NASA Human Spaceflight Conjunction Assessment: Recent Conjunctions of Interest
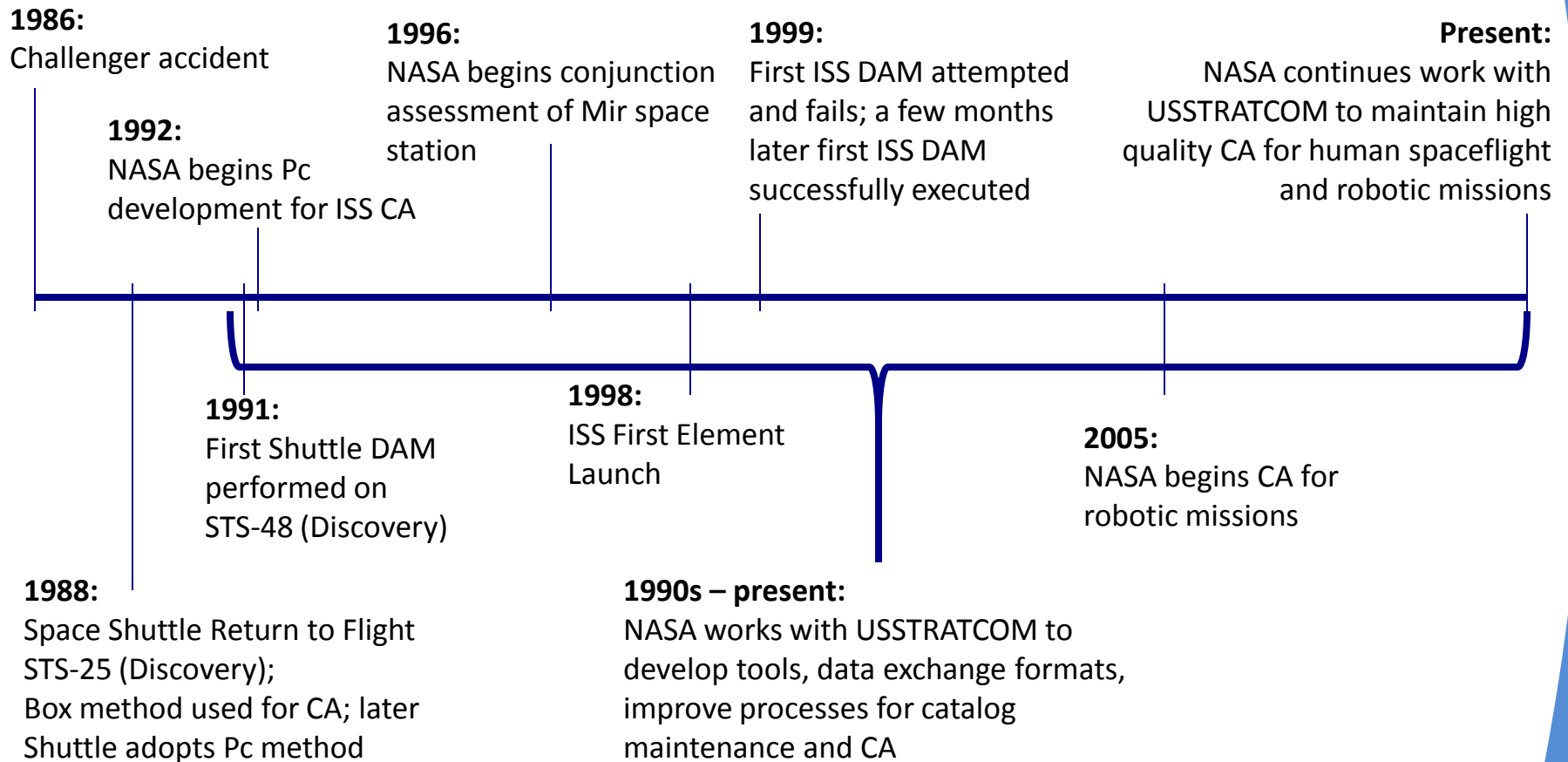
NASA/JSC – Ansley C. Browns

NASA-Dept of Defense Human Spaceflight
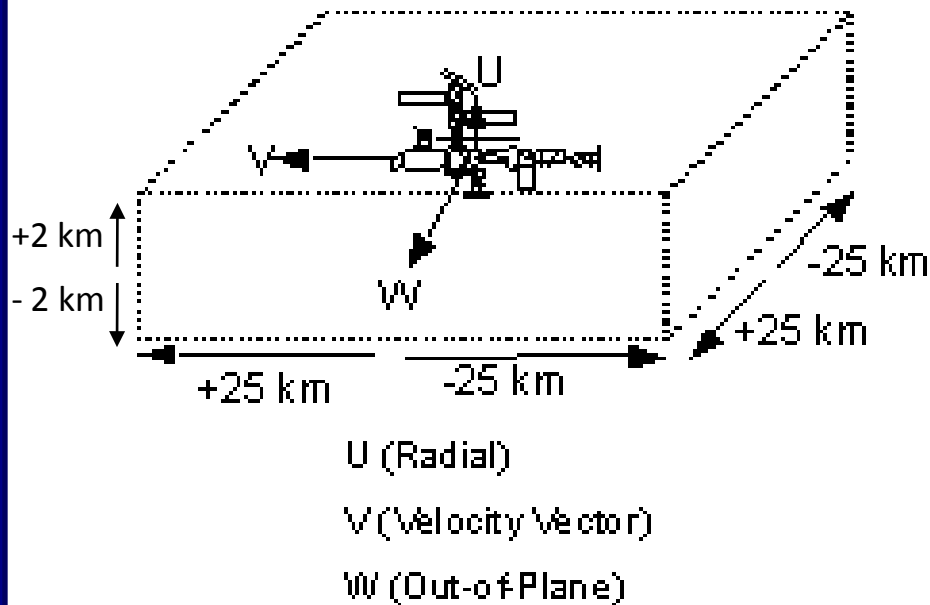
Interface Working Group Chair

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

1992:
NASA begins Pc development for ISS CA

1996:
NASA begins conjunction assessment of Mir space station

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

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

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

1998:
ISS First Element Launch

2005:
NASA begins CA for robotic missions

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

1990s – present:
NASA works with USSTRATCOM to develop tools, data exchange formats, improve processes for catalog maintenance and CA

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ISS and Shuttle Conjunction Screening and Notification

+2 km
- 2 km

-25 km
+25 km
+25 km
-25 km

U (Radial)

V (Velocity Vector)

W (Out-of Plane)

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

Pc $1E\text{-}05 \leq$ **Pc** $< 1E\text{-}04 \leq$ **Pc**

Shuttle-only DAM Box Method Downmode Thresholds

Yellow Threshold

1 Km (U) x 7 Km (V) x 7 Km (W)

Red Threshold

0.5 Km (U) x 4 Km (V) x 4 Km (W)

ISS Debris Avoidance Maneuver History

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

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

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

- 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

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?