Human Spaceflight Trajectory Operations: A case study from STS-132/ULF4

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Overview

- ISS and Space Shuttle Trajectory Operations
- The challenge: A post-docking conjunction
- Space Shuttle rendezvous profile
- The solution as flown for STS-132
- Best practices and lessons learned
Both ISS and Space Shuttle have their own Mission Control teams responsible for the operations of their vehicles.

Space Shuttle Flight Dynamics Officer ("FDO")
- Responsible for the trajectory of the Space Shuttle including:
  - Orbit determination
  - Ephemeris modelling
  - Maneuver targeting (orbit insertion, rendezvous, and deorbit)
  - Contingency planning
  - Conjunction evaluation
- Supported by a team of navigators and trajectory phase specialists

ISS Trajectory Operations and Planning Officer ("TOPO")
- Responsible for the trajectory of the ISS including:
  - Orbit determination
  - Ephemeris modelling
  - Maneuver planning (reboost)
  - Conjunction evaluation
  - Contingency planning
Conjunction Operations

• Both TOPO and FDO work with the Department of Defense (DoD) Joint Space Operations Center (JSpOC) to identify potential conjunctions between the ISS or Shuttle and space debris

• Process:
  – The trajectory (actual and predicted) for the Shuttle is provided to the DoD
    • The DoD uses their own tracking of the ISS
  – If an object is within a certain distance of the Shuttle or ISS, the DoD notifies the FDO/TOPO and provides data for the object
  – The FDO/TOPO will determine the risk of collision with the object
    • Risk can be dependent on uncertainty of the future trajectory due to perturbations and maneuvers planned
  – If the risk exceeds a certain threshold ("red" or "yellow"), a collision avoidance maneuver will be considered
    • If risk is below that threshold ("green"), no action will be taken
The Challenge: A conjunction with the ISS

• STS-132 Launch Minus 1 Day
  – The TOPO receives notification of a space debris conjunction with the ISS
  – The Time of Closest Approach (TCA) is ~1 hr after planned Space Shuttle docking
  – Early calculations show this conjunction is potentially “red” or “yellow”
    • The ISS may need to maneuver to keep a safe distance
    • The Space Shuttle launch is targeted based on rendezvousing with ISS in a predicted position
    • If the ISS does not maneuver, the Space Shuttle is also at risk since it will be docked to the ISS at the TCA
    • With 3 days to the TCA, lots of uncertainty
• Question: Does the Shuttle launch window or rendezvous plan need to be altered to accommodate a potential ISS collision avoidance maneuver?
• Operational challenge:
  – TOPO team needs to determine magnitude of maneuver that will create safe separation from debris (involves coordination with Russian trajectory team)
  – FDO team needs to determine if ISS maneuver impacts the rendezvous plan and advise on timeline issues
Space Shuttle / ISS Rendezvous Profile

• Phase angle
  • Defined as the angle between shuttle and ISS at orbit insertion
  • “Long Phase Angle” – The angle is large and the shuttle has to stay in a lower orbit than the ISS in the days before rendezvous in order to catch up.
  • “Short Phase Angle” – The angle is small and the shuttle is at nearly the ISS altitude in the days before rendezvous
  • Phase angle is launch day and time dependent

• Pre-Day of Rendezvous Ground Targeted Burns
  • NC-# - Phasing Burns - Performed in the morning and evening of crew day. These burns are targeted to place NC-4 at 40 nmi behind the ISS

• Day of Rendezvous Ground Targeted Burns
  • NH – Height Adjust – Only required on Long Phase Angle days to raise the orbit to just below ISS altitude
  • NC-4 – Phasing Burn #4 – Last ground targeted burn before the use of relative navigation sensors. Targets a Terminal Initiation (Ti) burn at 8 nmi behind the ISS
Space Shuttle / ISS Stable Orbit Rendezvous

TARGET-CENTERED RELATIVE MOTION -- ISS FD3 RENDEZVOUS

TGT ORBIT = 201 x 211 NMI
DI ALT = 174 NMI
STS-132 / ULF4 Rendezvous

• Long phase angle with a large Day of Rendezvous NH
• NC-3 on Flight Day 2 was the last opportunity to set up phasing rate to arrive NC-4 at 40 nmi behind ISS
  • Normally the ISS decision point for a go/no go for a collision avoidance maneuver would have occurred after NC-3. Coordination between the two teams moved the decision point to prior to NC-3
  • This allows two different NC-3 burn plans for two different ISS positions depending on go/no go for collision avoidance maneuver
  • Day of Rendezvous NH also gives you flexibility to adjust phasing.
    • In this case, even if NC-3 had been adjusted for one option, and decision changed, NH could have been altered
STS-132/ULF4 Rendezvous: “What If”

• What if it had been a short phase angle launch day?
  • No NH means Day of Rendezvous set up entirely by NC-3
  • Small perturbations in the ISS trajectory or Shuttle trajectory after NC-3 can result in ~20 nmi in dispersion of NC-4 position
    • A large perturbation like a collision avoidance burn could make an even larger difference resulting in significant extra propellant use or even delayed rendezvous
  • May not have been enough to make the decision prior to NC-3, but it may have been necessary to perform the burn and get post-burn tracking on the ISS before targeting NC-3
• Conclusion: Earlier decision points are required if you have a less flexible rendezvous plan
  • Could even require re-targeting launch time
Lessons Learned and Best Practices

- Team coordination
  - ISS/TOPO team is able to send burn plan and post-burn ISS state to Shuttle/FDO team using a common tool set that allows easy evaluation
  - Neither team could work to an independent timeline because they were tied to the other team’s decision points
  - “Two cooks in the kitchen” – since the conjunction was after docking, it was a potential risk to both vehicles, so both teams had to agree on a criteria for assessing risk, even though only one vehicle had to maneuver

- Strengths of Shuttle rendezvous profile
  - Burn targets need only be provided 30 minutes prior to a maneuver
    - This allows real time teams to continuously evaluate changes to the plan until the last minute
  - Long phase angle rendezvous profiles have NH
    - This allows team to adjust day of rendezvous profile as late as possible after all other trajectory events are complete

- What happened?
  - Updated tracking on Flight Day 2 showed a reduced threat from the object and just before NC-3 the team decided to call off the ISS collision avoidance burn
Questions
Bibliography

*Flight Dynamics Officer Console Handbook Volume 3 (Rev A, PCN 9-3) (2010)*
 NASA Johnson Space Center


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