATALOGING, AND ENHANCING TRACKABILITY

4.1 Cataloging

4.2 Trackability

4.3 Deployment

5.0 SPACECRAFT OPERATIONS

5.1 Ephemeris Generation

5.1.1 As-Flown State Information

5.1.2 State Estimation Parameters

5.1.3 Filter Tuning

5.1.4 Covariance Realism

5.1.5 Maneuver Execution Error

5.2 Conjunction Mitigation Options**5.3 Autonomous Maneuvering**

5.3.1 Objectives and Reach

5.3.2 Control Algorithm Particulars

5.3.3 Ground Communication and Control

5.3.4 Autonomous Action Representation in Ephemerides

5.3.5 Halting Autonomous Actions

6.0 RISK ASSESSMENT PARAMETERS**1.0 PROJECT OVERVIEW**

Provide a short description of the planned project, its concept of operations, and its primary goals. This description should include the project's purpose, the basics of any data collection and analysis activities, or any other higher level project details that provide a sense of how the project's purpose drives design decisions. Such information typically appears elsewhere (although not always in a single location) in other project documents and literature; the intent here is to summarize only the relevant information in a single location to provide needed context for the reader of the OCAP.

2.0 SPACECRAFT DESIGN

Describe the physical design of the spacecraft by providing the information requested below. This information should be the best estimate of anticipated values as understood at the time of performing OCAP analyses:

- Preferred orbit and acceptable alternatives.
- Anticipated mass
- The basic construction of the spacecraft such as stowed dimensions and deployable structures (e.g., solar panels, antennae, booms) including all their (rough) dimensions.
- Spacecraft exterior material types and colors, which will be used to determine trackability by DOD space surveillance network (SSN) sensors.

Describe planned operations of the spacecraft from launch to disposal including, as applicable, transitional staging, orbit design, navigation, and propulsion system details such as:

- Thruster size and orientation, propellant type.
- Expected launch date and operational and fuel lifetimes.
- The operational spacecraft attitude and attitude control method.
- Orbit control method (requirements in Section 4.4 and Chapter 5 of this NPR) with special attention given to the degree of ground-based versus on-board autonomous control.
- Planned deployments or jettisons.

3.0 ORBIT SELECTION AND PLACEMENT

Describe the selected orbital regime (including spacecraft altitude and inclination), rationale for the approach, and how the choices affect the mission objectives and performance. The description should include consideration of spacecraft colocation implications, the spacecraft transit burden, and the close approach event density. Estimate and describe the amount of spacecraft lifetime and propellant needed to accomplish the ascent, orbit maintenance, conjunction mitigation, and, if necessary, the disposal phase of the space flight mission. Ensure the spacecraft is adequately resourced and capable of implementing the plan.

Describe the expected insertion orbit at launch and any ascent sequence to achieve the final mission orbit after injection. If the spacecraft will maintain the planned orbit through orbit maintenance maneuvers, describe the expected frequency and size of maneuvers (See the CA2 Handbook sections 5.2 and 6.5 for more discussion and context.) Describe expected maneuvers at end of life for disposal.

Identify the ephemerides representing each of the orbits that the spacecraft will spend time in as well as launch vehicle trajectory predictions for determination of colocation in the injection orbit.

For spacecraft that take advantage of ridesharing arrangements, much of this information will not be known until late in the life-cycle. Under these conditions, it is understood that options for addressing analysis results may be limited.

4.0 DEPLOYMENT, IMPROVING CATALOGING, AND ENHANCING TRACKABILITY

4.1 Deployment

Describe the chosen method of deploying the spacecraft. See Table D-1 for planning activities needed for different types of deployment. CARA or the JSC FOD trajectory operations officer (TOPO) can assist the project in analyzing and optimizing choices for deployment and will lead any discussions with the U.S. Space Command (USSPACECOM). (See the CA2 Handbook Section 5.1.)

For projects using rideshare arrangements, very little may be known at design time about the future orbit, let alone the manner of launching and orbit placement. Even though it may not be known at design time precisely which approaches may be used, planning and preparation can offer to the project the launch and/or deployment approaches that can be safely embraced. Failure to perform

appropriate planning steps at design time could preclude the use of such launch and/or deployment approaches later should they be an integral part of an attractive launch and/or deployment option.

The design-time activities below ensure that needed information will be available to the launch cataloging agency if some of the more challenging launch and/or deployment mechanisms are employed.

Table D-1. Planning Activities for Deployment Scenarios

Deployment Scenario	Necessary Planning Activities
Single payload	<p>When the NASA spacecraft is the principal or the only payload for the launch and will be injected very close to its desired orbit location, no specific launch and/or deployment activities are required at design time. DOD tracking and cataloging of the launch is straightforward, and no additional information beyond what is contained in the "Ready minus 15" (R-15) standard launch alerting message is required.</p>
Parent/child (deploy or jettison)	<p>In a parent/child deployment, a payload is attached to (or entirely inside) another payload. The child spacecraft is released from the parent spacecraft after the parent spacecraft is deployed. Such scenarios can cause confusion during the identification and cataloging process if the details of this arrangement are not known.</p> <p>If project spacecraft will deploy another spacecraft or jettison an object, the project manager will identify all spacecraft or objects involved in the parent/child situation, describe the deployment scenario and timeline, delineate the steps taken to attempt to ensure that any secondary deployments take place a safe distance from other spacecraft released in the primary deployment, and establish a communications protocol to be used to inform DOD about the arrangement, both in advance and in real-time as the different parts of the deployment scenario are actually executed.</p>
Tethered	<p>Because tethered spacecraft follow an orbit defined by the center of mass of the tethered system but in general can be tracked only at the extremities, they present challenges for orbit determination and spacecraft identification. The use of a tether for spacecraft deployment is a form of the parent/child scenario described above.</p> <p>When a project employs a tethered deployment mechanism, the project manager supplies CARA or JSC FOD with the information necessary for CARA/JSC FOD to determine whether the spacecraft can be identified and the orbit determined to a level of fidelity sufficient to enable conjunction assessment. The information needed includes the masses of the spacecraft involved, the length of the</p>

...the masses of the spacecraft and the tether, the period of time during which the spacecraft will actually be operating as a tethered system, the orbit altitude, and the sizes and external materials of the two end objects to determine individual trackability.

4.2 Improving Cataloging (Applies to missions with multiple spacecraft deployments)

For multi-deployment scenarios, describe any method(s) of improving cataloging efficiency that will be employed by the project; for example, providing launch injection vectors, the rapid production of predicted spacecraft ephemerides, arranging for inter-payload deployment delays, or increasing the deployment velocities to increase payload separation.

4.3 Enhancing Trackability (Applies to missions with multiple spacecraft deployments or spacecraft that do not meet the minimum trackability size criteria.)

If the launch will be a large-deployment rideshare or if the spacecraft does not meet the minimum trackability size criteria, describe the tracking enhancement measures that will be employed to improve trackability and spacecraft identification. CARA or JSC FOD will determine whether the spacecraft meets the SSN trackability requirements based on the dimensions from template Section 2. (For more context, see Sections 4.5 and 5.2 of the CA2 Handbook.)

If the spacecraft is deemed too small to track or has selected an orbit that is unlikely to obtain regular or reliable SSN tracking, this section will document the proven detectability enhancement or explain how satellite-predicted ephemerides will be generated and supplied. Such measures can include an on-board tracking radio beacon to provide position and identification, the use of corner cubes and an arrangement with a laser tracking facility to track an identified payload, coded light signals from a light source on the exterior of the spacecraft, radio frequency interrogation of an exterior Van Atta array, passive increase of albedo, or arrangement with a commercial tracking provider to provide specialized tracking and payload identification.

5.0 SPACECRAFT Operations

5.1 Ephemeris Generation

Describe how the ephemeris produced is consistent with the requirements in Section 4.2 of the NPR. For spacecraft that can change their orbit or trajectory or for spacecraft with highly eccentric orbits, describe the capability of the spacecraft for ephemeris generation that meets the requirements of Section 4.3 of the NPR. (See the CA2 Handbook Section 4.6 for more information.)

The description should encompass as-flown state information, state estimation parameters, filter tuning, covariance realism, and maneuver execution error.

5.1.1. As-Flown State Information

Indicate the method that will be used to understand the spacecraft's current position (e.g., telemetry, Global Positioning System (GPS) fixes) and the different observables or measurements that will be provided, which should include the rates at which measurements will be taken; the regularity at which the downlinking of such information will occur; and how the uncertainties of these data will be assessed, represented, and provided to CARA or JSC FOD.

5.1.2 State Estimation Parameters

Indicate the state and non-conservative force parameters that the orbit determination process will estimate. For the state estimation, indicate which conservative force parameters will be employed and at what fidelity (e.g., geopotential order, third body effects, solid earth tides). If atmospheric drag is to be estimated (and typically should be for low-Earth orbit (LEO) and high-eccentricity missions), indicate the atmospheric density model to be used and any additional drag-related prediction improvement approaches (e.g., debiasing methods, solar storm prediction models). If solar radiation pressure is to be modeled (and typically should be for missions with perigee heights above ~500km), provide a general description of the approach and features of the model that will be employed. The models required are functions of the orbit, but the following general guidelines can be stated:

- 36 x 36 (zonal/tesseral) order geopotential model is generally required for LEO; lower-order models are often acceptable for higher orbits.
- Third-body effects (solar/lunar perturbations) are generally required, although analytic models rather than precision ephemerides are usually acceptable.
- For orbits with perigee heights less than 1000 km, a drag acceleration model driven by a dynamic atmospheric density model is usually required. CARA can provide suggestions for atmospheric density models that have worked well for previous missions.
- For orbits with perigee heights greater than 500 km, a simple (cannonball) solar radiation pressure model is usually required.

5.1.3 Filter Tuning

Describe the orbit determination method to be deployed, the tunable parameters, and the approach that will be used to set these parameters both before launch and once on orbit. For example, if a batch filter is used, tuning parameters include the orbit determination fit span (and minimum data requirements), residual exclusion thresholds, and goodness-of-fit parameters used to determine whether an orbit determination is acceptable such as the weighted residual root-mean-square error and percent of residuals accepted. Nominal values for these parameters are indicated along with the rationale used for choosing those values. Similarly, appropriate parameters and associated values are given if a sequential estimator is selected.

5.1.4 Covariance Realism

While covariances can easily be obtained from orbit-determination engines and propagated to future time points, such covariances rarely provide a realistic statement of the actual state errors at those points without initial tuning, regular monitoring, and tuning refinement. Describe the process that will be used to evaluate the realism of produced covariances and the overall covariance-tuning and monitoring approach planned. A set of open-source covariance realism evaluation tools is posted on the CARA software repository.

5.1.5 Maneuver Execution Error

Maneuvers do not always occur exactly as commanded, and this execution uncertainty should be

accounted for in the predicted post-maneuver state covariances that appear in owner/operator (O/O) ephemerides. Describe how spacecraft maneuver execution error will be determined and how it will be included in the covariances given in the predictive ephemerides. Previous approaches have included statistical characterization of actual maneuvers (requires a number of actual on-orbit maneuvers before the error characterization is meaningful) or Monte Carlo techniques that attempt to model all the possible process errors in maneuver execution.

5.2 Conjunction Mitigation Options

Describe whether active orbit maintenance, including controlled deorbit, is possible for the spacecraft and what method will be used for this. Characterize spacecraft reorientation capabilities and their effects on mission conduct. Describe the mitigation capability selected and the rationale for its selection. (See the CA2 Handbook Section 4.6.)

5.3 Autonomous Maneuvering

If any level of on-board, autonomous maneuvering is planned, describe as outlined in the subsections below how the autonomous maneuver control functionality or paradigm will perform the needed notifications, fail-safes, and functionality to meet the requirements of Section 4.4 of the NPR. Include the objectives and reach, the control algorithm particulars, ground communication and control, autonomous action representation in ephemerides, and the mechanisms for halting planned autonomous actions and notifying CARA or JSC FOD.

5.3.1 Objectives and Reach

Describe the overall purpose of the automated maneuver control approach. For example, is it just for station keeping or does it also autonomously manage transit to the on-station position and active deorbit at the end of mission life? Will each spacecraft be autonomously managed as an independent unit or is there a "mother ship" that will autonomously coordinate and execute constellation reconfiguration among the member spacecraft? Is automated conjunction assessment included in the autonomous maneuver control? If so, provide a detailed description and algorithmic specifications of the conjunction assessment and risk analysis functionality as well as the expected input data and interfaces for receipt of such data.

5.3.2 Control Algorithm Particulars

Describe the overall control paradigm employed and its driving parameters and timelines such as look-ahead periods, automatic controller cycle/reevaluation time, and "freeze time" after which planned maneuvers or other activities are not revisited or altered.

5.3.3 Ground Communication and Control

Describe the methods and frequency with which autonomously planned control actions will be communicated to the ground and the associated timeline. Delineate which actions, if any, require ground approval before execution or whether there are other "fail-safe" methods that can abort any autonomously planned action.

5.3.4 Autonomous Action Representation in Ephemerides

Describe the methods that will be used to represent autonomously selected actions in circulated spacecraft-predicted ephemerides, namely, how and at what frequency planned maneuver

information will be obtained from the spacecraft so that it can be represented in the distributed ephemerides. Because ephemerides are the mechanism by which a spacecraft's intended future positions will be represented both in conjunction assessment screenings against the space catalog and to other O/Os, it is important that the actions of autonomous control systems are relayed so that they can be made available to the screening and position deconfliction processes. Describe the way these ephemerides that include modeling of planned maneuvers will be made available in near-real-time and with sufficient lead-time to enable the conjunction assessment process.

5.3.5 Halting Autonomous Actions

Describe the mechanisms for ground personnel to halt planned autonomous actions when necessary and the way CARA or JSC FOD will be notified of such situations.

6.0 Risk Assessment Parameters

Describe the approach selected for the payload hard-body radius (HBR) value to use for operational conjunction assessment and risk analysis and summarize the rationale.

D.7 Explanatory Table

In the table below, each of the required areas of the template after Project Overview is explained in terms of inputs from the project, analysis by CARA/JSC FOD, and the context for the analysis. The purpose is to describe the needed input and the process involved in deciding on the approach for the project that will be documented in the OCAP.

Table D-2. Inputs, Analyses, and Context for OCAP Fields

Topic	2.0 SPACECRAFT DESIGN
Project Manager Inputs	<p>Describe the physical design of the spacecraft (best estimate of anticipated values as understood at the time of performing OCAP analyses) including:</p> <ul style="list-style-type: none"> ● Preferred orbit and acceptable alternatives. ● Anticipated mass ● The basic construction of the spacecraft such as stowed dimensions and deployable structures (e.g., solar panels, antennae, booms) including all their (rough) dimensions. ● Spacecraft exterior material types and colors, which will be used to determine trackability by DOD space surveillance network (SSN) sensors. <p>Describe planned operations of the spacecraft from launch to disposal including, as applicable, transitional staging, orbit design, navigation, and propulsion system details such as:</p> <ul style="list-style-type: none"> ● Anticipated propulsion system parameters or any propulsion system trade study. Include thruster size, thruster orientation, and propellant type. ● Target launch date or launch period and operational and fuel

	<p>lifetimes.</p> <ul style="list-style-type: none"> • The operational spacecraft attitude and attitude control method. • Orbit control method (requirements in Section 4.4 and Chapter 5 of this NPR) with special attention given to the degree of ground-based versus on-board autonomous control. • Planned deployments or jettisons.
CARA/JSC FOD Analyses and Context	Input to other analyses.
Topic	3.0 ORBIT SELECTION AND PLACEMENT
Project Manager Inputs	<p>The spacecraft orbit (or orbits) selected, rationale for that choice, and how strongly those choices affect mission performance (flexibility for adjustment).</p> <ul style="list-style-type: none"> • Ephemerides representing each of the orbits that the spacecraft will spend time in as well as launch vehicle trajectory predictions for determination of colocation in the injection orbit. • The expected insertion orbit at launch. • Description of any ascent sequence to achieve the final mission orbit after injection. • Description of expected maneuvers at end of life for disposal.
CARA/JSC FOD Analyses and Context	<p>Certain orbits present greater close approach safety risks and challenges than others. The purpose of this group of analyses is to elucidate the difficulties that a particular orbit will engender and determine whether the orbit as proposed is problematic for conjunction assessment.</p> <p>Results will be analyzed to determine whether minor adjustments to the proposed orbit could notably improve the spacecraft safety profile. If the chosen orbit presents considerable close approach challenges, additional safety capacities and activities may be necessary to mitigate the risk if the orbit selection cannot be modified. The goal of these analyses is to ensure that the spacecraft is properly equipped for handling the conjunction assessment implications of the selected orbit.</p> <p><i>Note: "Rideshare" spacecraft that do not determine the target orbit provide orbit selection information as soon as possible, which may not be until after PDR. Under these conditions, it is understood that the available options for addressing analysis results may be limited. If rideshares do not have information about their injection orbit until very close to the launch date, it is critical that project managers deliver this information as soon as possible to allow sufficient time for CARA to perform this analysis.</i></p>

	<p>Three aspects of the selected orbit and orbit placement approach must be investigated to determine the conjunction assessment and collision avoidance burdens imposed: spacecraft colocation analysis, spacecraft transit burden, and close approach event density.</p>
Subtopics	3.1 Colocation
Project Manager Inputs	Whether the spacecraft will maintain the planned orbit through orbit maintenance maneuvers. If so, the expected frequency and size of maneuvers (See the CA2 Handbook sections 5.2 and 6.5 for more discussion and context.)
CARA/JSC FOD Analyses and Context	<p>Active spacecraft routinely come into regular contact with debris objects, but the threat posed by any such objects is transient because, in most cases, these objects are decaying while the active spacecraft remain in stable or maintained orbits. However, in encountering actively maintained spacecraft (and other spacecraft placed in or objects finding themselves in frozen orbits), "systematic" conjunctions can arise; that is, conjunctions that regularly reappear over a long period of time. Such situations are both a safety hazard themselves and a particular nuisance because of the expanded O/O contact and coordination requirements for conjunctions between active spacecraft. Note that "colocation" in this context is defined as being in the vicinity of another operational spacecraft close enough that systematic conjunctions occur.</p> <p>Some spacecraft use a single nominal orbit, but others use different orbits for different mission stages. CARA or JSC FOD performs an analysis, using tools developed in-house, to determine whether any known or existing spacecraft present a systematic conjunction likelihood with the proposed spacecraft orbit. If any such spacecraft are identified, CARA or JSC FOD communicates to the project small changes to the spacecraft's orbit that could obviate the systematic conjunctions or, if an orbit change is not desired, the additional infrastructure and communications requirements needed to manage the systematic conjunction situation.</p> <p>If colocations cannot be eliminated by choosing an alternative orbit, or if it is not desirable to do so for space flight mission reasons, then the project manager develops a plan to coordinate orbit placement and/or sharing with the other affected operators. (See the CA2 Handbook Section 4.3.)</p>
Subtopic	3.2 Spacecraft Transit Burden

Project Manager Inputs	The project forwards its post-launch-injection ascent plans and if applicable, its end-of-life active descent plans to CARA or JSC FOD for transit burden analysis. Such information should be communicated by a trajectory ephemeris. If this is not possible, the project manager coordinates with CARA or JSC FOD on other documentation methods.
CARA/JSC FOD Analyses and Context	<p>The purpose of this analysis is to determine what conjunctions a spacecraft may encounter during its ascent from the injection orbit to the mission orbit and similarly, from the mission orbit to the disposal orbit.</p> <p>CARA or JSC FOD will determine the existing (and, if known, planned) active spacecraft orbits through which the spacecraft will be transiting, what existing communications and management protocols exist for the non-NASA spacecraft, and therefore, what active coordination activities and capabilities will be necessary for the NASA project to accomplish these transits safely. CARA will also ensure coordination with JSC FOD for transiting through the International Space Station (ISS) or any other human-space-flight (HSF) orbits, if applicable.</p> <p>If the CARA or JSC FOD recommendation is for implementation of a communications or other operational process, that will be documented in the CAOIA for non-HSF projects or other document specified for HSF projects. Communication with other operator(s) should begin as soon as possible, preferably for non-HSF projects before the CAOIA is written.</p> <p>During ascent and disposal, the expectation is that the spacecraft will yield right-of-way to on-station active spacecraft. The OCAP describes how, such as through risk mitigation maneuvers or trajectory alterations. If yielding is not possible, the project manager and CARA document the alternative plan. (See the CA2 Handbook Section 4.3 for more information.)</p>
Subtopic	3.3 Close Approach Event Density
Project Manager Inputs	Provide on-station orbits.
CARA/JSC FOD Analyses and Context	Different orbits contain different object densities and as such, they generate different numbers of conjunctions and high-interest close approach events. It is important to estimate the number of routine conjunctions that a mission will encounter, the number of high-interest close approach events that will require explicit planning and management engagement, and the number of actual conjunction risk

	<p>mitigation actions that will be needed so that appropriate operations plans, mission staffing, and fuel expenditure and/or mission interruption due to conjunction mitigation actions can be determined and incorporated explicitly into the project's planning.</p> <p>Drawing on its historical conjunction database, CARA or JSC FOD will take the project's provided on-station orbits and run appropriate tools to estimate the number of conjunctions, high-interest close approach events, and mitigation actions required over the mission's expected lifetime. CARA will furnish this information to the project so that it can be used in refining operations plans and staffing levels (documented in the CAIOA) and establishing the amount of fuel required and anticipated mission disruption for risk mitigation actions (needed for spacecraft design).</p> <p><i>Note: For spacecraft using rideshare arrangements, an event density analysis can be conducted once the injection orbit is known. Although changes in fuel budget, etc., cannot be pursued, staffing and operations planning adjustments are possible.</i></p>
Topic	4.0 DEPLOYMENT, IMPROVING CATALOGING, AND ENHANCING TRACKABILITY
Subtopic	4.1 Deployment
Project Manager Inputs	The project describes the chosen method of deploying the spacecraft.
CARA/JSC FOD Analyses and Context	<p>CARA or JSC FOD will assist in determining whether the method enables cataloging by the U.S. space surveillance network (SSN). CARA or the JSC FOD trajectory operations officer (TOPO) can assist the project with this analysis and will lead any discussions with the U.S. Space Command (USSPACECOM). (See the CA2 Handbook Section 5.1.)</p> <p>Single-payload, parent/child, and tethered deployment scenarios require planning at design time. The easiest approach to complying with deployment scenario requirements is by adopting the protocols used during similar previous launches that met the requirements. If requested, CARA or JSC FOD can assist the project manager in identifying such previous launches. Table D-1 summarizes the planning activities needed for each deployment scenario.</p>
Subtopic	4.2 Improving Cataloging

Project Manager Inputs	For multi-deployment scenarios, describe any method(s) of improving cataloging efficiency that will be employed by the project; for example, providing launch injection vectors, the rapid production of predicted spacecraft ephemerides, arranging for inter-payload deployment delays, increasing the deployment velocities to increase payload separation.
CARA/JSC FOD Analyses and Context	<p>It is now common under rideshare conditions for large numbers of spacecraft to be deployed, often en masse, as part of a single launch. Such launches make it difficult for the DOD cataloging authority as they try to positionally separate and catalog large clusters of essentially identical spacecraft. Large rideshare launches can require several weeks to be fully cataloged, which delays the on-orbit collision avoidance process for such spacecraft and adds risk for those spacecraft that begin their transit out of the cluster to other orbital locations.</p> <p>Analysis and pre-planning ensure that needed information will be available to the launch cataloging agency if some of the more challenging launch and/or deployment mechanisms are employed.</p>
Subtopic	4.3 Enhancing Trackability
Project Manager Inputs	The project manager will describe the particular tracking enhancement measures that will be employed to improve trackability and spacecraft identification if the launch will be a large-deployment rideshare or if the spacecraft does not meet the minimum trackability size criteria. Such measures can include an on-board tracking radio beacon to provide position and ID, the use of corner cubes and an arrangement with a laser tracking facility to track and identify the payload, coded light signals from a light source on the exterior of the spacecraft, radio frequency interrogation of an exterior Van Atta array, passive increase of albedo, or arrangement with a commercial tracking provider to provide specialized tracking and payload identification. (See the CA2 Handbook Section 4.5 for more details.)
CARA/JSC FOD Analyses and Context	Based on the dimensions provided in Section 1.0 of the OCAP, CARA or JSC FOD will determine whether the spacecraft meets the SSN trackability requirements. (For more context, see Sections 4.5 and 5.2 of the CA2 Handbook.) CARA or JSC FOD will evaluate the proposed tracking enhancement measures or how satellite-predicted ephemerides will be generated and supplied.
Topic	5.0 SPACECRAFT OPERATIONS
Subtopic	5.1 Ephemeris Generation

<p>Project Manager Inputs</p>	<p>Describe how the ephemeris produced is consistent with the requirements in Section 4.2 of the NPR. For spacecraft that can change their orbit or trajectory or for spacecraft with highly eccentric orbits, describe the capability of the spacecraft for ephemeris generation that meets the requirements of Section 4.3 of the NPR. (See the CA2 Handbook Section 4.6 for more information.)</p>
<p>CARA/JSC FOD Analyses and Context</p>	<p>CARA or JSC FOD will review and determine whether it believes the O/O orbit determination approach is adequate for providing O/O predicted ephemerides that can serve as the basis for conjunction assessment decisions. CARA or JSC FOD will recommend needed enhancements or upgrades.</p> <p>Given the different propulsion methods in use, more and more conjunction assessment activities are being performed directly from O/O ephemerides, so it is extremely important that these products provide accurate predicted states and realistic covariances. (Note that the common TLE [two-line element] format does not include the necessary covariance information to enable conjunction assessment.)</p> <p>Risk assessment for spacecraft close approaches is based on precise predictions of the two spacecrafts' states and state uncertainties at the time of closest approach. Because most secondary objects are not active spacecraft that cooperatively provide ephemeris data, a state solution derived from non-cooperative tracking needs to be used for these objects; typically, this solution comes from the DOD space catalog. However, the solution for the protected asset can frequently be improved over the DOD solution by using an O/O ephemeris. The following aspects of O/O ephemerides enable them to be more accurate than the DOD solutions:</p> <ul style="list-style-type: none"> ● Active spacecraft often receive copious precise tracking information, from on-board GPS receivers or from telemetry, that improves the accuracy of the initial state available for prediction. ● The spacecraft O/O has a more accurate calculation of the ballistic coefficient than one determined non-cooperatively by the DOD tracking capability. ● Finally, and most importantly, foreknowledge of spacecraft future maneuvers can be included in predicted ephemerides so that post-maneuver conjunction assessment screening can be executed meaningfully. <p>This last advantage is the most important reason for missions to provide their ephemerides to CARA or JSC FOD for conjunction assessment screening: doing so is the only way for other spacecraft</p>

	<p>O/Os to obtain information about collision risks that may arise due to the planned maneuver, allowing coordination with NASA to enable adjustments for maneuver timing or size to manage the risk.</p> <p>Details of the time, place, and manner of ephemeris construction and delivery to CARA or JSC FOD are documented in the CAIOA. Additionally, the actual evaluation of O/O ephemerides in terms of prediction error and covariance realism must be performed after the spacecraft achieves on-orbit operations and is generating real ephemerides, although simulated activities before launch are encouraged to ensure the proper operation of the orbit determination process and exercise tuning practices.</p> <p>At design time, however, it is important to ensure that the assembled orbit determination process will be able to produce the ephemeris products needed for conjunction assessment.</p>
Subtopic	5.1.1. As-Flown State Information
Project Manager Inputs	Indicate the method that will be used to understand the spacecraft's current position (e.g., telemetry, Global Positioning System (GPS) fixes) and the different observables or measurements that will be provided: the rates at which they will be taken; the regularity at which the downlinking of such information will occur; and how the uncertainties of these data will be assessed, represented, and provided to CARA or JSC FOD.
CARA/JSC FOD Analyses and Context	CARA or JSC FOD will review the information and make recommendations.
Subtopic	5.1.2 State Estimation Parameters
Project Manager Inputs	Indicate the state and non-conservative force parameters that the orbit determination process will estimate. For the state estimation, indicate which conservative force parameters will be employed and at what fidelity (e.g., geopotential order, third body effects, solid earth tides). If atmospheric drag is to be estimated (and typically should be for LEO and high-eccentricity missions), indicate the atmospheric density model to be used and any additional drag-related prediction improvement approaches (e.g., debiasing methods, solar storm prediction models). If solar radiation pressure is to be modeled (and typically should be for missions with perigee heights above ~500km), provide a general description of the approach and features of the model that will be employed.

<p>CARA/JSC FOD Analyses and Context</p>	<p>The models required are functions of the orbit, but the following general guidelines can be stated:</p> <ul style="list-style-type: none"> • 36 x 36 (zonal/tesseral) order geopotential model is generally required for LEO; lower-order models are often acceptable for higher orbits. • Third-body effects (solar/lunar perturbations) are generally required, although analytic models rather than precision ephemerides are usually acceptable. • For orbits with perigee heights less than 1000km, a drag acceleration model driven by a dynamic atmospheric density model is usually required. CARA can provide suggestions for atmospheric density models that have worked well for previous missions. • For orbits with perigee heights > 500km, a simple (cannonball) solar radiation pressure model is usually required.
<p>Subtopic</p>	<p>5.1.3 Filter Tuning</p>
<p>Project Manager Inputs</p>	<p>Describe the orbit determination method to be deployed, the tunable parameters, and the approach that will be used to set these parameters both before launch and once on orbit. For example, if a batch filter is used, tuning parameters include the orbit determination fit span (and minimum data requirements), residual exclusion thresholds, and goodness-of-fit parameters used to determine whether an orbit determination is acceptable, such as the weighted residual root-mean-square error and percent of residuals accepted. Nominal values for these parameters are indicated, along with the rationale used for choosing those values. Similarly, appropriate parameters and associated values are given if a sequential estimator is selected.</p>
<p>CARA/JSC FOD Analyses and Context</p>	<p>CARA or JSC FOD will review the information and make recommendations.</p>
<p>Subtopic</p>	<p>5.1.4 Covariance Realism</p>
<p>Project Manager Inputs</p>	<p>While covariances can easily be obtained from orbit-determination engines and propagated to future time points, such covariances rarely provide a realistic statement of the actual state errors at those points without initial tuning, regular monitoring, and tuning refinement. Describe the process that will be used to evaluate the realism of produced covariances and the overall covariance-tuning and monitoring approach planned. A set of open-source covariance realism evaluation tools is posted on the CARA software repository.</p>

CARA/JSC FOD Analyses and Context	CARA or JSC FOD will review the information and make recommendations.
Subtopic	5.1.5 Maneuver Execution Error
Project Manager Inputs	Maneuvers do not always occur exactly as commanded, and this execution uncertainty should be accounted for in the predicted post-maneuver state covariances that appear in O/O ephemerides. Describe how spacecraft maneuver execution error will be determined and how it will be included in the covariances given in the predictive ephemerides. Previous approaches have included statistical characterization of actual maneuvers (requires a number of actual on-orbit maneuvers before the error characterization is at all meaningful) or Monte Carlo techniques that attempt to model all the possible process errors in maneuver execution.
CARA/JSC FOD Analyses and Context	CARA or JSC FOD will review the information and make recommendations.
Subtopic	5.2 Conjunction Mitigation Options
Project Manager Inputs	Provide information concerning whether active orbit maintenance, including controlled deorbit, is possible for the spacecraft and what method will be used for this, as well as characterizations of spacecraft reorientation capabilities and their effects on mission conduct. (See the CA2 Handbook Section 4.6.)
CARA/JSC FOD Analyses and Context	<p>CARA or JSC FOD will review the information and make recommendations for the mitigation capability of the spacecraft.</p> <p>CARA's mission statement regarding orbital safety is "To take prudent measures, at reasonable cost, to improve safety of flight, without imposing an undue burden on mission operations." The word "prudent" here is operative: the NASA position does not translate into an absolute requirement for all missions to perform active collision risk mitigation. Indeed, many low-cost missions that use extremely small spacecraft with very short orbital lifetimes may not require any active risk mitigation methods at all. That said, "prudent measures" usually does mean that missions must avail themselves of any mechanisms they have available that can meaningfully reduce the collision likelihood of high-risk close approach events.</p> <p>Generally, missions that have the ability to adjust the orbit of their spacecraft must employ that mechanism to mitigate collision risk for</p>

	<p>Spacecraft must employ this mechanism to mitigate conjunction risk for high-risk close approach events. This ability is typically applied to chemical or electric propulsion systems, but other methods are also effective in reducing conjunction risk.</p> <p>One such additional method to perform orbit adjustment is "differential drag," in which the spacecraft reorients itself to change its ballistic coefficient and thus use the change in its drag acceleration to modify its orbit. While the effective ΔV that this method can apply is considerably smaller than what is possible using chemical propulsion, both directed studies and practical experience with spacecraft that employ this method have shown that it can be an effective means of conjunction risk mitigation when the lead times used are long enough.</p> <p>Another conjunction risk mitigation method is "attitude realignment," in which the smallest (or at least a smaller) cross-sectional presentation of the spacecraft is aligned to be perpendicular to the relative velocity vector of the two objects that are in conjunction. This approach reduces the protected asset's exposed area facing the oncoming secondary objects and thus reduces the probability of collision. For some spacecraft, attitude realignment does not render a substantial reduction in the probability of collision and thus is not mandated as a mechanism to be employed for conjunction risk mitigation, even if a spacecraft has no other mitigation techniques at its disposal. However, some spacecraft achieve a meaningful reduction in collision risk by employing this realignment method. Analysis is required to determine whether this method will be effective for a given spacecraft design.</p> <p>If the spacecraft does not have chemical or electric propulsion, CARA or JSC FOD will consider provided data concerning the spacecraft orbit maintenance methods and attitude control mechanisms to determine whether these additional methods can be used to appreciably reduce collision risk. CARA or JSC FOD will also assist in the development of a mission conjunction assessment concept of operations that includes the use of the recommended mitigation capability. The capability selected and the rationale for its selection will be documented in the OCAP, and for non-HSF projects, the conjunction assessment concept of operations that makes use of it will be documented in the CAIOA.</p>
Subtopic	5.3 Autonomous Maneuvering
Project Manager Inputs	If any level of on-board, autonomous maneuvering is planned, describe how the autonomous maneuver control functionality or paradigm will perform the needed notifications, fail-safes, and functionality to meet the requirements of Section 4.4 of the NPR, including the objectives and reach, the control algorithm particulars.

	<p>maneuvering the spacecraft and return, the control algorithm particulars, ground communication and control, autonomous action representation in ephemerides, and the mechanisms for halting planned autonomous actions and notifying CARA or JSC FOD.</p>
<p>CARA/JSC FOD Analyses and Context</p>	<p>CARA or FOD will review the responses to the above and determine whether the as-designed autonomous maneuver control approach will integrate properly with the collision avoidance paradigm or whether design changes will be necessary.</p> <p>Every attempt will be made to integrate autonomously controlled missions into the conjunction analysis and mitigation process with a minimum of disruption. However, the fact remains that collision avoidance, especially when two active spacecraft are in conjunction, is of necessity a communicative activity. Autonomous control must provide mechanisms for appropriate conjunction and maneuver intention data exchange to make safe spacecraft operation possible.</p>
<p>Subtopic</p>	<p>5.3.1. Objectives and Reach</p>
<p>Project Manager Inputs</p>	<p>Describe the overall purpose of the automated maneuvering. For example, is it just for station keeping or does it also autonomously manage transit to the on-station position and active deorbit at the end of mission life? Will each spacecraft be autonomously managed as an independent unit or is there a "mother ship" that will autonomously coordinate and execute constellation reconfiguration among the member spacecraft? Is automated conjunction assessment included in the autonomous maneuver control? If so, provide a detailed description and algorithmic specifications of the conjunction assessment and risk analysis functionality as well as the expected input data and interfaces for receipt of such data.</p>
<p>CARA/JSC FOD Analyses and Context</p>	<p>CARA or JSC FOD will review the information and make recommendations.</p>
<p>Subtopic</p>	<p>5.3.2 Control Algorithm Particulars</p>
<p>Project Manager Inputs</p>	<p>Describe the overall control paradigm employed and its driving parameters and timelines such as look-ahead periods, automatic controller cycle/reevaluation time, and "freeze time" after which planned maneuvers or other activities are not revisited or altered.</p>
<p>CARA/JSC FOD Analyses and Context</p>	<p>CARA or JSC FOD will review the information and make recommendations.</p>

Subtopic	5.3.3 Ground Communication and Control
Project Manager Inputs	Describe the methods and frequency with which autonomously planned control actions will be communicated to the ground and the timeline associated with this. Delineate which actions, if any, require ground approval before execution, or whether there are other "fail-safe" methods that can abort any autonomously planned action.
CARA/JSC FOD Analyses and Context	CARA or JSC FOD will review the information and make recommendations.
Subtopic	5.3.4 Autonomous Action Representation in Ephemerides
Project Manager Inputs	Describe the methods that will be used to represent autonomously selected actions in circulated spacecraft-predicted ephemerides, namely, how and at what frequency planned maneuver information will be obtained from the spacecraft so that it can be represented in the distributed ephemerides. Because ephemerides are the mechanism by which a spacecraft's intended future positions will be represented both in conjunction assessment screenings against the space catalog and to other O/Os, it is important that the actions of autonomous control systems are relayed so that they can be made available to the screening and position deconfliction processes. Describe the way these ephemerides that include modeling of planned maneuvers will be made available in near-real-time and with sufficient lead-time to enable the conjunction assessment process.
CARA/JSC FOD Analyses and Context	CARA or JSC FOD will review the information and make recommendations.
Subtopic	5.3.5 Halting Autonomous Actions
Project Manager Inputs	Describe the mechanisms for ground personnel to halt planned autonomous actions when necessary, and the way CARA or JSC FOD will be notified of such situations.
CARA/JSC FOD Analyses and Context	CARA or JSC FOD will review the information and make recommendations.
Topic	6.0 RISK ASSESSMENT PARAMETERS

Project Manager Inputs	<p>Describe the approach selected for the payload hard-body radius (HBR) value to use for operational conjunction assessment and risk analysis and summarize the rationale.</p> <p>The project will furnish CARA or JSC FOD with dimensioned schematics for their spacecraft.</p>
CARA/JSC FOD Analyses and Context	<p>Based on this information, CARA or FOD will produce a set of possibilities for a payload HBR value and document the analysis in this section. From this set of possibilities, CARA or JSC FOD and the project will then agree on the HBR value to use for operational conjunction assessment and risk analysis.</p> <p>Of the risk assessment parameters used in the risk evaluation, the one associated with a particular mission payload is the HBR. The probability of collision (P_c), which is the principal conjunction risk assessment calculation, determines the likelihood that the actual miss distance will be smaller than a specified threshold. This threshold is usually set to represent the combined sizes of the two spacecraft in conjunction so that the P_c truly does give the probability of collision because a collision can be presumed to occur if the miss distance between the two objects is smaller than their combined size. This combined size is historically realized as a sphere that encapsulates both objects if they are placed adjacent to each other. The radius of this sphere is called the HBR.</p> <p>In each conjunction, estimates of the size of the secondary object are computed by CARA or JSC FOD. This estimate is based either on published spacecraft dimension data or, lacking that, on spacecraft skin-track signature data such as radar-cross section or visual magnitude measurements. Because the actual dimensions of the protected asset are known, determinations of its size are more straightforward, but there is a range of options for representing the three-dimensional size as a single numeric value from very conservative to risk tolerant. The selection of a size representation methodology is governed largely by the risk posture of mission personnel. It is not beneficial to employ an approach that is unnecessarily conservative as this generates excessive false alarms and results in unneeded work for both the mission and CARA or JSC FOD.</p>

Appendix E. Conjunction Assessment Operations Implementation Agreement (CAOIA) Elements

E.1 The CAOIA documents the operational processes that the project implements to protect the space environment. (See Section 3.3.) Operational requirements are detailed in chapters 4 and 5 of this directive. The CAOIA includes processes for the conjunction assessment screening, conjunction risk assessment, and conjunction mitigation steps.

E.2 Project managers obtain the most recent template for the CAOIA from CARA. The project manager and CARA coordinate the specific contents of the CAOIA template depending on specific mission characteristics.

E.3 A notional table of contents for a maneuverable mission is provided below.

Table of Contents

1. INTRODUCTION

1.1 Purpose of Document

1.2 Mission Overview

1.3 Points of Contact

1.4 Units of Measure

2. APPLICABLE DOCUMENTS

2.1 Project Documents

2.2 Governing Documents

2.2.1 Compliance Documents

2.2.2 Reference Documents

2.2.3 Industry Partner Documents

2.2.4 Other Documents

3. PROJECT OPERATIONS OVERVIEW

3.1 Background

3.2 Launch and Transfer Orbit Philosophy

3.3 Nominal Orbit and Orbit Maintenance Philosophy

3.4 End-of-Mission Planning

3.5 Hard Body Radius (HBR) and Spacecraft Mass

3.5.1 HBR Calculation and Usage

3.5.2 Spacecraft Mass Calculation and Usage

4. CARA SCREENING PROCESS [Provided by CARA]

4.1 Process Overview

4.2 Launch, Early Orbit, and End-of-Mission Conjunction Assessment Screenings

4.3 Nominal Orbit Conjunction Assessment Screenings

4.4 High Interest Event (HIE) Conjunction Assessment Screenings and Support

4.4.1 HIE Actionability

4.4.2 HIE Secondary Owner/Operator Contact

4.5 Conjunction Assessment Screening Volumes and Pc Threshold

5. DELIVERABLES TO CARA Team

5.1 Data Products**5.2 Data Product Transfer - to CARA Team****5.3 Ephemeris Delivery Frequency and Duration****5.4 Data Product ID 01 - Nominal Predicted Ephemeris and Covariance****5.5 Data Product ID 02 - No-burn Predicted Ephemeris and Covariance****5.6 Data Product ID 03 - Risk Mitigation Maneuver Ephemeris****5.7 Data Product ID 04 - Predicted Maneuver Report****6. CARA TEAM DELIVERABLES TO THE PROJECT****6.1 CARA Team Data Products****6.2 Security Requirements to Receive CARA Team Data Products****6.3 Data Product Transfer -CARA to****6.4 Conjunction Assessment Screening Summary Results****6.5 High-Interest Event Summaries****6.6 Maneuver Screening Analysis Report****Appendix A. Product Formats****A.1 Ephemeris Format for Data Products 01, 02, and 03****A.2 Report Format for Data Product 04**

Appendix F. References

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