Mission Status at the Earth Science Constellation (ESC) Mission Operations Working Group (MOWG) Meeting at the Kennedy Space Center (KSC)

December 6, 2017

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Topics

• Mission Summary
• Spacecraft Subsystems Summary
• Recent and Planned Activities & Process Improvements
• Inclination Adjust Maneuvers
  – Spring 2018 Calendar – FINAL
  – Long-Term Plan – NO CHANGES (see Flight Dynamics Presentations)
• Propellant Usage & Lifetime Estimate
• End of Mission Plan
• 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 Aqua Mission Summary

(Updates since June 2017 MOWG Meeting at GSFC in Greenbelt, MD are in blue text)

- **05/04/2002**: Launch
  - 6-Year Design Life
- **12/02/2008**: End of Prime Mission Review
- **12/08/2015**: End of AMSR-E Operations
- **11/17/2016**: A-Train PS Teleconference
- **01/25/2017**: ESMO Annual Review #10
- **03/03/2017**: Senior Review Proposal #6
  - Reliability Estimates thru 2025
  - Consumables through 2022
  - Potential After the A-Train Extended Mission
- **05/04/2017**: Aqua 15-Year Anniversary
- **06/22/2017**: NASA Earth Science Senior Review Subcommittee Report – 2017
  - Continue as baselined
  - Subcommittee recommended to continue at least through FY23 (Awaiting HQ Guidance)
Aqua Spacecraft Subsystems

All subsystems configured to primary hardware

Changes since June 2017 MOWG Meeting are in blue

- Command & Data Handling (CDH) – Nominal
  - Solid State Recorder (SSR) – only holds 2 orbits of data

- Communications (COMM) – Nominal

- Electrical Power System (EPS) – Nominal
  - Array Regulator Electronics (ARE) 4A: 9/9/2004 – self-recovered – stable for 5+ years
    - Re-occurred 1/11/2010 and 7/18/2013 (2 strings)
  - ARE-1C: 11/8/2010 (1 string) and ARE-3A: 2/14/2012 (1 string)
  - ARE-6C: 10/20/2011 – Numerous power drops/current fluctuations – last on 11/4/2015 (6 strings)
  - ARE-5C: 5/3/2016 – Power drop, partial recovery on 6/17/2016 (1 string)
  - Summary: Estimated that Aqua has lost 13 strings of solar cells out of a total of 132 strings
  - Battery Cell Anomaly (9/2/2005)
  - Solar Array (SA) Panel #8 Thermistor #6 Failure (8/3/2009)

- Flight Software (FSW) – Nominal

- Guidance, Navigation & Control (GN&C) – Nominal

- Propulsion (PROP) – Nominal
  - Dual Thruster Module (DTM-2) Heater Anomaly (9/8/2007)

- Thermal Control System (TCS) – Nominal
Recent Spacecraft Activities
(June 2017 – 11/30/2017)

- **6 CARA High Interest Orbital Debris Events (HIEs):** see charts 19-21
  - 3 that required significant action
    - 3 RMM/DAMs PLANNED – 3 SELF-MITIGATED – 0 EXECUTED
  - 0 Planned routine DMUMs postponed/replanned and/or rescheduled

- **1 Spacecraft Bus Anomaly:** Ongoing loss of solar array (SA) strings
  - 07/17/2017: ARE-4C Power drop and current fluctuations

- **0 Instrument Anomalies:**

- **6 Spacecraft Delta-V Maneuvers:**
  - 6 Routine Drag Make-Up Maneuvers (DMUMs):
    - All performed without yaw slews
  - 0 Inclination Adjust Maneuvers (IAMs)
  - 0 Debris Avoidance Maneuvers (DAMs)

- **7 Instrument Calibration Maneuvers:**
  - Monthly MODIS Lunar Calibrations
Ongoing Process Improvements

- **Aqua/Aura Maneuver Working Group: Reestablished in May 2016**
  - Develop retrograde maneuver capability for use during operational mission
  - Develop more fuel-efficient propulsive maneuvers
    - Constellation exit retrograde maneuvers using reaction wheels and thrusters
    - IAMs using reaction wheels for spacecraft attitude reorientation

- **EOS Automation (EA): Critical Design Review (CDR) 2/2013**
  - Phase II (S/C H&S Monitoring): CDR 1/29/2014, Delivery 2/2/2015
  - Phase II: R2.6.1 Development & Testing 9/1/2015 – 12/16/2016
  - Phase II: R2.7 Operations Readiness Review (ORR) 8/3/2017
  - Phase III (S/C Commanding and Contact Execution): CDR 10/5/2017
  - Phase III: ORR Summer 2018

- **Collision Risk Management System (CRMS)**
  - See summary on next slide
  - Additional details in Dimitrios Mantziaras presentation
Collision Risk Management System (CRMS)

- ESMO has developed ground system capabilities to autonomously identify and develop maneuver options to assist in Risk Mitigation Maneuver (RMM) / Debris Avoidance Maneuver (DAM) planning.

- Developed in response to an increased number of predicted close approaches with orbital debris and operational satellites (slides 21 & 22):
  - More High Interest Events (HIEs) had led to more effort to plan mitigation maneuvers.
  - Concern is that updates to the US Air Force Space Fence will significantly increase the size of the Space Catalog.

- Key CRMS capabilities include:
  - User defined collision risk thresholds.
  - Maneuver optimization to address multiple conjunctions with secondary object conjunctions including repeating conjunctions.
  - Unconstrained and user defined constrained maneuver options.

- EOC is currently operating with CRMS Release 5.2 (ORR 06/22/2017)
  - Patch allows for data retrieval of JSpOC and/or CARA generated CDMs.
Planned Activities
(2018)

• January 2018: Flight Operations Annual Review (#11)
• Spring 2018: Annual Inclination Adjust Maneuvers
• Spring 2018: Aqua Decommissioning Review (DRAFT)
  – Document Phase F spacecraft activities, any new products to be developed for spacecraft / instrument calibration, proposed Engineering Tests, and Passivation Sequence
• June 5-7, 2018: ESC/A-Train MOWG Meeting in Sioux Falls, SD
  – DRAFT 2019 Inclination Adjust Maneuver Schedule
• July 2018: DRAFT 2018 Aqua Decommissioning & Lifetime Analysis
• October 2018: FINAL Aqua Decommissioning & Lifetime Analysis
• December 2018: ESC/A-Train MOWG Meeting
  – Update propellant budget and decommissioning analysis
  – FINAL 2019 Inclination Adjust Maneuver Schedule
• Late 2018: Updated End of Mission Plan (if necessary)
Planned Activities
(Mid-to-Long-Term)

• **Aqua/Aura Maneuver Working Group**
  – Adopt experience and lessons learned on Aura for Aqua
  – Targeting Aqua 2019 IAMs for using reaction wheels to perform the spacecraft attitude reorientation necessary to align the spacecraft thrusters to perform the inclination adjust

• **EOS Automation (EA) – automation of routine operations**
  – EA Phase III – ORR Summer 2018

• **Continue to improve DAM planning and execution process**
  – CRMS: Full automation end-to-end, identification-to-approval 24x7

• **Possible Re-fueling Mission**
# FINAL Spring 2018 Aqua/Aura Inclination Adjust Plan

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<td>18 Aura Back-up</td>
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Golden Week in Japan

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12/6/2017
ESC MOWG Meeting - December 2017
# Aqua Propellant Usage

**November 2017**

**KEY: Updates since last MOWG Meeting in blue**

- **2006:** Initial Aqua lifetime fuel analysis
- **2008:** Detailed Aqua & Aura lifetime analyses
  - Presented to A-Train MOWG and at Aqua EOPM Review
- **September 2012:** Initial Aqua Decommissioning Plan
  - Updated Lifetime Estimates
- **August 29, 2013:** Updated Decommissioning Plan
  - Updated Constellation Exit Plan
- **September 30, 2014:** Updated Decommissioning Plan
  - Updated definitive fuel usage and predicted solar flux levels
  - Updated propellant trends for IAMs & DMUMs
- **September 2015 Delayed to allow additional time to evaluate long-term plan and decommissioning maneuvers**
- **Summer 2016:** Investigated more fuel efficient inclination adjust and retrograde maneuver options and various options for extending operations into mid-2020ies
- **December 16, 2016:** Updated Decommissioning Plan (V1.1)
  - Updated definitive fuel usage & predicted solar flux levels
  - Updated propellant estimates for IAMs & DMUMs
- **November 13, 2017:** Updated Decommissioning Plan (V1.1)
  - Updated definitive fuel usage & predicted solar flux levels
  - Updated propellant estimates for IAMs & DMUMs
- **Annual updates will be provided each July (started in 2017)**
  - Final will be produced 60 days before start of decommissioning
Long-term orbit simulations were run for Aqua through 2023

- Used mean nominal Schatten solar flux predictions (March 2017)
- Estimated the frequency of drag make-up maneuvers (DMUMs) to maintain Aqua’s WRS-2 ground track requirements
- Estimated the required number of annual inclination maneuvers (IAMs) for Aqua to maintain its 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 Aqua shows that the spacecraft will have sufficient fuel to maintain its current orbit within the Afternoon Constellation through the 2021 inclination adjust series of maneuvers.

Exit from the constellation in March 2022 will be into a new operational orbit, not the decommissioning and passivation orbit, approximately 4.4 km below the current ESC/A-Train operational orbit.

Currently investigating various options to extend the potential Aqua mission life out into the 2025 time frame and possibly beyond.

BOTTOM LINE: Aqua will hold sufficient fuel in reserve after exiting the constellation to lower perigee such that its reentry will meet the NASA 25-year reentry requirement.
Fuel Usage: Actual & Predicted
(November 2017)

- Bookkeeping
- PVT
- Predicted
- Constellation Exit Fuel Limit

Actual fuel usage based on Bookkeeping method and Pressure, Volume and Temperature (PVT) method of calculation

- Ascent Maneuvers
- Spring 2007 Inclination maneuvers (4)
- Spring 2009 Inclination maneuvers (9)
- Fall 2004 Inclination Maneuvers (5)
- Fall 2006 Inclination Maneuvers (4)
- Annual Inclination Maneuvers 2010-2017
- Annual Inclination Adjust Maneuvers Spring 2018-Spring 2021
- Predicted fuel needed to meet 25-year Requirement

Fuel reserved to safely exit constellation is approximately 11.5 kg
Fuel Usage:
Predicted Available & Required
(November 2017)

2018 IAMs (5-burns)
2019 IAMs (5-burns)
2020 IAMs (5-burns)
2021 IAMs (5-burns)

Available Fuel
Required Fuel to Exit Constellation and Meet 25-Year Requirement

Fuel Remaining (kg)

Unusable Fuel ~ 1.2 kg

Fuel required to perform ~4.4 km circular constellation exit ~ 5.5 kg
Estimated uncertainty in EOL fuel measurements ~ 4.8 kg

Year
2019 2020 2021 2022 2023

12/6/2017 ESC MOWG Meeting - December 2017
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 2.1.1)

DAS requires several inputs describing the spacecraft’s mission:
- Launch date = 05/04/2002
- Start inclination = 98.2°
- Tumbling Area = 47.80 m² (FDSS-II-07-0084 Aqua Average Area Version 1.0 Dated 28Feb2017)
- Spacecraft dry mass = 2854.6 kg (includes 1.2 kg of unusable fuel and 4.8 kg of uncertainty)
- Area to Mass Ratio = 0.01671 m²/kg = Tumbling Area/(Dry Mass + unusable + uncertainty)
- Start Apogee (Average Height) of orbit after constellation exit (early-February 2022) = ~696 km
- Start Perigee of orbit after final perigee lowering burn (early-March 2022) = 678 km

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 the NASA requirements.

Aqua has a waiver to the 30-years from launch requirement.
Aqua will hold sufficient fuel in reserve to meet the 25-year requirement.
Aqua Orbital Decay

With A-Train Exit and perigee lowering in early 2022, Aqua is predicted to reenter within the required 25-year Agency & International requirement.
Aqua End of Mission Plan

- Initial draft February 2009
- “Interim” End of Mission Plan: May 2011
  - Approved by NASA HQ July 2011
- End of Mission Plan (Rev A): February 2013
  - Updated Lifetime Estimates (09/2012)
  - Added Small Object Collision Assessment
  - Safely exit the A-Train Constellation (19 km)
  - Passivate to the extent possible for uncontrolled reentry
  - Aqua 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
- End of Mission Plan (Rev C): August 2017
  - Latest Annual Lifetime Estimate
  - Includes ~4.4 km exit from A-Train in early 2022
  - Retrograde maneuver slews on reaction wheels
  - Currently in FINAL Signature cycle
- Final produced 60 days before End of Mission
Summary

KEY: Updates since last MOWG Meeting in blue

- **Spacecraft Status** - **GREEN**
- **Instrument Status** - **GREEN**
  - AIRS, AMSU, CERES & MODIS:
    » AIRS, CERES and MODIS: Nominal Operations
    » 09/24/2016: AMSU-A2 Anomaly – currently no further recovery attempts are planned
    » 01/31/2017: JPL AMSU-A2 Anomaly Closeout Review
  - HSB: Survival Mode since 2/5/2003
  - AMSR-E: Powered Down 03/03/2016
- **Data Capture/L0 Processing Status** – **GREEN**
  - SSR Data Capture **November 2017**: 100%
  - SSR Data Capture to **11/30/2017**: 99.97897%
- **Data Latency** – Excellent
- **Ground Systems** – Responding to new security requirements and upgrades to obsolete hardware or COTS systems, as required
  - EOS Automation (EA) 2.7: Phase 2 operational as of 8/7/2017
  - EA Phase 3: CDR 10/5/2017, ORR Summer 2018
Additional Slides

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 MOWG Meeting in blue

• **Mission Requirement**: Perform Drag Make-Up Maneuvers (DMUMs) to maintain Aqua’s ground track error (GTE) with respect to the World Reference System (WRS-2) within +/-10 Km at the Descending Node
  – Changed from +/-20 Km with DMUM #19 (1/12/05)
  – 124 DMUMs have been performed to date (Last #124 on 11/8/2017, Next #125: 12/13/2017)
  – Variation in performance from –20.9% (cold) to +24% (hot) #108 was 20.9% COLD

• **Control Box Excursions**: Since 2012 there have been 6 Control box Excursions
  – 4 on +10km front-side: 11/4/12 to 11/14/12, 10/23/13 to 10/24/13 and 3/6/14 to 3/10/14
    » 03/16/2015 to 04/02/2015
  – 2 on -10km back-side: 11/07/13 to 12/14/13 (Emergency DAM on 10/24 and DAM on 11/28)
    » 04/02/2016 to 05/07/2016

• **Mission Requirement**: Perform inclination adjust maneuvers (IAMs) to maintain the Mean Local Time (MLT) as measured at the Ascending Node between 1:30 and 1:45 MLT (Mission Goal starting in 2011: 13:35:45 +/- 45 seconds)
  – 55 Inclination Adjustment Maneuvers (IAMs) performed to date
    » Fall 2003 (1), Spring 2004 (1), Fall 2004 (5), 2005 (NONE)
    » Fall 2006 (4 of 6 - cancelled final 2 burns), Spring 2007 (4 - interrupted 2-weeks),
    » Spring 2008 – NONE per special request from PARASOL
    » Spring 2009 (9), Spring 2010 (3), Spring 2011 (3), Spring 2012 (4)
    » Spring 2013 (4 with #3 being delayed 1-week), Spring 2014 (4), Spring 2015 (5)
    » Spring 2016 (all 4 IAMs completed, one had to be re-scheduled), Spring 2017 (4)
### Aqua Conjunction Assessment

#### High Interest Events (HIEs)

**KEY: Updates since last MOWG Meeting in blue**

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2013: 28 CARA HIEs – 9 required significant action  
2014: 34 CARA HIEs – 14 required significant action  
2015: 26 CARA HIEs – 16 required significant action  
2016: 21 CARA HIEs – 4 required significant action

2017 thru 10/30/2017: **(11 CARA HIEs – 4 that required significant action (Tiers 3 & 4)**

1. 02/26/2017: CA vs. 81514 at 13:55:27 GMT – DAMs planned & approved, new tracking dropped risk (T3)  
2. 03/04/2017: CA vs. 33503 at 10:48:40 GMT – DAMs planned, self-mitigated (T3)  
3. 09/02/2017: CA vs. 82112 at 18:24:15 GMT – DAMs planned, self-mitigated (T3)  
4. 09/07/2017: CA vs. 37494 at 09:47:44 GMT – DAMs planned as part of DMUM replan, self-mitigated (T2)  
5. 10/16/2017: CA vs. 26294 at 15:33:42 GMT – DAMs planned, self-mitigated (T3)

**2017 Aqua Summary:** 5 DAM Planned, 0 DAMs Executed, 5 DAM that self-mitigated  
0 Routine maneuvers were postponed/replanned and/or rescheduled (Tier 4s)
The “All Secondary Objects” covers conjunctions will all secondary objects, while the “All Debris Objects” covers conjunctions with any secondary labeled as DEB and excludes events with AnalystSats, Rocket Bodies, and other potentially actives. The three specific debris type categories are subsets of the “All Debris Objects”, but do not necessarily cover everything in that category. Any events with other types of debris are included in the “All Debris Objects” category, but are not called out specifically in their own category.
WRS Ground Track Error (GTE)  
(As of November 11, 2017)
The current target MLT range for Aqua is **13:35:45 +/- 45 sec**
Aqua Definitive & Predictive MLT @ Ascending Node
(As of November 11, 2017)

Mission Operations Range for Aqua MLT is 13:30 – 13:45

The current target MLT range for Aqua is 13:35:45 +/- 45 sec

MLT Mission Requirement 13:30 +/- 15 minutes
EOS Flight Dynamics has analyzed and updated the nominal inclination schedule that ensures Aqua’s mean local time of the ascending node (MLTAN) remains within the current target range.

- The current target MLTAN range for Aqua is 13:35:45 +/- 45 sec.
- Aqua’s current mission MLTAN requirements are {13:30:00 - 13:45:00}
- Aqua’s performance for the 2017 inclination series was -0.64% (COLD)

Proposed long-term inclination adjust plan is predicted to keep Aqua within the target MLTAN range.

- Nominal case schedules Aqua inclination maneuvers that are not on weeks starting with Easter. The maneuvers are not currently centered around the ideal dates.
- Developing a more fuel-efficient Inclination Adjust Maneuver capability

Will re-visit/re-validate the long-term plan after each series of annual inclination adjust maneuvers.

See EOS Flight Dynamics Presentation for long-term plan.
Inclination/MLT Maintenance
(Long-Term Plan)

International Earth Science Constellation
Mission Operations Working Group
December 6-8, 2017
Aqua/Aura Inclination Adjust Maneuver Series
Spring 2018 Planning
Elena Trenholme, Omitron, Inc.  Spencer Boone, Omitron, Inc.
EOS FDS, esmo-eos-fds@lists.nasa.gov, +1.301.614.5050
Terra to Aqua Phasing
(as of November 11, 2017)

Terra goes through orbital intersection point about 17.5-minutes (~1050-seconds) prior to Aqua.

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Separation at Orbit Intersection (sec)

Aqua +20 km GTE

Terra

Aqua -20 km GTE

Date

12/6/2017
ESC MOWG Meeting - December 2017
Questions
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<th>Abbreviations</th>
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<td>Advanced Microwave Scanning Radiometer for EOS</td>
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<td>AMSU –</td>
<td>Advanced Microwave Sounding Unit</td>
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