NASA Human Spaceflight
Conjunction Assessment:
Recent Conjunctions of Interest

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Presentation Overview

• Brief history of NASA Human Spaceflight Conjunction Assessment (CA) activities
• Overview of NASA CA process for ISS and Shuttle
• Recent examples from Human Spaceflight conjunctions
NASA Human Spaceflight Conjunction Assessment (CA) History

1986: Challenger accident

1988: Space Shuttle Return to Flight STS-25 (Discovery); Box method used for CA; later Shuttle adopts Pc method

1991: First Shuttle DAM performed on STS-48 (Discovery)

1992: NASA begins Pc development for ISS CA

1996: NASA begins conjunction assessment of Mir space station

1998: ISS First Element Launch

1999: First ISS DAM attempted and fails; a few months later first ISS DAM successfully executed

1999s – present: NASA works with USSTRATCOM to develop tools, data exchange formats, improve processes for catalog maintenance and CA

Present: NASA continues work with USSTRATCOM to maintain high quality CA for human spaceflight and robotic missions

2005: NASA begins CA for robotic missions
ISS and Shuttle Conjunction
Screening and Notification

Screening Process
- Every 8 hours, JSpOC screens ISS/Shuttle against high accuracy catalog 72 hours into the future
- Depending on miss distances, JSpOC notifies NASA (see Screening Volumes below)
- NASA and JSpOC discuss each conjunction
- If object is a concern
  - JSpOC increases tasking on object
  - JSpOC provides NASA with more frequent updates

Screening Volumes (in Kilometers – U x V x W)
10 x 40 x 40: JSpOC automated notification – refine threat object solution – no NASA notification
2 x 25 x 25: JSpOC notifies NASA of conjunction – shown above
0.75 x 25 x 25: NASA notifies larger ISS team – only for ISS or joint ISS/Shuttle conjunctions
ISS and Shuttle Debris Avoidance Processes

- NASA/MCC-Houston (MCC-H) calculates Probability of Collision (Pc) upon notification and data from JSpOC
- MCC-H uses Pc along with additional conjunction data to make recommendation on Debris Avoidance Maneuver (DAM)
  - ISS
    - Decision is coordinated between ISS International Partners
    - Decision must be made no later than 24 hours prior to conjunction Time of Closest Approach
    - DAM performed with engines on the Russian Segment of ISS – no crew involvement
  - Shuttle
    - Decision can be made closer to Time of Closest Approach
    - Crew must be awake to perform DAM
- Flight Rules in place to determine when DAM should be performed based on Pc
  - Risk of conjunction is weighed against risk of mission safety and success
  - For the Shuttle only, a “box method” downmode is available to make a decision on DAM if Pc is not available
DAM Thresholds

ISS/Shuttle DAM Pc Thresholds

\[ 1 \times 10^{-5} \leq \text{Pc} < 1 \times 10^{-4} \leq \text{Pc} \]

Shuttle-only DAM Box Method Downmode Thresholds

\begin{align*}
\text{Yellow Threshold} & : 1 \text{ Km (U) x 7 Km (V) x 7 Km (W)} \\
\text{Red Threshold} & : 0.5 \text{ Km (U) x 4 Km (V) x 4 Km (W)}
\end{align*}
# ISS Debris Avoidance Maneuver History

<table>
<thead>
<tr>
<th>Date</th>
<th>Debris</th>
<th>Vehicle</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>06/13/99</td>
<td>SL-3 Rocket Body</td>
<td>FGB</td>
<td>Maneuver Execution FAILED. Two Red Pc violations early in event based on bad data</td>
</tr>
<tr>
<td>10/26/99</td>
<td>Pegasus Rocket Body</td>
<td>FGB</td>
<td>First successful ISS DAM and only DAM performed by FGB.</td>
</tr>
<tr>
<td>09/29/00</td>
<td>SL-3 Rocket Body</td>
<td>Progress</td>
<td>Yellow Pc threshold violation</td>
</tr>
<tr>
<td>02/10/01</td>
<td>Unknown Debris</td>
<td>STS-98</td>
<td>Shuttle Box method used</td>
</tr>
<tr>
<td>12/15/01</td>
<td>SL-8 Rocket Body</td>
<td>STS-108</td>
<td>Shuttle Pc method used</td>
</tr>
<tr>
<td>05/15/02</td>
<td>SL-8 Rocket Body</td>
<td>Progress</td>
<td>Red Pc threshold violation</td>
</tr>
<tr>
<td>05/30/03</td>
<td>MEGSAT</td>
<td>Progress</td>
<td>Red Pc threshold violation</td>
</tr>
<tr>
<td>08/27/08</td>
<td>COSMOS 2421 Debris</td>
<td>ATV-1</td>
<td>Maneuver Execution FAILED. Largest Pc calculated to date</td>
</tr>
<tr>
<td>08/27/08</td>
<td>COSMOS 2421 Debris</td>
<td>ATV-1</td>
<td>Red Pc threshold violations on consecutive orbits (~50)</td>
</tr>
<tr>
<td>03/22/09</td>
<td>CZ-4 Debris</td>
<td>STS-119</td>
<td>Conjunction orbits were during an EVA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Retrograde DAM was executed early by having orbiter hold attitude</td>
</tr>
<tr>
<td>07/18/09</td>
<td>Unknown Debris</td>
<td>STS-127</td>
<td>Conjunction occurred 15 hours after STS-127 docking during crew sleep.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Red Pc threshold violation post-docking</td>
</tr>
</tbody>
</table>

More than 700 ISS conjunction notifications to NASA
10 Debris Avoidance Maneuvers Attempted
  5 performed by ISS
  1 attempted by ISS, but failed (ISS first attempt)
  4 performed by Shuttle during mated operations

Annual Maneuver Rate (theory suggests ~1.2 maneuvers/year)
  ~0.9 Maneuvers/year (including failed DAM)
  ~0.8 Maneuvers/year (not including failed DAM)
Shuttle Debris Avoidance Maneuver
History from 3 Shuttle Flights

<table>
<thead>
<tr>
<th>Date</th>
<th>Debris</th>
<th>Flight</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>08/11/07</td>
<td>Delta Rocket Body</td>
<td>STS-118</td>
<td>No maneuver for very close conjunction</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Notification too late (18 minutes prior to time of conjunction)</td>
</tr>
<tr>
<td>03/11/08</td>
<td>USA-193 Debris</td>
<td>STS-123</td>
<td>Existing burn modified, used box method</td>
</tr>
<tr>
<td>03/25/08</td>
<td>Breeze-M Debris</td>
<td>STS-123</td>
<td>Existing burn modified, although no Pc violation</td>
</tr>
<tr>
<td>11/28/08</td>
<td>Cosmos 2421 Debris</td>
<td>STS-126</td>
<td>Separation burn delayed several hours to avoid Yellow Pc violation</td>
</tr>
</tbody>
</table>

- Typically Shuttle modifies existing burns for Debris Avoidance rather than adding a burn for a high risk conjunction
- On average, approximately 5-10 conjunction notifications are received during Shuttle mission
  - Of those, usually 1-2 at most are serious enough to require a modification to a burn
Recent ISS/Shuttle Conjunction Examples
August 27, 2008: COSMOS 2421 debris

- Notable for: First ISS DAM attempted in 5 years, Retrograde DAM
- Retrograde DAM – performing a posigrade DAM would violate Soyuz launch and landing constraints, as well as Shuttle rendezvous altitude constraints
- DAM Clearing Assessment was very difficult due to multiple conjunctions in the vicinity if the DAM was performed
  - Eventually found a 1.0 m/s option that was technically clear with respect to Flight Rules (no post-burn conjunction within 48 hours of a maneuver)
  - The DAM option chosen with the best prospects still had one object (different piece of Cosmos 2421 debris) that could be a potential problem 3 days into the future
- New COSMOS 2421 Debris
  - DAM was nominal for original debris which resulted in a predicted conjunction with another piece of Cosmos 2421 debris 3 days later
  - DAM planning to avoid the 2nd piece of debris began soon after the previous DAM executed
  - Ultimately, the Pc dropped below the yellow threshold and DAM was not performed
March 12, 2009: PAM-D debris

- Notable for: Late notification, crew placed in Soyuz
- Complicating factors
  - High eccentricity
  - High radial velocity
  - Extremely high drag
  - Low inclination
  - Small radar cross section
  - Space weather prediction of geomagnetic spike did not occur as expected
- Notification from JSpOC
  - TOPO notified at TCA-42 hours that a piece of PAM-D debris would enter 2x25x25 km box
    - Usual screening horizon is 72 hours
  - At TCA-19 hours, prediction entered 0.75 x 25 x 25 km box
    - At this point, TOPO informed Russians and ISS Flight Control Team
    - ISS DAM template kick off process NLT TCA-28.5 hours
March 23, 2009: CZ-4 debris

- Notable for: Retrograde mated DAM during STS-119
  - MCC-H had been monitoring this repeating conjunction as a “no threat” item
    • Object had similar orbital period to the ISS/STS stack, so there were TCAs on multiple consecutive orbits
  - ISS/STS stack had a Loss of Attitude Control at ~TCA-48 hours, which pushed the radial miss distances much closer (within the 0.75 x 25 x 25 km box)
  - Probability of Collision calculations showed multiple red threshold violations
  - TCAs would occur during the next spacewalk
  - The posigrade delta-V needed to be safe would violate the rendezvous conditions necessary for the upcoming Soyuz – a small retrograde maneuver was planned
    • DAM was unique in that it was performed using the Shuttle to hold attitude control such that an overall retrograde trajectory perturbation was accomplished
- Due to the retrograde DAM, this object ultimately showed up as a repeating conjunction again in the week following STS-119 undocking.
  - No PC threshold violations occurred and no action was necessary
April 9, 2009:
Fengyun 1C debris

• Notable for: DAM planning initiated on account of post-Soyuz undocking trajectory
• Complicating factors:
  – Pre-undock trajectory indicated no DAM planning would be required
  – Soyuz undocking at TCA-30 hours moved ISS to <1 km total miss from Fengyun at TCA (though larger radial miss)
  – Since collision probability requires JSpOC ISS covariance, MCC-H had to wait for several USSTRATCOM tracks
    • Immediate ISS GPS vector from indicated a likely low-Pc
    • DAM cancelled 4 hours later, as expected, following post-undock ISS tracking
• The object was relatively easy to track and predict

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281-244-6487
May 16, 2010: Unknown Debris

- Notable for: TCA occurred ~1 hour after STS-132 docking
- NASA notified 72 hours prior to TCA
  - Approximately 24 hours prior to STS-132 launch
- Docking perturbations would invalidate the Pc method
- Not enough time post-docking to track the mated stack to get an accurate prediction
- Trajectory teams discussed the option of having ISS perform a stand-alone DAM the evening prior to docking. However, this would require ISS to make a decision to perform a DAM without official Pc.
- Trajectory teams discussed the possibility of having the Orbiter delay docking to ensure a good PC
- After NASA analysis, teams became comfortable that the perturbations from docking activities would not be large enough to statistically affect the overall risk
Questions?