International Space Station (ISS) Orbital Debris Collision Avoidance Process

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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 ±2 km (local vertical) x 25 km x 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) ≤ 48 hours
    - Local vertical miss ≤ 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 11, 2008
- 1 AM CDT Thursday
- NWS TPC/National Hurricane Center
- Intermediate Advisory Area
- Current Center Location: 25.4 N 80.2 W
- Max Sustained Wind: 100 mph
- Current Movement: WNW at 9 mph

**Hurricane Watch**
- Forecast Center Positions
- Hurricane Warning
- Potential Day 1/3 Track Area
- Tropical Storm Warning

**Landfall**
- 7 PM Thu
- 1 AM Thu
- 7 PM Sat
- 2 PM Sun
- 1 AM Fri
- 7 PM Fri
- 2 PM Sat
- 1 AM Sun
- 8 PM Sun

**Landfall**
- 48 hours
- 24 hours
- 5 hours

**Hurricane Ike**
- September 12, 2008
- 8 PM CDT Friday
- NWS TPC/National Hurricane Center
- Intermediate Advisory Area
- Current Center Location: 23.8 N 86.3 W
- Max Sustained Wind: 100 mph
- Current Movement: WNW at 15 mph
- Forecast Center Positions
- Hurricane Warning
- Potential Day 1/3 Track Area
- Tropical Storm Warning
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
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