



External Impact Effects on Operational Availability ESMO Experience

Maintenance, Availability and Maintainability Workshop

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Question: "How do you currently forecast Operational Availability in relation to Avoidance Maneuvers?"

Unaware of any OA Requirement for NASA's Earth Observing System (EOS) Missions – Terra, Aqua and Aura

- All three missions have Data Capture/Latency Requirements
 - Flight Operations Team (FOT) Goal: Capture all the data all the time
 - Typical Internal impacts to data capture include:
 - Spacecraft Maneuvers and Instrument Calibration Activities
 - Spacecraft Hardware Anomalies and Failures
 - Operator Errors
- Unexpected External impacts to data capture
 - Communications Problems (Ground Network and Space Network)
 - Communication Network Outages
- Big Internal/External Impact Control Center Failure



EOS Aqua Data Capture

(Life of the mission)





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EOS Aqua Fuel Usage

(Life of the mission)







EOS FOT Operations Errors

(18-Months: March 2018 – August 2019)







EOS/ESC Background



NASA's Earth Observing System (EOS)





As of 6/26/2019	Terra	Aqua	Aura
Launch Date	12/18/1999	5/4/2002	7/15/2004
Current Orbit #	103,832	91,193	79,499
Duration	19y 6m 8d	17y 1m 23d	14y 11m 12d
HIEs	176	226	241
DAMs	16	11	10

Combined 51+ years of orbital debris collision-free safe operations

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EOS Mission Orbit Constraints

(16-day, 233-orbit Repeat Cycle)



Source: EOS Flight Dynamics, 2016



- Flying at 705km sun-synchronous orbit provides the benefit of repeating the same exact ground track every 16 days
- Both the <u>Altitude</u> and <u>Mean Local Time (MLT)/Inclination</u> have to be controlled to achieve this benefit



Spacecraft Design/Constraints



- EOS Missions fly in repeat ground track orbits at 705km
- Spacecraft designed to perform Drag Make-Up (DMU) and Inclination Adjust Maneuvers (IAMs)
 - Retrograde capability not part of nominal maneuver set
- Drag Make-Up Maneuvers therefore used as Debris Avoidance Maneuver (DAM) to mitigate collision risk
 - Raise altitude (can only go up, one direction)
- Differences in DMU & DAM concepts are significant

	DMU	DAM	
Purpose	Maintain Orbit Altitude	Avoid Debris	
Notification Time	Several Weeks	Few Days or Less	
Operations Mentality	Routine, Methodical	Urgent, Quick Turnaround	
Contingency Action	Reschedule	Health & Safety Concern	
Burn Duration	Well Defined	Variable	
Burn Options	One	Multiple	
Execution Time	Day Shift Only, M-F	Anytime, Any Day	



International Earth Science Constellations





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EOS Mission Orbit Constraints

(Afternoon Constellation (aka "A-Train") view)



- EOS Missions fly in 705 km, polar sun-synchronous orbits at 98.2° Inclination with 16-day, 233-revolutions repeat cycle
- Mission Science goals dictate orbital maintenance requirements including ground track error (GTE) and mean local time (MLT) of the node crossings
- EOS Missions fly in constellations, therefore must fly inside their control box (orbital safety & science)



*CALIPSO and CloudSat will pass underneath the A-Train every ~20 days



Operational Collision Avoidance External Influences





Source: ESA via https://www.youtube.com/watch?v=zT7typHkpVg

Maneuvers are required to avoid catastrophic losses but they cost operational time.



One way to address the challenge



Source: US Air Force Television Commercial Link





EOS Debris Avoidance Maneuver (DAM) Statistics



EOS Debris Avoidance Maneuvers

(2005 - 2019-05-31)



	Terra	Aqua	Aura	Total	Postponed and/or
Year	25994	27424	28376	DAMs	Replanned
2005	1	0	0	1	0
2006	0 (1)	0	0	0	1
2007	1	0	0	1	0
2008	0	0	1 (2)	1	2
2009	0	1	0	1	0
2010	1	0	1	2	0
2011	0	4 (5)	0 (1)	4	6
2012	0 (1)	0 (1)	1 (1)	1	3
2013	3	4 (2)	1 (3)	8	5
2014	3 (3)	1 (2)	1 (2)	5	7
2015	2 (4)	0 (4)	0 (4)	2	12
2016	0	0	2 (3)	2	3
2017	1	0	1 (3)	2	3
2018	2	1 (2)	1	4	2
2019	2	0 (1)	1	3	1
TOTAL	16 (9)	11 (17)	10 (19)	37	45

Key: DAMs Executed (Maneuvers postponed and/or Replanned)



EOS Conjunction Statistics

(Monthly Average – September 2005 thru March 2019)



CREDIT: Megan Johnson & Joseph Bryce/CARA Team



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Observations/Challenges



Mega Constellations Source http://www.parabolicarc.com/2017/03/03/spacex-launch-12000-satellites

A Risk to one is a Risk to ALL Nothing will happen until something happens

- Space Fence:
 - Conservatively a 3-5 fold increase
 - Maybe larger? an Order-of-magnitude? Maybe more?
- Mega Constellations: The BIG Three
 - SpaceX Starlink: 4,425 11,943
 - Boeing: 1,396 2,956
 - OneWeb: 720 2,720

Bottom Line: Owner/Operators need to be prepared for a potentially significant increase in collision avoidance activities



Space News – September 2, 2019



ESA spacecraft dodges potential collision with Starlink satellite

by Jeff Foust - September 2, 2019



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Future Plans (Code 371)



- Conduct an Operational Availability analysis for each mission
 - With current and increased LEO populations
 - With current and modified science/observation protocols

Thank you for your time and attention

Questions

Source 2010 USAF Television Commercial

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Abbreviations/Acronyms List



A-Sat –	Anti-Satellite
ASW –	Astrodynamics Workstation
CA –	Conjunction Assessment
CAE –	FOT Collision Avoidance Engineer
CAM –	Command Authorization Meeting
CARA –	Conjunction Assessment Risk Analysis
CRMS –	Collision Risk Management System
CSpOC –	Combined Space Operations Center
DAM –	Debris Avoidance Maneuver
DMUM –	Drag Make-up Maneuver
EDT –	Eastern Daylight Time
EDR –	Energy Dissipation Rate
EOS –	Earth Observing System
ESC –	Earth Science Constellation
ESMO –	Earth Science Mission Operations
FDS –	Flight Dynamics System
FOT –	Flight Operations Team
FST –	Flight Support Team
GMT –	Greenwich Mean Time

Anti Satallita

- GSFC -Goddard Space Flight Center GTE -Ground Track Error
- HIE High Interest Event
- HIEB -High Interest Event Briefing
- HQ Headquarters
- JAXA -Japan Aerospace **Exploration Agency**
- kilometer km –
- LUPI Length of Update Interval
- **Mission Director** MD –
- MLT -Mean Local Time
- MOWG -**Mission Operations Working** Group
- MTS -Maneuver Trade Space
- National Aeronautics & NASA – Space Administration
- OA **Operational Availability**
- OD **Orbit Determination**
- OSA -**Orbital Safety Analyst**
- Pc-Probability of Collision
- RIC -Radial, In-track, Cross-Track
- RMM **Risk Mitigation Maneuver**
- SP **Special Perturbations**
- To Be Determined TBD -

- TCA -Time of Closest Approach USSTRATCOM – United States Strategic Command UT – Universal Time
- UTC -**Coordinated Universal Time**