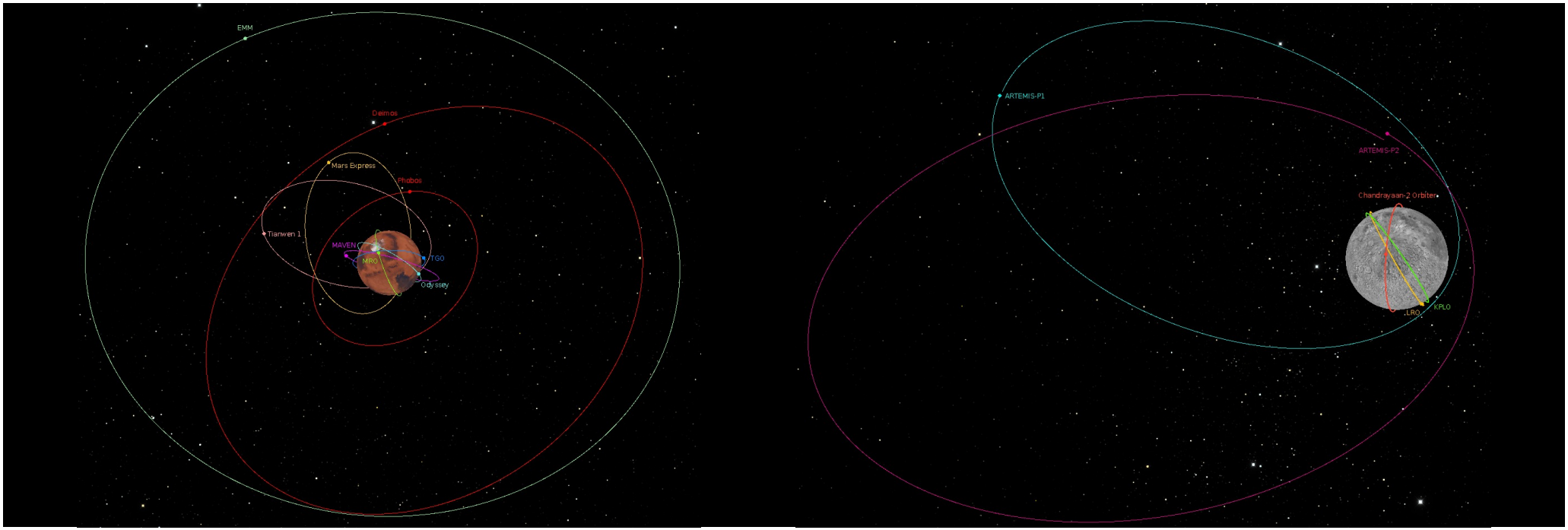

Introduction to MADCAP for New Customers

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Introduction

- It is well known that conjunction assessment (CA) is necessary in the Earth orbiting environment to prevent spacecraft collisions and reduce debris in orbit.
- There is currently no known orbital debris field at the Moon or Mars (other than a handful of inactive spacecraft) since there is no reliable method to realistically track debris from Earth
- The creation of a debris field in these environments would complicate existing and future operations and could take many years to dissipate.
- Due to the lack of passive tracking capability in deep space, keeping these environments safe is reliant on self-reported ephemeris and uncertainty data from mission teams

MADCAP

- The Multimission Automated Deepspace Conjunction Assessment Process (MADCAP) was developed at the NASA Jet Propulsion Laboratory for conjunction assessment use in shared deep space environments, for which ground-based radar tracking is a challenge.

- MADCAP is a component of NASA's Space Sustainability Division.

- MADCAP has been used to screen objects in orbit at Mars (since 2011), the Moon (since 2011), Sun/Earth Libration points L1 (since 03/2020) and L2 (since 01/2022), and in Cislunar space (since 11/2024).

Current MADCAP-Monitored Environments

Mars
- Daily analysis initiated at 13:45 Pacific Time
- Objects within Mars SOI (range to Mars < 600,000km)

Moon
- Daily analysis initiated at 08:45 Pacific Time
- Objects within Moon SOI (range to Moon < 65,000km)

Cislunar
- Weekly analysis initiated at 15:00 Pacific Time every Wednesday
- Objects within “Cislunar zone” (range to Moon > 65,000km AND 45,000km < range to Earth < 500,000km)

Sun-Earth L1
- Weekly analysis initiated at 15:30 Pacific Time every Wednesday
- Objects within “L1 zone” (range to L1 point < 1,000,000km)

Sun-Earth L2
- Weekly analysis initiated at 16:00 Pacific Time every Wednesday
- Objects within “L2 zone” (range to L2 point < 1,000,000km)

New environments are added as soon as they become shared (>1 SC operating)
- Jupiter and Venus expected to be included in the near future

Trajectory & Uncertainty Inputs

- In order to perform conjunction assessment, MADCAP requires the following information for each body in the orbital environment:
  - Trajectory information to find close conjunctions
  - Trajectory uncertainty information (normally computed by the spacecraft's navigation team as part of the orbit determination (OD) process) to evaluate the risk of collision
- At lunar distances and beyond, this information must be obtained from the project's navigation teams.

Sending Trajectory Data to MADCAP

- MADCAP accepts trajectory data in the CCSDS (Consultative Committee for Space Data Systems) OEM (Orbit Ephemeris Message) format [V.2]
- OEM files can be submitted via:
  - Upload to the Deep Space Network (DSN) Service Preparation Subsystem (SPS) Portal
    - The most recently uploaded “Predicts Grade Baseline” file will be used
  - Upload to the “MADCAP Deepspace Ephemeris eXchange” (MDEX), a secure Amazon Web Services (AWS) S3 system
    - The most recently uploaded “Primary” file will be used
    - An additional file may be uploaded as “Secondary” to support burn/no-burn analysis
  - Emailed to the MADCAP team
    - This option should only be used for testing or emergency cases as pre-coordinated with the MADCAP team

Frequency and Span of Ephemeris Deliveries

- Ephemeris files should be updated as frequently as is needed to capture significant changes to the spacecraft trajectory.
  - This cadence will depend on the orbital regime and mission operations of each spacecraft.
  - Highly dynamic orbits with frequent spacecraft activities may need to update as often as daily (or more), while those in more stable environments could be refreshed as infrequently as weekly.
- Accurate and timely MADCAP analysis is dependent on ephemeris files which predict out at least 14 days into the future from the MADCAP run time.
  - The frequency of deliveries and timespan of the predicted trajectory should be sufficient to cover this requirement.
  - For missions updating ephemeris data weekly, the minimum requested predict span would be 21 days.
- For NASA Missions: Details will be established in a Conjunction Assessment Operations Implementation Agreement (CAOIA) Document

When to Start

- MADCAP requests missions begin submitting files at least 14 days before arrival in a shared deep-space environment.
  - For spacecraft launching directly into a deep-space environment with less than 14 days operations, MADCAP requests a pre-launch reference trajectory as well as the first post-launch update available.
- “Planning” or “Test” trajectory files can be sent to MADCAP for testing as early as mission teams have such data available.
  - It is advisable to perform such a pre-operational test delivery to ensure that there are no issues with the process.

Receiving MADCAP Output Reports

- MADCAP sends out a summary report via email after very run.
  - Each mission team must submit a list of email addresses to add to the distribution.
  - This list will also be used to contact the mission team if a Red Event is discovered. A designated point-of-contact (or two) can instead be used for Red Event discussions.
  - A Red Event is a high risk, near-term conjunction event that may require action (defined by an overlap of 3σ uncertainties)
- MADCAP can send out optional ancillary data (tables, plots)
  - This can be sent to a different email list than the summary report if desired.
  - The data consist of a table and/or plot showing close approach event attributes for pairs involving a specified object for the entire timespan overlap of the trajectories available (at most 60 days).

MADCAP Conjunction Risk Categorization

- Probability of Collision (Pc) is used as the main conjunction risk assessment metric in the Earth Environment

- MADCAP will calculate and report Pc when there is uncertainty covariance data available for both objects involved in a close conjunction.

- If covariance data is only available for one object, then a worst-case Pc is calculated and reported.

- No Pc can be calculated if uncertainty covariance information is not available for either body.

MADCAP Conjunction Risk Categorization

- **Problem:** Covariance data has historically not been provided for most spacecraft operating in deep space environments, and MADCAP cannot compute Pc without this data.

- **Resolution:** In the absence of covariance data for aging missions, MADCAP calculates thresholds used to categorize conjunctions as High Risk or “Red” based on three conjunction attributes intended to reflect the typical 3-sigma orbit position uncertainties.
  - See previously published paper* for details on threshold derivations
    - Thresholds are set by the Spacecraft Mission Teams with guidance from the MADCAP Team.
  - New missions are expected to deliver covariance data from which thresholds will be derived and Pc calculated, facilitating more accurate risk categorization.

*Tarzi, Zahi B., Young, Brian T., Berry, David S., “Deriving Event Thresholds and Collision Probability for Automated Conjunction Assessment at Mars and the Moon”, AAS 22-042, 2022 AAS/AIAA Astrodynamics Specialist Conference, Charlotte, NC, August, 2022

Conjunction Risk Mitigation

- When a High Risk or “Red” conjunction is reported, the MADCAP Team will reach out within 24 hours to the missions involved to ensure they are aware of the situation, and gain further knowledge to assess conjunction risk.
- Such information would include estimates of uncertainty (if not provided via covariance data), known upcoming trajectory altering events (maneuver, momentum wheel unload, landing plan), and other operational considerations.
- This data, along with the Pc (if available), will be used by the Mission Teams to come to a decision on any action that may be required to mitigate conjunction risk.
- If Mission Teams cannot come to a conclusion as to necessary action, a "Maneuver Coordination Meeting" will be convened by the MADCAP Team to determine (1) IF anything needs to be done, (2) IF “yes”, who will do it.

Conclusions

- Keeping shared Deep-space environments safe is reliant on self-reported ephemeris and uncertainty data from mission teams
- With accurate trajectories for orbiters regularly available, MADCAP can help avoid creation of hazardous debris fields, thus benefiting all spacefaring entities wishing to explore in these shared orbital environments
- The MADCAP Team strongly believes in the necessity of international cooperation and collaboration in extraterrestrial conjunction assessment, to keep shared orbital environments safe for all space operators
- Please contact the MADCAP Team with any questions

Email: madcap_team@jpl.nasa.gov Website: https://www.nasa.gov/cara/madcap