Mission Status at Earth Science Constellation MOWG Meeting @ GSFC June 2, 2015

EOS Aura

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Topics

• Mission Summary
• Spacecraft Subsystems Summary
• Recent & Planned Activities
• Inclination Adjust Maneuvers
  – Spring 2016 Calendar (DRAFT)
  – 2015 Results & Long-Term Plan (in EOS FD Presentation)
• Propellant Usage & Lifetime Estimate
• Mission Summary
• Additional Slides:
  – Orbit Maintenance Maneuvers
  – Conjunction Assessment High Interest Events
  – Ground Track Error & Mean Local Time History
  – Spacecraft Orbital Parameters Trends & Predictions
EOS Aura Mission Summary
(Updates since October 2014 MOWG at LaRC)

• 07/15/04: Launch
  – 6-Year Design Life
• 09/30/10: End of Prime Mission Review
  – #4 Ranked Earth Science Mission
  – Mission extension through FY17
• 07/22/13: Submitted Phase F Study
• 01/21/15: FOT Annual Review #8
• 03/03/15: Senior Review Proposal #4
  – Reliability Estimates thru 2022
  – Consumables through 2023+
• 07/15/14: 10-Year Anniversary
Aura Spacecraft Subsystems

All subsystems configured to primary hardware

• Command & Data Handling (CDH) – Nominal
  – Solid State Recorder (SSR) Anomaly (December 4-18, 2007)
    » Returned November 2010 at reduced level – then subsided January 2011
    » Returned again 04/15/2012 – currently still “active”

• Communications (COMM) – Nominal

• Electrical Power System (EPS) – Nominal
  – Solar Panel Connector Anomaly – ARE-3C (January 12, 2005)
  – Solar Array Offset (Reported 11/17/09, Corrected 06/29/10 and each year since)
  – Array Regulator Electronics (ARE) 5A Anomaly (03/12/2010) additional power drop on 04/25/2013
    » Simultaneously with GN&C Attitude Disturbance – attributed to MMOD Strike
  – 12/08/2014 ARE-4A power drop (first power drop anomaly in 15-months – last observed on Aura)
  – Other older ARE Anomalies: ARE-5C (9/27/12 & 2/4/13), ARE-1A (3/12/10 & 11/5/11) & ARE-6A (9/14/13)
    » Estimated that Aura has lost 25 strings of solar cells out of a total of 132 strings
    » Aura continues to have significant power margin where the life limiting item is fuel

• Flight Software (FSW) – Nominal

• Guidance, Navigation & Control (GN&C) – Nominal
  – Earth Sensor Assembly (ESA) Anomaly (05/29/2009) – Re-calibrated in Fall 2009

• Propulsion (PROP) – Nominal

• Thermal Control System (TCS) – Nominal

Recent Activities
(October 2014 – May 2015)

• 26 CARA High Interest Orbital Debris Events (October 2014 – May 2015)
  – 5 that required significant action (Tier 3 + Tier 4) plus 4 additional Tier 2 HIEs
    » See charts 18 & 19 and CARA presentation
  – 3 RMM/DAMs PLANNED – 0 APPROVED/LOADED/WAIVED-OFF – 0 EXECUTED
  – 3 Routine DMUMs were re-scheduled/re-planned (CARA Tier 4 HIEs)
  – 17 Potential High Interest Events (PHIEs – Tier 1’s) required monitoring and/or planning

• No significant Instrument related anomalies – 1 minor spacecraft bus anomaly
  – 12/08/2014 ARE-4A power drop anomaly

• Spacecraft Delta-V Maneuvers: 8 Routine DMUMs, 5 IAMs and 0 DAMs
  – 8 Routine Drag Make Up Maneuvers (DMUMs): #’s 72-79
  – 0 Debris Avoidance Maneuvers
  – 5 Inclination Adjust Maneuvers:
    » 2015: 3/19 (#40), 3/26 (#41), 4/2 (#42), 4/16 (#43) and 4/23 (#44)
  – 3 DMUMs re-scheduled/re-planned due to post maneuver conjunctions of concern
    » 2015: 1/22, 2/5 and 2/18

• 1 Instrument Calibration Maneuver – MLS Moon Scan on 3/7/2015 (#10)
• ESMO Maneuver Planning Process Review (Final Report sent 4/20/2015)
Planned Activities

• June 2015: Drag Make Up Maneuver (DMUM) # 80
• Fall 2015: Earth Science Constellation(ESC)/A-Train MOWG
  – Update propellant budget, decommissioning analysis, reliability predictions,…

• January 2016: Flight Operations Annual Review (#9)
• Spring 2016: Afternoon Constellation Science Meeting and ESC MOWG
• Spring 2016: Annual Inclination Adjust Maneuvers (DRAFT SCHEDULE)
• May 2016: 2nd Annual CNES Conjunction Assessment Workshop (?)

• Mid-to-Long-Term Plans
  – Routine Operations
• Continue to improve Debris Avoidance Maneuver (DAM) responsiveness
  – Additional details in John Nidhiry’s Quick DAM (QDAM) presentation
In response to the constantly increasing number of predicted close approaches with orbital debris and operational satellites (High Interest Events – HIEs – see slide 18)

The EOS Flight Operations Team (FOT) has developed new ground system capabilities, operational procedures and products, to safely plan and execute Debris Avoidance Maneuvers (DAMs) in a significantly reduced amount of time (hours vs. days)

The new and improved procedures and products have:

- Eliminated the current critical path for instrument and communications subsystem commanding in the daily stored command load
- Required less personnel and man-hours for preparation
- Required fewer systems for preparation
- Required generation of fewer products
- Allows greater flexibility with burn duration and timing
# DRAFT Spring 2016

## Inclination Adjust Plan

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Propellant Usage
(Updated September 2014)

- Initial Aura lifetime fuel analysis in 2006
- Detailed Aqua & Aura lifetime analysis in 2008
  - Presented to MOWG and at Aura End of Prime Mission Review in September 2010
- Initial Aura Decommissioning Plan was delivered in September 2012
  - Updated Lifetime Estimates
- Updated August 29, 2013
  - Updated propellant trends for IAMs & DMUMs
  - Updated definitive fuel usage
  - Updated predicted solar flux levels
  - Updated Constellation Exit Plan
    - Safely exiting the Afternoon Constellation requires that Aura’s final apogee be at least two kilometers below the minimum perigee of the other constellation members (692 km target)
    - Perform orbit lowering maneuvers centered at apogee and perigee (pairs of maneuvers)
- Updated September 30, 2014
  - Updated propellant trends for IAMs & DMUMs
  - Updated definitive fuel usage
  - Updated predicted solar flux levels
- Annual updates will be provided
  - Final will be produced 60 days before start of decommissioning

Flight Dynamics (FD)
Task Order 1012
TECHNICAL MEMORANDUM
Updated Analysis for Aura Decommissioning

Issue Date: September 30, 2014

Updated by:
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Remaining Fuel Estimate
(September 2014)

• Long-term orbit simulations were run for Aura through Feb 2023
  – Used mean nominal Schatten solar flux predictions
  – Estimated the frequency of drag make-up maneuvers to maintain
    Aura’s WRS-2 ground track requirements
  – Estimated the required number of annual inclination maneuvers for
    Aura to maintain it’s mean local time (MLT) requirement
  – Did not include potential debris avoidance maneuvers
  – Utilized FreeFlyer 6.7.2 which incorporated the solid earth tide
    model allowing greater accuracy for long term predictions of
    inclination, beta angle, and mean local time

• Lifetime predictions for Aura show that the spacecraft will have
  sufficient fuel to maintain its current orbit within the Afternoon
  Constellation through at least early 2023 and possibly beyond

• Analyses are updated annually by ESMO Flight Dynamics Team after
  each series of inclination adjust maneuvers
Fuel Usage: **Actual & Predicted**
(Updated October 1, 2014)

**Aura Definitive Data**
- Ascent Maneuvers
  - Fall 2004
  - Inclination Maneuvers
- Spring 2007
  - Inclination Maneuvers
- Spring 2009
  - Inclination Maneuvers
- Spring 2014
  - Inclination Maneuvers

**Aura Predicted 2014**
- Annual Inclination Maneuvers
  - Spring 2015 – Spring 2022

**Constellation Exit Fuel Limit**

**Aura spacecraft has sufficient fuel to maintain its current orbit within the Afternoon Constellation through early 2022 and possibly beyond**

- Fuel Reserved to safely exit constellation, lower perigee and meet Agency 25-year reentry requirement is approximately 28.5 kg
Debris Assessment Software
(September 2014)

• The Debris Assessment Software (DAS) was created by the Orbital Debris Office in Johnson Space Center and is the Agency standard for end of mission life analyses and lifetime estimations
  – Current Version 2.0.2

• DAS requires several inputs describing the spacecraft’s mission:
  – The operational orbit parameters
  – The mission launch date
  – Length of a mission’s lifetime

• In turn, DAS outputs:
  – If the mission is compliant with NASA requirements for limiting orbital debris
  – A recommended apogee and perigee that will allow the spacecraft to reenter within a specific period and satisfy NASA requirements

• Aura will have enough fuel onboard to safely exit the constellation and de-orbit to the DAS recommended perigee out through the 2023 time frame
Aura DAS End of Life Predictions

(September 2014)

Aura Required Fuel
Nominal Solar Flux Predictions and Operational Reentry Area

- 30 Year Requirement
- 25 Year Requirement
- Predicted Fuel Use
- Constellation Exit Fuel Limit

Date: 5/8/2015 11:13 AM
ESC MOWG - June 2015
Aura End of Mission Plan

- Initial draft February 2009
- Produced the first “Interim” End of Mission Plan (EoMP) in May 2011
  - Approved by NASA HQ July 2011
- Produced EoMP (Rev A): February 2013
  - Updated Lifetime Estimates (09/2012)
  - Added Small Object Collision Assessment
- Produced EoMP Rev B: February 2015
  - Final will be produced 60 days before EoM
  - Latest Annual Lifetime Estimate (09/2014)
- Synopsis
  - Safely exit the A-Train Constellation
  - Passivate Aura to the extent possible for uncontrolled reentry
  - Aura has five (5) approved waivers for passivation
    - Pressurant Passivation
    - Large Object Collision Probability
    - Small Object Collision Probability
    - Orbital Lifetime (30-Year)
    - Re-entry Risk (Un-controlled)
  - Waivers were approved in May 2013
Summary

• **Spacecraft Status** - **GREEN**

• **Instrument Status** - **GREEN**
  – **HIRDLS**: Chopper Stalled 03/17/08 – Not collecting science data
  – **MLS**: Operating Normally – Only periodic Band 13 measurements
    » THz module in Standby Mode – Tested Annually – Latest: 08/18/14 - 09/30/14
    » 08/06/2013: Band 12 Shut down (reached end of useful life – 2-year design)
    » 09/16/2013: 190 GHz Signal Chain Anomaly (Recovered 09/16/2013)
    » 08/19/2014: GHz Anomaly (SEU in SAA – recovered the same day)
  – **OMI**: Operating Normally
    » Field-of-View Anomaly started in September 2007 – currently stable
  – **TES**: Operating Normally
    » 05/18/2014: TES ICS Stall #2 (Recovered 07/05/2014)
    » 07/09/2014: TES Laser A Failure (Switched to Laser B on 7/23/2014)
    – TES returned to routine Special Observation operations on 07/26/2014

• **Data Capture/L0 Processing Status** – **GREEN**
  – SSR Data Capture to 03/31/2015: 99.99511135 %

• **Ground Systems** – System Upgrades completed no current issues
  – Responding to new security requirements and upgrades to obsolete hardware or COTS systems, as required – Automation Effort underway

5/8/2015 11:13 AM
Additional Charts

Orbit Maintenance Maneuvers
Conjunction Assessment High Interest Events
Ground Track Error & Mean Local Time History
Spacecraft Orbital Parameters Trends & Predictions
Orbit Maintenance

KEY: Updates since last ESC MOWG in blue

• **Mission Requirements:** Perform Drag Make-Up Maneuvers (DMUMs) to maintain Aura’s Ground Track Error (GTE) with respect to the World Reference System (WRS-2)
  – Requirement: +/-20 Km as measured at the Descending Node

• **To meet coincident viewing requirements,** Aura’s initial ground track was offset from Aqua’s by one WRS path plus 25.4 Km
  – Aura was maintained -5.4 to -45.4 Km west of Aqua until late 2007
  – Since May 8, 2008, a new control box, +/- 10 Km from a +18 Km (east) offset of the Aqua WRS-2 path is used to maintain MLS-CALIPSO viewing request

• **To date a total of 79** routine DMUMs have been performed
  – 07/19/2012: DMUM # 43 No Yaw Slew Maneuver (NYS) #1 – NYS Maneuvers (37)
  – Last maneuver 04/09/2015 (#79) – Next maneuver June 2015 (#80)
  – Variation in performance from -6.7% (cold) to +5.3% (hot)

• **Conducted 9 series of inclination adjustment maneuvers**
  – Fall 2004 (4), Fall 2006 (4 of 6), Spring 2007 (4), Spring 2009 (9), Spring 2010 (3),
  – Spring 2011 (3), Spring 2012 (4), Spring 2013 (4), Spring 2014 (4) & Spring 2015 (5)
  – Variation in performance from -4.5% (cold) to +1.9% (hot)
1. 09/26/2014: CA vs. 38472 on 10/01 at 09:00:37 GMT – Small miss distance CA (7 meters) with low-risk (1:83K) Pc (T1)
2. 10/20/2014: CA vs. 82983 on 10/22 at 08:42:28 GMT – Medium-risk (Pc about 1 in 3700) CA that self-mitigated (T1)
3. 11/07/2014: CA vs. 34822 on 11/10 at 23:57:06 GMT – Planned DAMs, required large maneuvers, suspended DAM planning (T3)
4. 11/21/2014: CA vs. 26137 on 11/25 at 00:05:19 GMT – Planned DAMs, Pc rolled-off, suspended DAM planning (T2)
5. 12/05/2014: CA vs. 81817 on 12/06 at 13:02:39 GMT – Short-notice (2.5-days) PHIE, requested MTS plots, self-mitigated (T2)
6. 12/05/2014: CA vs. 38189 on 12/11 at 10:50:06 GMT – Repeating CAs, DMUM scheduled for 12/17 re-scheduled to 12/11 (T1)
7. 12/24/2014: CA vs. 35185 on 12/25 at 05:57:58 GMT – Short-notice (12-hours), Pc 1 in 9K, never reported in another screening (T1)
8. 12/25/2014: CA vs. 89305 on 01/24 at 13:34:35 GMT – DMUM (QDAM) Postponed #9 due to post-maneuver conjunction (T4)
9. 01/19/2015: CA vs. 30085 on 01/24 at 13:34:35 GMT – DMUM (QDAM) Postponed #9 due to post-maneuver conjunction (T4)
10. 01/25/2015: CA vs. 38237 on 01/26 at 20:48:30 GMT – 8+ repeating CAs (T1)
11. 01/24/2015: CA vs. 87471 on 01/28 at 09:10:03 GMT – Monitor only, no action required (T1)
12. 02/02/2015: CA vs. 37770 on 02/07 at 02:16:20 GMT – Postponed 2/5 DMUM, Planned DAMs, 3 HIEBs (T4)
13. 02/16/2015: CA vs. 32084 on 02/18 at 22:36:55 GMT – 2/18 QDAM Postponed (T4)
14. 02/18/2015: CA vs. 82593 on 02/21 at 19:04:30 GMT – Monitored but no action (T2)
15. 04/13/2015: CA vs. 36491 on 04/15 at 21:51:15 GMT – Planned DAMs, risk rolled-off with updated tracking (T3)

Aura Summary: 3 DAMs Planned, 0 DAMs Executed, 3 DAMs self-mitigated, 0 DAMs approved and waived-off 3 Routine maneuvers rescheduled (Tier 4s)
Aura Conjunction Assessment
Statistics
(September 2005 thru December 2014)

CREDIT: CARA Team & Ryan Frigm

WRS Ground Track Error (GTE)
(As of March 2015)

Aura WRS Groundtrack Error at the Descending Node
(Maneuver planning targets included)

May 8, 2008 Re-Phase Maneuver

Date
7/15/04 4/16/05 1/16/06 10/18/06 7/20/07 4/20/08 1/20/09 10/22/09 7/24/10 4/25/11 1/25/12 10/26/12 7/28/13 4/29/14

WRS Error (km)
-80 -60 -40 -20 0 20 40 60 80

EAST

WEST
WRS Ground Track Error (GTE)
(As of April 8, 2015)
DMUM #79 CAM

Aura WRS Groundtrack Error at the Descending Node
(Maneuver planning targets included)
Aura MLT @ Ascending Node
(As of March 2015)
Aqua/Aura Mean Local Time (MLT) @ Ascending Node

Aqua and Aura MLT Separation

Updated Annually after Inclination Adjust Maneuvers
International Earth Science Constellation
Mission Operations Working Group
June 02-05, 2015
Aqua and Aura Results from Spring 2015 IAM Campaign
Avery C. Ruel & David A. Tracewell
EOS FDS, esmo-eos-fds@lists.nasa.gov, +1.301.416.5050

International Earth Science Constellation
Mission Operations Working Group
Jun 2-4, 2015
Aqua and Aura 2015 MLT Prediction Changes
Ryan J. Moore & David A. Tracewell
EOS FDS, esmo-eos-fds@lists.nasa.gov, +1.301.416.5050
Aura and Landsat-8 (LS-8) Orbit Phasing

With Aura in the intersection point, LS-8 will be ~ 77 seconds away from the intersection Point worse case.

Typically 420 – 480 seconds

Terra ~ 30 min behind LS-7

1 Orbit = ~ 100 minutes

By Design – LS-8 and LS-7 are ½ orbit apart
LS-8/Aura Phasing at Poles
@ Northern Intersection Point

Updated Biannually for ESC MOWG Meetings

Separation at Orbit Intersection (sec)

Date


5/8/2015 11:13 AM
ESC MOWG - June 2015
Questions