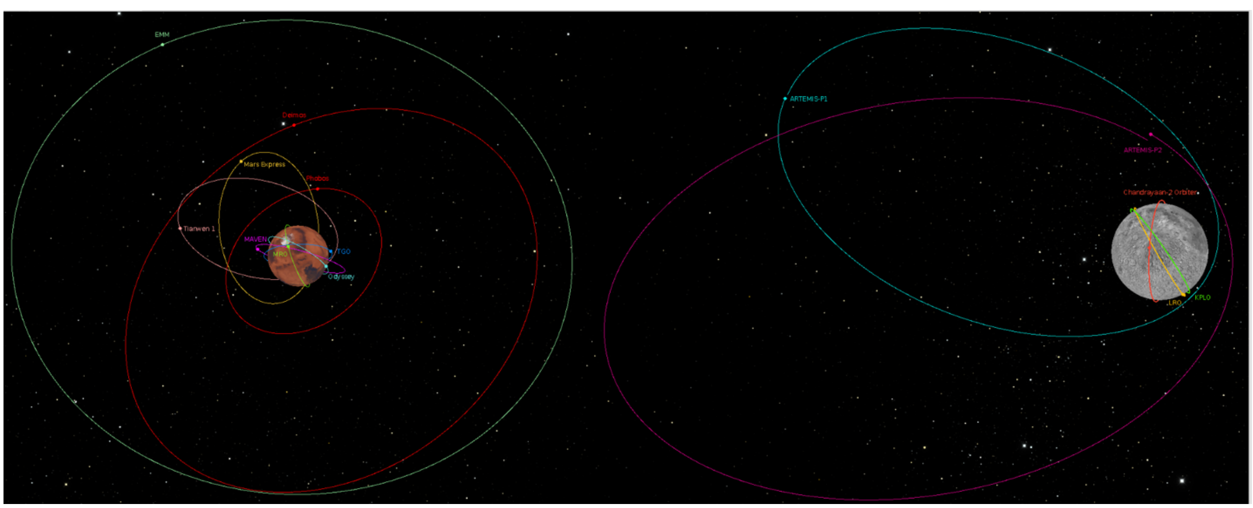
MULTIMISSION AUTOMATED DEEPSPACE CONJUNCTION ASSESSMENT PROCESS (MADCAP) GENERIC INTERFACE CONTROL DOCUMENT

Version 1

October 2024



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Clearance number CL#24-5967

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1. INTRODUCTION

1.1 Purpose of Document

This document defines the interfaces and interaction for implementation of conjunction assessment processes between the NASA/AMMOS Multimission Automated Deepspace Conjunction Assessment Process (MADCAP) Team and a mission operating in a shared extraterrestrial orbital environment (e.g., Moon, Mars, Sun/Earth L1, Sun/Earth L2, Venus, etc.).

1.2 Points of Contact

Contact information for the MADCAP Team and the flight project organizational Points of Contact (POC) are provided in Table 1 below.

Table 1: Contact Information for the MADCAP Team

Organization	Role	Contact Information	When to Contact
MADCAP Team	Team Lead	David S. Berry david.s.berry@jpl.nasa.gov 1-818-354-0764	• Administrative/Policy matters • Routine operations • Emergencies
MADCAP Team	Cognizant Engineer	Zahi B. Tarzi zahi.b.tarzi@jpl.nasa.gov 1-818-354-4684	• Conjunction Assessment Technical Questions • Routine operations • Special Runs, Special Tests • MADCAP S/W anomalies • Emergencies
Conjunction Assessment Program Office	Program Manager	Lauri K. Newman lauri.k.newman@nasa.gov cell: 240-374-9146	• Issues that cannot be resolved by working with the MADCAP Team

1.3 MADCAP Governing Documents

a) NASA Spacecraft Conjunction Analysis and Collision Avoidance for Space Environment Protection, NPR 8079.1, June 27, 2023.
b) JPL Software Development Requirements, Rev 10, JPL Rules document # 57653, 10/20/2020.
c) MGSS Implementation and Maintenance Task Requirements, MGSS DOC-001455, Rev I, 08-May-2024.
d) AMMOS Mission Design & Navigation Software Management Plan, MGSS DOC-000200, Rev G, 29-Mar-2022.
e) MADCAP Requirements, MGSS DOC-001813, Rev G, 29-Feb-2024.

1.4 MADCAP Driving Requirements

a) MADCAP shall perform conjunction assessment analyses routinely for all maneuverable spacecraft operating in shared extraterrestrial orbital environments.

b) MADCAP shall identify potentially high risk orbiter close approaches and communicate any to key stakeholders sufficiently in advance to enable an avoidance response.

c) MADCAP shall maintain (on best efforts basis) estimated locations of non-functioning orbiting spacecraft.

1.5 MADCAP Units of Measure

Unless stipulated otherwise, all units of mass shall be kilograms (kg), all units of distance shall be kilometers (km), all units of time shall be seconds (s), all angular measures shall be degrees (deg).

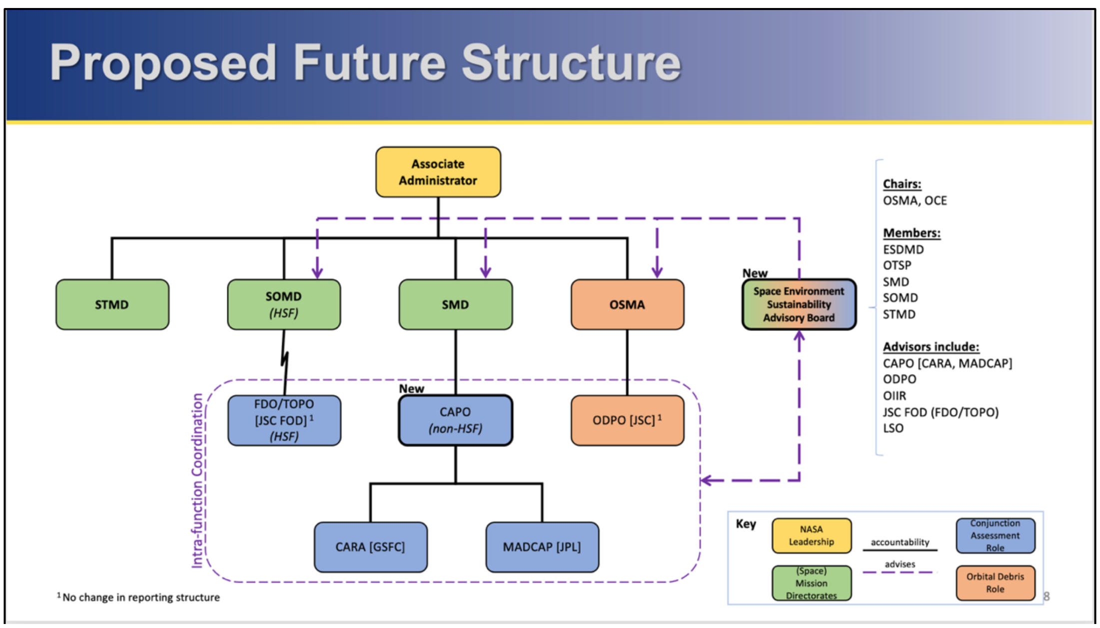
1.6 Terminology

"Red Event": Orbit crossing distance AND orbit crossing timing both below mission defined thresholds within 14 days from run time.

2. INTRODUCTION TO MADCAP AND BRIEF HISTORY

As is well known, there is a significant problem in the Earth orbital environment due to the large space debris population in that environment. There are currently no known debris fields at the Moon and Mars, but the creation of such debris fields would be highly undesirable due to the general infeasibility of tracking such objects from Earth. There are a growing number of missions in extraterrestrial shared orbital environments (i.e., more than one spacecraft in orbit, e.g., Moon, Mars, Sun/Earth L1, Sun/Earth L2, etc.) with many more planned in the coming years (e.g., Venus, Jupiter). The creation of debris fields in these environments would greatly jeopardize future operations in those orbital regimes for both robotic and human missions. Preventing such debris fields is imperative to safely continue spacecraft operations... and that is the fundamental purpose for developing and running MADCAP.

NASA currently expends resources to monitor the Earth's orbital debris environment via its Conjunction Assessment and Risk Analysis (CARA) program located at the Goddard Space Flight Center (GSFC). In 2023, NASA's official Conjunction Assessment Program Office organization was created (see org chart below). Aligned under this organization is the Multimission Automated Deepspace Conjunction Assessment Process (MADCAP), which has been used at the Jet Propulsion Laboratory to perform conjunction assessment at Mars and the Moon since 2011, and Sun/Earth libration points since 2020. See the org chart below... although the title says "Proposed Future", this organization has effectively been implemented circa July/August 2023.



The MADCAP process has been described in several previous conference publications (see "References", particularly [1]). The general process is reviewed there, along with deliverables between the MADCAP Team and the flight project and details of the method for delivery. Specifically, this paper defines procedures and interfaces for data generation and data exchange, the means for performing the MADCAP process by the MADCAP Team at JPL, and data exchanges with the mission designated personnel. Types of data, media formats, physical interfaces, error conditions, timing, security, along with a detailed explanation of how thresholds are used to categorize conjunction events are described. The derivation of these thresholds from orbit uncertainty data delivered by spacecraft navigation teams is described. Covariance processing capabilities and Probability of Collision (P_c) calculations are also covered.

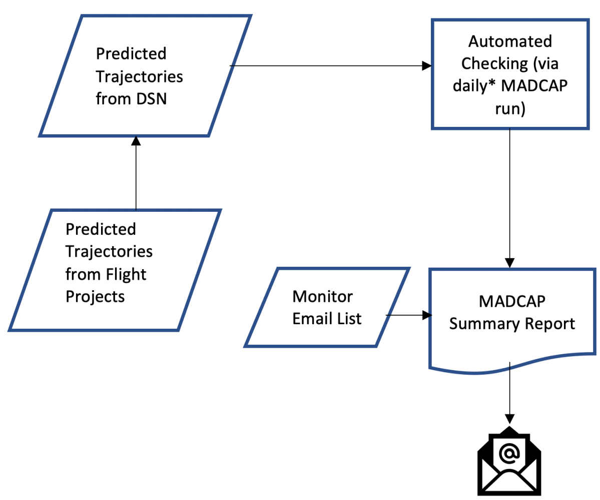
The MADCAP conjunction assessment process routinely monitors extraterrestrial orbiter spacecraft trajectories for future orbit crossings and close approaches, as it exists today. The same process is used for all the shared environments: Mars (since 2011), Lunar (since 2011), and Sun/Earth Lagrange Points (since 2020); to date the only differences are environment specific values specified in a parameter file. MADCAP will be extended to Venus and Jupiter by the mid-2020s through early 2030s given several planned missions destined for these environments.

2.1 MADCAP Process General Overview

Close approaches are analyzed and predicted as follows:

- The mission generates a predictive ephemeris for each spacecraft based on the most recent orbit determination solution as well as any maneuvers planned during the duration of the predict.
- The predictive ephemeris is provided to the MADCAP Team, generally by uploading it to the DSN SPS site at JPL (other options exist).
- MADCAP software identifies conjunctions between objects operating in the orbital environment, based on pairwise comparisons of the ephemerides of objects contained in the catalog.
- Predicted closest approach distance (CAD), orbit crossing distance (OXD) and orbit crossing time (OXT) miss distance, along with other quantitative characteristics for the close encounter, are calculated
- Near term predicted events (within 14 days from run time) are reported in the daily MADCAP Summary Report, along with detailed data tables and plots, delivered to mission representatives by email. If the ephemeris files have been provided with covariance data, MADCAP will calculate a probability of collision.
- When the risk of collision poses a significant threat to the missions, the MADCAP Team consults with the navigation teams to determine and plan action to mitigate, if required.

The most common MADCAP process is the regular orbital environment "monitoring function" screening, depicted below. It is essentially the same for all orbital environments. The frequency of execution is nominally daily. The frequency can be increased/decreased if conditions render it necessary or desirable.



- For step-by-step details of the MADCAP Mars Procedure, see reference [7]. It describes the Monitoring Function, Response Function, and Conflict Resolution Function.
- For step-by-step details of the MADCAP Lunar Procedure and the procedure for Sun/Earth Lagrange Points (S/E L1 and S/E L2), see reference [8]. It describes the Monitoring Function, Response Function, and Conflict Resolution Function. The same process is used for the Moon and Sun/Earth Lagrange point orbital environments.

3. THE "TWO PAGE" MADCAP ICD

Generally Required Documentation Between the Mission and MADCAP: There are 2 documents that are required for NASA missions by NASA NPR 8079.1 (reference 1.3(a) above), the Orbital Collision Avoidance Plan (OCAP) and the Conjunction Assessment Operations Implementation Agreement (CAOIA). The OCAP documents the results of study and analysis tasks and design considerations. Creation of the OCAP is started as early in the mission as possible (Phase A or B); it is baselined at the Preliminary Design Review (PDR). The CAOIA documents specific operational processes the project implements to protect the spacecraft and space environment. It is started in Phase C and is finalized at the Operations Readiness Review (ORR).

Ephemeris Format Compatibility: MADCAP can use either SPICE/SPK (*.bsp) files (normally Type 13 or Type 12, see reference [9]), CCSDS Orbit Ephemeris (OEM) Version 1, or CCSDS OEM Version 2 files with or without covariance (see reference 10). EME2000 reference frame.

Ephemeris Delivery Frequency: Whenever the mission navigation team updates (at least after any significant changes).

Preferred Ephemeris Characteristics: CCSDS OEM Version 2 with covariance matrix, 3-week span, updated at least weekly, provided to the DSN Service Preparation Subsystem/SPS (or a soon to be available Amazon Web Services (AWS) server external to DSN). No ephemeris naming conventions are currently imposed, but this could change in the future.

Ephemeris Delivery (DSN Mission): As part of setting up DSN tracking, spacecraft ephemeris files will be uploaded on a regular schedule to the DSN/SPS. MADCAP automatically queries the SPS for the most recently uploaded Predicts Grade, Baseline SPK file or CCSDS OEM and uses them for conjunction assessment. It is also possible for missions to request screening against a longer term Scheduling grade file in each MADCAP run.

Ephemeris Delivery (Non-DSN Mission): The MADCAP Team is working to setup an AWS ephemeris exchange server for spacecraft not tracked by the DSN. Availability TBD. In rare instances, the DSN may allow missions not tracked by the DSN to upload ephemeris to SPS for use in conjunction assessments.

Ephemeris Delivery (DSN or Non-DSN Missions): It is possible, but much less preferred and much less automated, to email an ephemeris to one of the first two points of contact listed in Table 1.

MADCAP Operations Runs: The MADCAP Team usually begins including a mission's ephemeris in daily runs two to three weeks prior to arrival in the shared environment. This provides advance warning to the missions already operating in that environment that (a) a new spacecraft is arriving, and (b) whether or not there are any concerns that must be addressed immediately.

MADCAP Test Runs: Pre-launch, reference, or other special case trajectories provided to the MADCAP Team can be tested to ensure it is usable by the MADCAP software.

Thresholds: Used to characterize the risk of predicted conjunctions. Three types of threshold categories are used in MADCAP: orbit crossing distance (OXD), orbit crossing timing (OXT), and close approach distance (CAD). The ‘Red’ thresholds correspond to the 3-sigma uncertainties as follows: OXD-radial position uncertainty, OXT-downtrack timing uncertainty. When covariance files are provided, they will be used to calculate these values based on interpolation and mapping of the position covariance matrices which bracket the event in time. Threshold values for both bodies in a pairing are calculated for each event, and the Root Sum Square (RSS) of the two values is then used as the event threshold. In the absence of formal covariance files, ‘Red’ thresholds are based on a quadratic fit of the 3-sigma uncertainty values (as provided by the spacecraft navigation team) as a function of time to the event. The polynomial equations used to calculate ‘Red’ threshold values for bodies without covariance data specified are described as follows:

$$\text{RED OXD Threshold} = 3\sigma_r = OXD0 + OXD1 * t + OXD2 * t^2 \quad \text{[km]} \qquad (1)$$

$$\text{RED OXT Threshold} = 3\sigma_t = OXT0 + OXT1 * t + OXT2 * t^2 \quad \text{[sec]} \qquad (2)$$

$$\text{Where t} = Close\ Approach\ Epoch - Ephemeris\ Submit\ Time\ (in\ days) \qquad (3)$$

See reference [1] for comprehensive details about MADCAP thresholds.

Report Distribution: MADCAP reports are sent after each run, by email. At least one email address must be provided to the MADCAP Team, preferably more. Decision maker(s) in the event of red events should be indicated. For example reports, see reference [1] and reference [3].

Nominal Conjunction Assessment Screening Times: MADCAP currently supports one screening for Moon and Mars daily, and one screening for Sun/Earth L1/L2 weekly. This is subject to change based on the number of missions, rate of changes in the environment, or special events. Each screening will generally use the latest mission ephemeris delivered prior to the ephemeris delivery deadline. MADCAP runs are scheduled in US Pacific time, which means that UTC run times and report delivery times shift by an hour forward or backward when local times change for daylight savings time or standard time.

Table 2: Nominal Screening Times

Full Catalog Screening	Frequency	Nominal Run Start
Lunar Run	Daily	0845 Pacific Time
Mars Run	Daily	1345 Pacific Time
Sun/Earth L1	Weekly	2000 Pacific Time
Sun/Earth L2	Weekly	2100 Pacific Time

MADCAP Body Numbers: Each body in the MADCAP Summary Report is assigned a number. There's nothing particularly special about this "body number". It's just a sequential assignment. It can vary from one report to the next depending on a new spacecraft being added, or an obsolete spacecraft being deleted. A good example is the recent addition of ESA's JUICE spacecraft, which had a lunar flyby 19-Aug-2024. That was added as #7 (Active), pushing CH1 (Inactive) down to #8. The MADCAP Summary Report generally lists Active spacecraft first, followed by Natural satellites (e.g., at Mars), followed by Inactive spacecraft. Spacecraft are added to runs as needed about 2-3 weeks prior to entering the respective orbital environment.

4. REFERENCES

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[12] 8715.6B NASA Procedural Requirements for Limiting Orbital Debris and Evaluating the Meteoroid and Orbital Debris Environments

[13] 8079.1 NASA Procedural Requirements for Spacecraft Conjunction Analysis and Collision Avoidance for Space Environment Protection, June 27, 2023

[14] https://jpl.nasa.gov/cara/madcap

[15] NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook, https://nodis3.gsfc.nasa.gov/OCE_docs/OCE_50.pdf, December 2020.

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5. ACRONYMS

CAD	Close Approach Distance
CARA	Conjunction Assessment Risk Analysis
DSN	Deep Space Network
GSFC	Goddard Space Flight Center
HTML	Hyper Text Markup Language
ICD	Interface Control Document
MADCAP	Multimission Automated Deepspace Conjunction Assessment Process
MONTE	Mission-design and Operations Navigation Toolkit Environment
NASA	National Aeronautics and Space Administration
OD	Orbit Determination
OEM	Orbit Ephemeris Message
OXD	Orbit Crossing Distance
OXT	Orbit Crossing Time
Pc	Probability of Collision
PDF	Portable Document Format
POC	points of contact
SPK	Spacecraft and Planet Kernel
SPS	Service Preparation Subsystem
UTC	Coordinated Universal Time