Mission Status at Aura Science Team MOWG Meeting
Rotterdam, Netherlands
August 31, 2016

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Topics

- Mission Summary
- Spacecraft Subsystems Summary
- Recent & Planned Activities
- Spacecraft Anomalies
- Data Capture
- Propellant Usage & Lifetime Estimates
- Overall Summary
- Additional Slides:
  - Spacecraft Maneuvers & Ground Track History
  - Mission Highlights & Past Spacecraft Anomalies
  - Reliability Estimates

September 16, 2014

Aura Mission Operations Status
EOS Aura Mission Summary
(Changes since September 2014 MOWG @ College Park)

- 07/15/04: Launch
  - 6-Year Design Life
- 09/30/10: End of Prime Mission Review
- 09/16/14: STM & MOWG @ College Park
- 03/04/15: Senior Review Proposal #4
  - Reliability Estimates through 2021
  - Consumables through 2022
- 07/15/15: Aura 11-Year Anniversary
  - #4 Ranked Earth Science Mission
  - Mission extension through FY17
- 01/27/16: ESMO Annual Review #9
- 07/15/16: Aura 12-Year Anniversary
Aura Spacecraft Subsystems
(Changes since September 2014 MOWG @ College Park)

• 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 & 04/25/2013)
    » 03/12/2010: Simultaneous with GN&C Attitude Disturbance – attributed to MMOD Strike
  – 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), & ARE-4A (12/08/14)
    » 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

• Propulsion (PROP) – Nominal

• Thermal Control System (TCS) – Nominal

All subsystems configured to primary hardware
Summary of Activities
(Since the last MOWG on 09/16/2014)

- 62 CARA High Interest Orbital Debris Events (Tiers 1-4)
  - 13 that required significant action (T3 / T4)
    » 01/19/2015: DMUM (QDAM) Postponed #9 due to post-maneuver conjunction (T4)
    » 02/02/2015: Postponed 2/5 DMUM, Planned DAMs, 3 HIEBs (T4)
    » 02/16/2015: 2/18 QDAM Postponed (T4)
    » 11/06/2015: Postponed 11/05 DMUM (T4)
    » 01/18/2016: Executed DAM (DMU #88) (T4)
    » 03/15/2016: Executed DAM (DMU #90) (T4)
  - Note: (T1 – Notify (email/phone), T2 – Conduct Briefing, T3 – Plan Maneuver, T4 – Execute Maneuver)

- 1 Spacecraft EPS ARE power drop anomalies – no impact to operations
  - 12/08/14 (ARE-4A)

- 10 Significant instrument related anomalies (Generated NASA Anomaly Reports)
  - TES: 6 Stalls (8/17/15, 8/23/15, 11/8/15, 1/12/16, 7/20/16, 8/1/16), 1 Laser-B Anomaly (9/11/15),
    1 Safe Events (3/27/16)
  - OMI: 1 Survival Event (5/29/16), 1 Safe Event (6/10/16)

- Spacecraft Delta-V Maneuvers: 24 Routine DMUMs and 9 IAMs

- 2 Instrument Calibration Maneuvers
  - 03/07/2015: MLS Yaw Slew #10 Lunar Cal, 03/25/2016: MLS Yaw Slew #11 Lunar Cal

- Completed 2 Series of Annual Inclination Adjust Maneuvers (2015 & 2016)
- Completed 2 EOS Flight Operations Annual Reviews (#8 - 01/20/15 & #9 - 01/27/16)
Planned Activities

- 09/01/2016: Drag Make Up Maneuver (DMUM) #95 (Target as of 8/1/16)
- March 2017: Submit Senior Review Mission Extension Proposal
- April 2017: A-Train Science Symposium (Pasadena, CA)
- Spring 2017: Annual Inclination Adjust Maneuvers (DRAFT SCHEDULE)
  - 03/02/17 (#49), 03/09/17 (#50), 03/23/17 (#51), & 03/30/17 (#52)

- Mid-to-Long-Term Plans
  - Continue to improve RMM/DAM execution
    » See additional details on CA automation (CRMS) in the following slide
  - 2016 Fall Earth Science Constellation (ESC) MOWG (Albuquerque, NM)
    » Update propellant budget, decommissioning analysis, reliability predictions,…
  - Working on Lifetime & Decommissioning Analysis
    » Developing a retrograde maneuver capability - FOT conducting research, planning and analysis with FDS and ESMO
  - 2017 Senior Review Proposals
In response to the constantly increasing number of predicted close approaches with orbital debris and operational satellites (High Interest Events – HIEs) and anticipated updates to the US Air Force Space Fence which will significantly increase size of the Space Catalog (20K $\Rightarrow$ 150-200K).

ESMO is developing a new ground system capabilities to autonomously identify and develop maneuver options to assist in Debris Avoidance Maneuver planning.

Collision Risk Management System (CRMS) capabilities include:

- Goal is to develop an automated debris avoidance maneuver planning process
- User defined collision risk thresholds
- Maneuver optimization to address multiple conjunctions with secondary object conjunctions
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**A-Train Science Symposium in Pasadena, CA**
Spacecraft Anomalies

Array Regulator Electronics Anomalies
Current Status
Last ARE Anomaly (4A) on 12/08/2014

• 07/17/2013: Met with NGAS to review the results of their anomaly investigation to date (focus to date had been on Aqua ARE-6A that occurred 10/20/2011)
  – Loss could be for many possible reasons including short or open circuits
  – Most failure modes exhibited by Aqua and Aura appear most likely to be caused by loss of output from multiple solar array strings (see NGAS Fishbone Diagram Analysis & Final Report)
  – Additional Aura ARE Anomalies due to other causes
    » 01/12/2005: Disengaged Solar Array Connector (ARE-3C)
    » 03/12/2010: MMOD (?) Vacuum Arching (ARE-5A)
• 09/25/2013: NGAS Follow-up Meeting (Focus on Aura investigation)
• 09/27/2013: FOT reports ARE-6C current drop on 9/14 masked by TES transition to Safe on 9/22
• 11/13/2013 & 12/11/2013: NGAS Follow-up Meeting (Focus on Aura investigation)
• 01/15/2014: EPS Performance Review & Anomaly Closeout → 02/05/2014 → 03/05/2014
• 03/05/2014: NGAS Investigation Status Meeting
• 03/21/2014: Follow-up/Close-out Meeting while NGAS was at GSFC
• 06/04/2014: NGAS Briefing – Final Briefing/Report planned for July
• 07/28/2014: NGAS delivers draft final report and presentation
• 09/17/2014: NGAS Briefing to ESMO and AETD at GSFC
• 12/04/2014: EPS Power Working Group and initial Margins Analysis Meeting
• 12/08/2014: ARE-4A Power Drop Anomaly #1 (Last observed on Aura) – Data sent to NGAS on 12/15/2014
• 09/01/2015: EPS Power Working Group Meeting
  – Aura appears to have lost output from about 25 of 132 strings – No impact to mission operations at this time
• 01/19/2016: EPS Power Working Group Meeting
  – FOT & NGAS continues to closely monitor the overall performance of the Electrical Power System (EPS)

9/5/2014
ESMO PSR - August 2014
Data Capture – SSR Data Losses
September 2014 to August 2016

- 64 months without a solid state recorder (SSR) data loss
- SSR Data Capture to 6/30/2016: 99.99550194%

Mission Capture Req. = 95%
Operational Errors

Aura: 64 Months since last operational error (April 2011)

+5 years of Aura FOT Error Free Operations

Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul

Terra
Aqua
Aura
Total

0 0 2 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0
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Aura 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
- Fuel Usage updated January 2016

Flight Dynamics Support Services
FDSS-1012-0005
CODE 585

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

Issue Date: September 30, 2014

Updated by:
Brandon Holladay
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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 2022 and possibly beyond

• Analyses are updated annually by ESMO Flight Dynamics Team after each series of inclination adjust maneuvers
  – Next full update: September 2016
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.
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)

No Changes or Updates

Aura Required Fuel
Nominal Solar Flux Predictions and Operational Reentry Area

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

4/13/2016
ESC MOWG - April 2016
Aura End of Mission Plan (EOMP)

- 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
- Next End of Mission Plan (Rev C): Feb 2017
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
    » 08/06/13: Band 12 Shut down (reached end of useful life – 2-year design)
    » THz module in Standby Mode – Tested Annually – Latest: 08/18/14 - 09/30/14
    » 01/02/2016: R2_GUNNBias_V Yellow Alarms (due to aging, limit changes TBD)
  - OMI: Operating Normally
    » Field-of-View Anomaly started in September 2007 – currently stable
    » 03/03/16: OMI-IAM Command Reject Anomaly – recovered 03/16/16
    » 05/29/16: OMI Survival Mode Transition (Recovered 06/09/16)
    » 06/10/16: OMI Safe Mode Transition (Recovered 06/13/16)
  - TES: Operating Normally – Showing signs of aging and reaching end-of-life
    » 09/09/15: TES Laser B Anomaly (on-going activities to extend life)
    » 03/27/16: TES Power on Reset (POR) Anomaly (Recovery is currently on-going)
    » TES ICS Stalls (#3, 8/16/15), (#4, 8/23/15), (#5, 11/7/15), (#6, 1/12/16), (#7, 7/20/16), & (#8, 8/1/16)
- **Data Capture/L0 Processing Status** – **GREEN**
  - SSR Data Capture to 06/30/2016: 99.99550194%
- **Ground Systems** – Responding to new security requirements and upgrades to obsolete hardware or COTS systems, as required – Automation efforts are underway
Additional Charts

Maneuvers & Ground Track History
Orbital Trends
Orbit Maintenance

- **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 94 routine DMUMs have been performed
  - 07/19/2012: DMUM # 43 No Yaw Slew Maneuver (NYS) #1 – NYS Maneuvers (37)
  - Last maneuver 07/28/2016 (#94) – Next maneuver 09/01/2016 (#95)
  - Variation in performance from -3.5% (cold) to +3.3% (hot)
- Conducted 11 series of inclination adjustment maneuvers
  - Fall ‘04 (4), Fall ‘06 (4 of 6), Spring ‘07 (4), Spring ‘09 (9), Spring ‘10 (3),
  - Spring ‘11 (3), Spring ‘12 (4), Spring ‘13 (4), Spring ‘14 (4), Spring ‘15 (5), Spring ‘16 (4)
  - Variation in performance from -4.5% (cold) to +1.9% (hot)
Aura WRS Groundtrack Error at the Descending Node
(Maneuver planning targets included)

May 8, 2008 Re-Phase Maneuver

WRS Ground Track Error (GTE)
(As of March 27, 2016)
WRS Ground Track Error (GTE)
(As of March 27, 2016) Past 18+ months

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

Aqua and Aura MLT Separation

- AquaMax
- Aqua
- AuraMax
- Aqua/AuraMin
- Aura

Dates:
- Fall 2004 IAMs
- Fall 2006 IAMs
- Spring 2007 IAMs
- Spring 2009 IAMs
- Spring 2011 IAMs
- Spring 2012 IAMs
- Spring 2013 IAMs
- Spring 2014 IAMs
- Spring 2015 IAMs

Updated Annually after Inclination Adjust Maneuvers
Aura Predicted Beta Angle
(With Yearly Inclination Maneuvers)

September 16, 2014
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

By Design – LS-8 and LS-7 are ½ orbit apart

Typically 330 – 190 seconds

Terra ~ 30 min behind LS-7

1 Orbit = ~ 100 minutes
LS-8/Aura Phasing at Poles @ Northern Intersection Point
(as of March 01, 2016)
Questions
Backup Charts
## Aura Conjunction Assessment High Interest Events

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Note: (T1 – Notify (email/phone), T2 – Conduct Briefing, T3 – Plan Maneuver, T4 – Execute Maneuver)
Future Debris Population
**Future Space Catalog**

**WHAT CAN BE TRACKED NOW**

- ~20,000 SPACE DEBRIS OBJECTS

**WHAT SPACE FENCE WILL TRACK**

- ~200,000 SPACE DEBRIS OBJECTS

**TIPPING POINT**

Space debris has reached a tipping point, an unstoppable chain reaction of collisions.

17,000 MPH

**SPEED OF IMPACT**

Traveling at nearly 17,000 miles per hour, a debris piece as small as a speck of paint can damage and destroy a satellite.

**DOCUMENTED DEBRIS:**

1. Collision Debris
2. Glove
3. Disabled Satellite
4. Abandoned Rocket Part

**MODERN LIFE RELIES ON SATELLITES IN SPACE FOR:**

- GPS
- ATMs
- Weather Prediction
- Satellite/Digital TV