International Space Station (ISS) Orbital Debris Collision Avoidance Process

*Presented by:*
James S. Cooney
IMOC II

October 2016
Program Description

• Risk of orbital debris
• History of NASA orbital debris collision avoidance process prior to the ISS
• Current NASA orbital debris collision avoidance process for ISS
Business Problem – Risk of Orbital Debris

- Orbital debris presents one of the highest risks to the ISS
  - ISS is one of approximately 23,000 objects currently tracked by the Space Surveillance Network (SSN)
    - New objects enter the catalog (launches, debris generating events, deploys)
    - Old objects leave the catalog (directed deorbit, natural decay)
  - Debris has been collecting since the early space age
  - Oldest satellite in the catalog is over 60 years old
  - Collision between one of these objects and the ISS could be catastrophic
  - The joint American and Russian flight control teams have been prepared to maneuver the ISS out of the way should the threat of a collision trigger a certain threshold since the launch of the first ISS module
Technology Solution – Early DAM Process Pre ISS

- Pre-Challenger - little thought given to orbital debris
- Post-Challenger - refocused attention on flight safety
- A process was created to limit risk to Space Shuttles from orbital debris
- A box, centered on the Shuttle was defined, such that predicted violations by a cataloged object could result in a maneuver
  - Maneuvers not likely
    - low catalog count, Shuttle maneuverability, short duration missions
  - No maneuvers and few notifications prior to ISS related missions
• ISS’s long duration, continuous space operations demanded more focus on debris
• The Shuttle “shoebox” method was found to be inappropriate
  – Inconsistent with potential ISS and debris position uncertainties
  – Statistically inefficient: too many false positives and/or negatives
  – Predicted high debris avoidance maneuver rate
  – ISS limited maneuverability
• A strict probability based method was investigated
  – Maneuvers based on risk of collision only
  – Screening volume and maneuver thresholds efficiently chosen to maximize protection while minimizing maneuver rate
  – But ... requires trajectory position uncertainties for debris and ISS
  – ISS need for high quality state uncertainty information drove joint NASA/USAF Space Command improvements now used by many US Government missions as well as a host of current commercial and foreign satellite owner/operators
Technology Solution – Current ISS DAM Process

• Propulsion Capability
  – All core propulsive capability is performed by the Russian segment controlled by Mission Control Center – Moscow (MCC-M)

• DAM ΔV
  – Typically ≤1m/s

• DAM propulsion source options
  – Progress resupply vehicle
  – Service Module (SM)

• DAM attitude
  – Dedicated attitude maneuver
  – Torque Equilibrium Attitude (TEA)
Technology Solution – Current ISS DAM Process

• Identify Risk
  – Personnel at the Joint Space Operations Center (JSpOC), located at Vandenberg Air Force Base, maintains a catalog of objects in orbit based on radar tracking
  – Screens the ISS trajectory against all other objects in the catalog three times per day
  – Notifies the ISS Trajectory Operations and Planning Officer (TOPO) if anything is predicted to pass within a \( \pm 2 \) km (local vertical) \( \times 25 \) km \( \times 25 \) km (local horizontal) volume within the next 72 hours
  – TOPO uses data from JSpOC to compute the probability of collision \( (P_c) \)
  – Based on a set of criteria, TOPO notifies flight control teams in Houston and Moscow of the potential collision hazard
    ▪ Time of Closest Approach (TCA) \( \leq 48 \) hours
    ▪ Local vertical miss \( \leq 0.5 \) km or \( P_c \geq 1E-06 \) (1 in 1,000,000)
Technology Solution – Current ISS DAM Process

- When do you need to start DAM planning?
- How long can you wait before required to make the Go/No-Go decision?
- Hurricane Ike example below (September 2008)

Hurricane Ike
September 12, 2008
1 AM CDT Friday
NWS TPC/Direct Hurricane Center
Intermediate Advisory A

Max Sustained Wind: 100 mph
Current Movement WNW at 12 mph
Current Center Location: 28.4 W, 84.4 N

Landfall - 48 hours

Landfall - 24 hours

Landfall - 5 hours
Technology Solution – Current ISS DAM Process

• Maneuver Decision
  – TOPO continues to refine $P_c$ as new tracking information arrives on both ISS and threat object
  – TOPO monitors trends in orbit determination, covariance behavior, miss distance, and $P_c$
  – Flight Rules govern when a DAM should be performed to minimize risk of collision
    ▪ $P_c$ threshold to maneuver depends on ISS activities underway or planned in near future
    ▪ Flight Rules dictate the exceptions to perform a DAM
      – Example – inbound crewed Soyuz has launched requires higher $P_c$ to warrant a DAM
  ▪ Action thresholds:
    – **Black** $P_c \geq 1.0 \times 10^{-2}$ (1 in 100)
    – **Red** $P_c \geq 1.0 \times 10^{-4}$ (1 in 10,000)
    – **Yellow** $P_c \geq 1.0 \times 10^{-5}$ (1 in 100,000)
    – **Green** $P_c < 1.0 \times 10^{-5}$ (no action taken)
Technology Solution – Current ISS DAM Process

- Maneuver Execution – Legacy Debris Avoidance Maneuver (DAM)
  - Dedicated command script (cyclogram) built by Moscow flight controllers uplinked to ISS
  - Pros:
    - Custom ΔV within vehicle capability – useful if eliminating near-term planned reboost
    - ISS can maneuver from any attitude to the DAM attitude LVLH YPR 0,0,0 or 180,0,0 deg
  - Cons:
    - Requires approximately 24-hours notice due to requirements to run on dedicated test stand
      - Late-notice conjunctions with high risk
        - Crew must shelter-in-place inside Soyuz
      - Risk of debris not always known well at 24-hour decision point
        - Unused work - DAM planning which is ultimately canceled once risk decreased below action thresholds
Technology Solution – Current ISS DAM Process

- Maneuver Execution – Pre-determined Debris Avoidance Maneuver (PDAM)
  - New operation late 2012 and primary method for ISS DAM
  - Pre-canned cyclogram executed by MCC-M or the crew 1 hour before the PDAM ignition
  - Normally, ignition occurs ~2 hr 20 min prior to closest approach
  - ΔV options (expanded from original 0.5 m/s only option)
    - 0.3, 0.5, 0.7, 1.0 m/s using aft engines (Progress, Service Module)
    - 0.3, 0.5 m/s using Progress docked to DC1-nadir port
  - PDAM can be performed from either LVLH YPR 0,0,0 or 180,0,0 deg attitude
  - Pros
    - Decision point to perform maneuver as late as 5 hr 20 min prior to closest approach
      - Long pole is getting ISS US systems configured for reboost (appendages in position and power down, if required)
      - Reduced unused work
      - Reduced chance of ISS crew needing to shelter-in-place for high-risk conjunctions
  - Cons
    - ΔV limited to discrete options
    - ISS must be near LVLH YPR 0,0,0 or 180,0,0 attitude for PDAM cyclogram to initiate
Future Roadmap

• PDAM Enhancements in work
  – Later PDAM options
    ▪ Houston and Moscow flight control team personnel working together to allow PDAM to occur NLT 30 minutes prior to closest approach
    ▪ Allows planning process to start NLT 3hr 30 min prior to closest approach
  – ISS maneuvers from any attitude to preferred PDAM attitude
    ▪ Currently, ISS must be near either the LVLH YPR 0,0,0 deg or 180,0,0 deg attitude to initiate PDAM
    ▪ ISS may not be near either option for PDAM initiation
    ▪ Best PDAM attitude may the option opposite of current operations
      – Example - retrograde PDAM may be preferable in some circumstances
James S. Cooney (Jim)
Email: jscooney@sgt-inc.com or james.s.cooney@nasa.gov
Phone: (281)-483-2102