

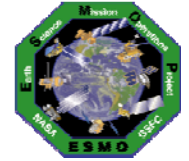
Constellation Mission Operation Working Group

ESMO Maneuver Planning Process Review

Prepared by: Eric Moyer
Eric.M.Moyer@nasa.gov



Review Board Charter



The Earth Science Mission Operation (ESMO) Project created an Independent Review Board to review our Conjunction Risk evaluation process and Maneuver Planning Process to identify improvements that:

1. Safely manages mission conjunction risks
2. Maintains ground track science requirements
3. Minimizes overall hours expended on High Interest Events (HIE)

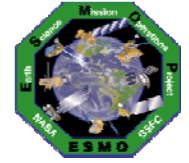
The Review Board is evaluating the current maneuver process which requires support by multiple groups:

- Flight Dynamics Facility (FDF) – provides inputs to FDS
- Flight Dynamics Systems (FDS)
- Flight Operations Team (FOT)
- Conjunction Assessment Risk Analysis (CARA)
- Joint Space Operations Center (JSpOC)
- ESMO Management

In the past year, there have been several changes to the processes although many prior and new concerns exist



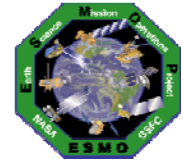
Goals



- Identify additional Limitations/Challenges and provide Recommendations in the areas of Operations, Orbit Maneuver Planning and Screening/Evaluating Conjunction Risks
- Safely reduce Risk Mitigation Maneuver planning timeline
- Conduct Maneuver Process Review bi-annually:
 - Ensure ESMO is continuing to improve our maneuver processes reducing risks and level of support required for each High Interest Event
 - Capture and share lessons learned
 - Identify weaknesses and areas to focus possible process improvements (prioritize)



ESMO Maneuver Process Review - Meetings



Meeting 1 (January 17, 2014, 1-3pm, Bldg 32 Rm E103/109):

- Introduction
- Maneuver Timeline
- CARA/JSpOC Maneuver Planning
- Recent Changes and Improvements

Meeting 2 (March 20, 2014, 1-3pm EDT, Bldg 16W, Rm 76/80):

- FDS Maneuver Process
- Aqua and Aura FOT Maneuver Process
- Terra FOT Maneuver Process

Meeting 3 (March 26, 2014, 1-4pm EDT, Bldg 34, Rm W150):

- Explanation of High Accuracy Satellite Drag Model and Space Weather – by Matt Hejduk

Meeting 4 (April 30, 2014, 1-4pm EDT, Bldg 32, Rm E103/109):

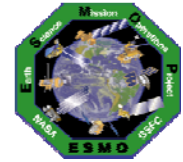
- Case Study #1: Routine Risk Mitigation Maneuver (RMM) Planning
- Case Study #2: Aqua vs Debris 34510
- Case Study #3: Terra vs COSMOS 1174 Debris (12343)

Meeting 5 (June 11, 2014, 3-5pm EDT, Bldg 32, Rm E103/109):

- Provide Request For Action (RFA) Status - Review Previous Action Items
- Capture Recommendations
- Assign Action Items



ESMO Maneuver Process Review Board Comments



Finding:

- Outstanding support by all teams (FDS, FOT, CARA, ESMO) taking a proactive approach to identify inefficiencies in the RMM Process, capturing lessons learned and taking reasonable steps to improve the process
- To the extent possible, reduce uncertainties in modeling predictions to improve Pc accuracy
 - Improvements in Atmospheric Density Modeling predictions
 - Improvements in ephemeris predictions
- Benefit of additional screening per day needs to be assessed
- Eliminate manual processes where possible (i.e. renaming of ephemerides)
- Additional automation of processes, more frequent updates and shorter response times will be necessary

Observations:

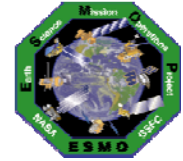
- Increasing number of quick-reaction events (surprises) indicates prediction uncertainty
- Significant resources are applied to HIEs and maneuver planning that at TCA are not actionable
- There is a trade between preparing for a lot of maneuvers and execution vs excepting the risk of collision
- Each ESMO mission has different response to HIE. Standardizing thresholds and processes where possible identifying potential exceptions
- Increase of OSA support was a very good use of resources. Should OSA/CARA be 24x7?
- Ability to quickly plan, schedule and execute a RMM is essential. Screening of maneuver(s) still required
- Software should help optimize selection of maneuver(s) based on multiple conjunctions (repeaters or multiple objects)

Recommendations:

- Formal Process improvement event facilitated by a non-interested party to streamline process (Six Sigma)
- Share lessons learned after critical events and semi-annually
- All future missions should have posigrade and retrograde maneuver capability that can be easily exercised



ESMO Assessment and Path Forward

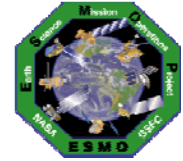


Implement Quick Debris Avoidance Maneuver (QuickDAM) Capability (High Priority)

- Aqua and Aura
 - Implement Ground System Changes to allow for setting the burn duration and time from the Command & Telemetry System
 - Aura Demonstration conducted on February 20, 2015. Approved for use
 - Aqua Demonstration conducted on February 26, 2015. Approved for use
- Terra
 - Developing a Relative Time Command Sequence and Telemetry Monitor that allows for setting the maneuver time
 - Burn Duration is already easy to configure
 - Expect ready for use by end of May 2015
- Benefits for Aqua, Aura and Terra
 - Greatly reduces operation maneuver planning and execution timeline
 - Allows for quicker response to late notice surprises requires only 6 hours to plan and execute a maneuver
 - Allows for planning closer to TCA when data is more accurate for Risk Mitigation Maneuvers
- Potential Risks to planning RMM closer to TCA
 - JSpOC/CARA System and Staffing Resource concern
 - The current timeline for CARA and JSpOC to screen the maneuver and provide results before executing maneuver is approximately 24 hours (many times quicker but no guarantees)
 - ESMO frequently plans multiple maneuver options as many planned maneuvers have post maneuver conjunctions
 - Occasionally, all planned maneuvers had a high risk post maneuver conjunction
 - RMM planning time must have sufficient buffer to perform a re-plan of the RMM
 - JSpOC and CARA Staffing availability may be required during non-normal hours depending on when TCA is and how close to TCA before starting RMM Planning



ESMO Future Plans (2 of 3)



Provide Funding for CARA enhancements

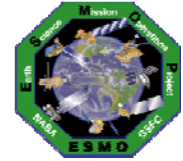
- Fund CARA for one additional OSA to increase support at JSpOC
 - Increases OSA Support coverage from 16 to 18 hours better aligns with GSFC nominal schedule
 - Adds a screening during swing shift which screens each LEO asset with secondary conjunctions identified in previous full catalog screening (1v1)
 - (Still not 24x7)
- Fund CARA for certain enhancements to Reporting and Tools to improve ESMO's ability to quickly evaluate risk and plan Risk Mitigation Maneuvers
 - Enhance Probability of Collision calculation tool to provide P_c uncertainty and sources of uncertainty (miss vector and miss distance, covariance realism, atmospheric drag and space weather, etc.)
 - Enhancements to Maneuver Trade Space Tool – helps for maneuver planning when encountering multiple secondary conjunctions
 - Implement automation where possible, identifying when new track was observed on secondary, improving screening report content and ability to quickly access the detailed analysis
- Fund CARA for increased post maneuver analysis to capture lessons learned

Automate development of Risk Mitigation Maneuver options

- Create RMM options 24-48 hours prior to TCA (with preference during normal business hours) for all conjunctions with $P_c > 1e-5$ (1 in 100,000).
- Incorporate a commercially available product which optimizes maneuver planning based on all conjunctions within the Tasking Volume
- Work with CARA to automate where feasible



ESMO Future Plans (3 of 3)



Create maneuver ephemeris covariance for Terra, Aqua and Aura

- Beneficial in accurately reflecting maneuver uncertainties and post maneuver conjunction risk
- Current post maneuver conjunction risk estimates are based on ASW calculated covariance derived for non-maneuvering satellite

Create ESMO/CARA ICD – due June 30, 2015

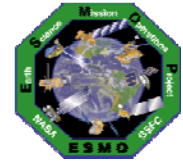
Schedule next ESMO Maneuver Process Review

- Tentatively Scheduled for August 2015
- Allow for implementation and evaluation of the QuickDAM process
- Ensure ESMO is continuing to improve our maneuver processes reducing risks and level of support required for each High Interest Event
- Identify weaknesses and areas to focus possible process improvements
- Review a couple case studies
- Share Lessons Learned



ESMO Maneuver Process Review

ESMO Concerns (1 of 2)



Limited Resources (JSpOC/CARA Staffing and System Access)

- JSpOC system is schedule driven with limited opportunities for CARA to access the data. **Outside ESMO ability to change.**
- OSA Support at JSpOC is not 24x7. Partially mitigated by funding CARA for one additional OSA Support. (ESMO preference is OSA to provide 24x7 support)
- CARA is not 24x7 – CARA does support HIE during off hours and weekends if warranted although does require individuals to be at GSFC (ESMO preference is CARA to provide 24x7 support)
- ESMO and CARA Staffing
 - Partially mitigated by ESMO funded efforts to automate and develop tools
 - Partially mitigated by efforts to reduce number of meeting required to evaluate conjunction risk and determine RMM option(s)
- Only one full screening is conducted per day and couple 1v1 throughout the day. ***For 400km orbit, since greater variability in drag and ability to predict conjunction risk, ESMO desires 3 full screening per day***

Unexpected changes in conjunction miss distances

- High Drag objects have poor predictability especially during Solar Events
- Significant/unexpected changes in conjunction miss distances near Time of Closest Approach (TCA) may make low-risk conjunction high-risk with little to no time to respond
- Risk Mitigation Maneuver Planning is complicated by unexpected changes in conjunction miss distances which could make conjunction risk worse by performing the maneuver
- Risk also exists when mission is quiescently flying (no maneuvers planned)
- Post-maneuver conjunction risk

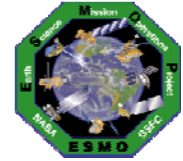
Maintaining Ground Track Requirements when Risk Mitigation Maneuver is warranted

- *Evaluating change to Orbital Maintenance Plan to keep margin for multiple RMM with enough buffer to replan maneuver if have to waive off due to post maneuver conjunctions.*



ESMO Maneuver Process Review

ESMO Concerns (2 of 2)



Ability to quickly respond to unexpected High Interest Events

- *Mitigate via implementation of Quick DAM*

Probability of Collision does not provide uncertainty in calculation

- *Funding CARA to investigate and improve Pc calculation with uncertainty*

Maturity of Space Weather predictions

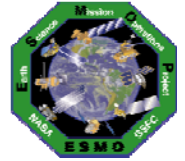
- *Outside Scope of Review*
- Accuracy of Solar Event Arrival Times
- Accuracy of Atmospheric Density Predictions

Preparedness for significant increase in Catalog size

- *Outside Scope of Review - future concern - Mitigate by automating processes where possible*
- Future debris generating events
- New missions, cubesats launched/released near ESMO missions
- Ability to track smaller debris (Space Fence)



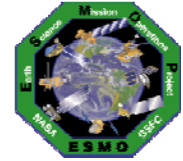
ESMO Maneuver Process Review



Backup Slides



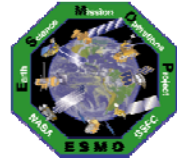
Mission Director Observations



- Why an independent review of the ESMO EOS Maneuver Planning and Screening Process:
 - Recent “surprises”
 - Terra Risk Mitigation Maneuver (RMM) required planning second RMM for same conjunction in March 2013
 - Aqua postponement of planned Inclination Adjust Maneuver in April 2013
 - Aqua short-notice emergency RMM within 36-hours of performing a routine drag make up maneuver in October 2013
 - Second Aqua short-notice emergency RMM in November 2013
 - TRMM short-notice emergency RMM in November 2013
 - Recent “challenges”
 - Aura predicted close approach with an operational Chinese satellite (SJ-11-02) in September 2013



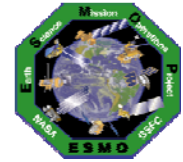
Recent Changes



- Changing Solar Activity (Last 8 years of ESMO Conjunction Assessment experience has been during relatively quiet solar period)
- JSpOC High accuracy satellite drag model (HASDM) update in June 2013 now utilized 6 days prior to Time of Closest Approach (TCA)
- CARA's Maneuver Trade Space charts
 - Improves ability to select burn time and duration to mitigate conjunction risks
- Operations revised planning/scheduling timeline and changes to maneuver
 - Aqua/Aura no-yaw option for Risk Mitigation Maneuvers (RMM)
 - Aqua and Aura require yaw to align thrust in velocity direction
 - Aqua/Aura Variable Burn Duration
 - Ability to perform RMM during back orbit
 - Reduce maneuver planning/notification time
 - Change Maneuver execution procedures



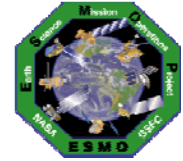
Concerns



- Limited Resources (Staffing and System Access)
- Unexpected changes in conjunction miss distances
 - High Drag objects have poor predictability during Solar Events
 - Significant/unexpected changes in conjunction miss distances near Time of Closest Approach (TCA) may make low-risk conjunction high-risk with little to no time to respond
 - Risk Mitigation Maneuver Planning is complicated by unexpected changes in conjunction miss distances which could make conjunction risk worse by performing the maneuver
 - Risk also exists when mission is quiescently flying (no maneuvers planned)
 - Post-maneuver conjunction risk
- Maintaining Ground Track Requirements when Risk Mitigation Maneuver is warranted
- Ability to quickly respond to unexpected High Interest Events
- Owner/Operator (O/O) Ephemeris vs JSpOC's Astrodynamics Support Workstation (ASW) differences
- Maturity of Space Weather predictions (Outside Scope of Review)
 - Accuracy of Solar Event Arrival Times
 - Accuracy of Atmospheric Density Predictions
- Preparedness for significant increase in Catalog size (Outside Scope of Review - future concern)
 - Future debris generating events
 - New missions, cubesats launched/released near ESMO missions
 - Ability to track smaller debris (Space Fence)



Case Studies



- For each of the Case Studies, the Board members are requested to:
 - Review sequence of events
 - Verify corrective actions and process improvements already identified are appropriate
 - Provide any additional corrective actions and process improvements
 - Recommend any additional corrective actions and process improvements
- Case Studies:
 - Case Study #1: Terra vs Object 09040
Routine Risk Mitigation Maneuver (RMM) Planning Example
 - Case Study #2: Aqua vs Object 34510
The routine Aqua Delta-V Maneuver performed on October 23, 2013 resulted in an unexpected High Interest Event (HIE) 36 hours post maneuver requiring an emergency RMM
 - Case Study #3: Terra vs Object 12343
Executed RMM on March 24, 2013 which failed to mitigate Conjunction, required planning 2nd RMM for same Conjunction