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Space Administration

Extending the Life of NASA’s Tracking and Data Relay Satellite (TDRS)-8

TDRS-8 Power Challenges and Planning for End of Mission

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Carissa Brealey Bonacci

TDRS Spacecraft Engineering Manager
White Sands Complex | Las Cruces, NM

- Rudy Perea (Systems TDRS Analyst)
- Brandon Lujan (Attitude Control System TDRS Analyst)
- NASA Goddard Space Flight Center Sustaining Engineering Team

AGENDA

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- Introduction & Background
- Power Management Strategies
- End of Mission Planning
- Path Forward

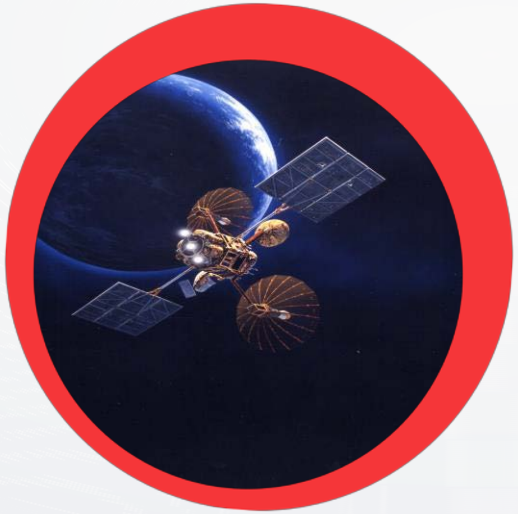
Missions Depend on the Space Network

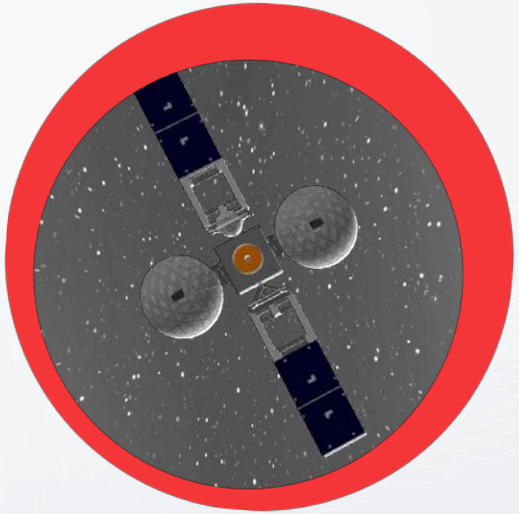
The SN provides critical and reliable communication support to NASA missions including the International Space Station, visiting vehicles, the Orion spacecraft, space science missions like Hubble Space Telescope, and Earth science missions such as Aqua, Aura and Terra.

Furthermore, services are provided to commercial missions, such as ULA and SpaceX, and remote science from Antarctica. The SN supports a variety of customers with proficiency in excess of 99.97%.”

Space Segment: A Constellation of Satellites

- The Space Network Space Segment is comprised of a constellation of Tracking and Data Relay Satellites in geosynchronous orbit.
- The three generations of satellites began launching in 1983 with the most recent launched August 2017.
    - Four “legacy” first generation TDRSs that were built by TRW: TDRS-3, TDRS-5, TDRS-6 and TDRS-7.
    - Three second generation and three third generation TDRSs, all of which are Boeing 601 spacecraft: TDRS-8 through TDRS-13.
- Twelve TDRSs have successfully launched to date, with only two being retired.





Ground Segment: A Global Network

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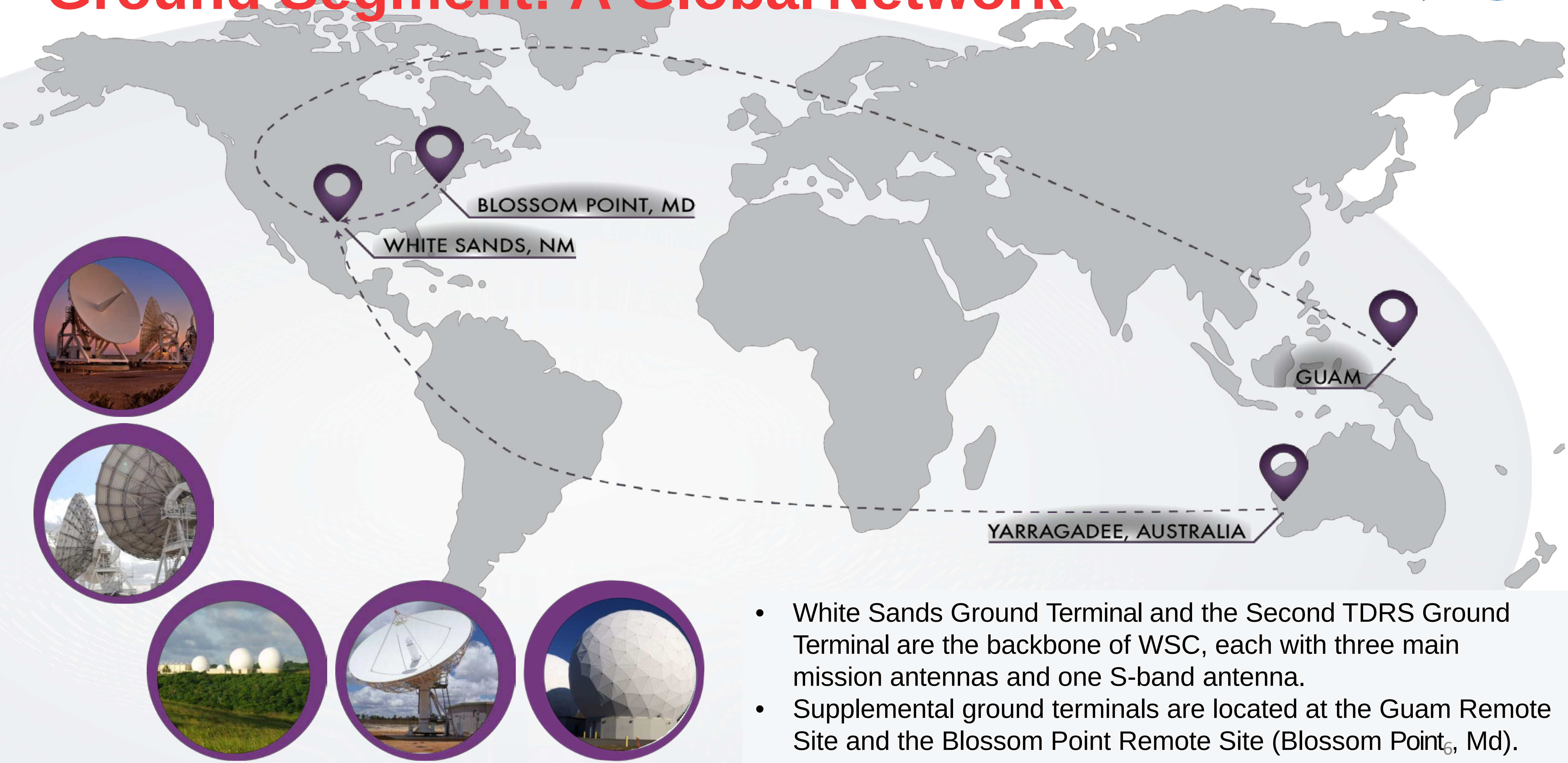

- White Sands Ground Terminal and the Second TDRS Ground Terminal are the backbone of WSC, each with three main mission antennas and one S-band antenna.
- Supplemental ground terminals are located at the Guam Remote Site and the Blossom Point Remote Site (Blossom Point, Md).

TDRS-8 flown from Guam Remote Site

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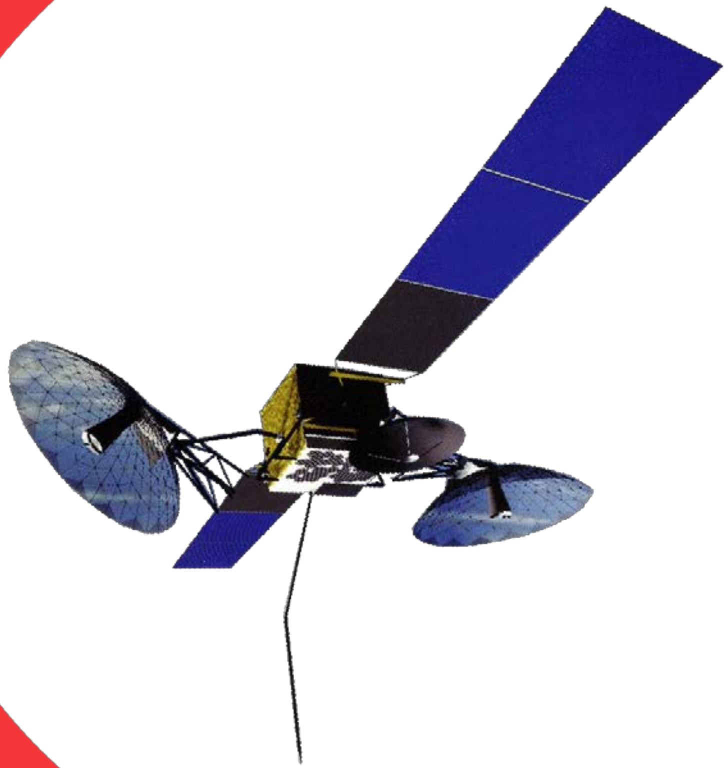
Retired spacecraft are moved to supersync orbit (~300km)

TDRS-8 (TDRS-H)

Launched: June 20, 2000

- Oldest of the Boeing-built TDRSs and has been recently experiencing power subsystem challenges
- Activities are underway to identify strategies that may be able to extend the serviceable life of the spacecraft if further failures occur
- In parallel, preparations are underway to develop an End-of-Mission Plan in the event that the next failure is critical
    - While the operations staff at WSC have experience in decommissioning TDRSs, TDRS-8 will be the first Boeing TDRS to be retired. As such, it presents a number of unique technical and logistical challenges
- This briefing will focus on both the life extending strategies and well as the EOM planning challenges



TDRS-8 Power Subsystem Decline

Background

- TDRS-8 has suffered at least 6 solar array circuit failures out of the 32 total circuits.
    - Arrays are producing 20% less current than expected (accounting for normal degradation) after over 17 years on orbit
    - 2 circuits failed in 2012, two in 2016 and 2 more in 2017 for a total of six
    - Should the spacecraft lose more than 5 additional circuits, NASA believes TDRS-8 will reach the point where deorbit is recommended
- Bus Voltage Limiter (BVL) units are experiencing module anomalies.
    - The units use shunting to regulate bus voltage. The anomaly shunts a static amount of current with no regulation.
    - Anomalous signatures have been corrected by disabling a module on each solar wing. 2 of 6 BVL modules (one on each BVL) have been disabled to recover the parasitic shunts. There are two more anomalous BVL modules still in use.
    - Require a long term strategy to mitigate risk of unregulated bus voltage and consequent harm to units.
- TDRS-8 battery has 4 underperforming cells.
    - Analysis shows that the spacecraft can survive the loss of 2 more battery cells.
    - Batteries are not an immediate concern at this time.
    - BVL/Solar Array strategies may affect the life of battery due to increasing depth of discharge.

Power Management Strategies

Load Shedding & Thermal Management

- Payload deactivation techniques have been developed and procedures created. These procedures provide operator instructions on selecting and shutting down individual or combinations of payload equipment.
  - Validated using TDRS Spacecraft Emulator (TSE) simulations.
  - Ensured that the proper sequencing of commanding is built into command stacks which were delivered to the operational system.
  - Simulation data forwarded to Thermal Team to determine impacts to thermal profile.
- Simulators at WSC were determined to provide inadequate thermal simulations.
- NASA-based desktop thermal model provided greater fidelity simulations of the TDRS-8 thermal profile.
  - Additional simulations to be conducted as global heater operation is optimized to provide best power margin regained for each payload shutdown or payload combination.

BVL Top-Off Tests

- In order to characterize the behavior of the TDRS-8 BVLs, top-off tests were implemented as part of the TDRS Gen-II and Gen-III nominal operating posture.
    - These tests are performed as the spacecraft exits eclipse and allow the engineer to quantify the level of shunting for each BVL module.
    - These tests have also been added to the TDRS-9 through TDRS-13 nominal operating posture.
- If top off tests reveal a large anomalous shunting, disabling another BVL module may be required to remain power positive.
- Mitigations under investigation in loss of BVL operations.
    - Increase bus load with or without solar array offsets.
    - Modified battery management plan requires charging battery to limit high bus voltage.
    - Re-enabling failed BVL modules following safe hold.
    - Power management posture containing autonomous or semi-autonomous load bus overvoltage detection & prevention response logic for solstice and eclipse seasons.

Solar Array Off-Pointing Strategy

- Solar Array Offset Testing Strategy has been developed to determine whether off-pointing the arrays could be used as a power management technique if BVLs must be deactivated.
  - The test characterized the power output by the arrays as a function of offset angle.
  - The procedure for off-pointing the arrays was developed, simulated and reviewed as a joint effort between WSC and Sustaining Engineering.
- A modified version of the test was performed during an eclipse prior to execution in full sun to reduce risk and validate the test procedure.

Solar Array Off-Pointing Test

Test Description

- In full sunlight, one solar array was commanded to a pre-determined angle off of the sun line using the solar wing bias algorithm.
  - Maximum commanded offset angle was 85º, as the margin of error in the pointing algorithm is ±5º.
  - Setting a limit of 85º prevented the possibility of exposing the back side of the array to the sun.
- The other solar array was left in sun tracking mode.
- Once the offset angle was reached, the off-pointed wing was commanded back to the sun.
  - The full duration of the slews out and back was validated during the eclipse test to be total of about 60 minutes.
- During a separate test window, the other solar array underwent the same procedure while the previously offset array remains in sun tracking mode.

Data Collected

- Characterization of power output by each array as a function of sun incidence angle.
- Comparative outputs of the two arrays.

Solar Array Off-Pointing Test Results

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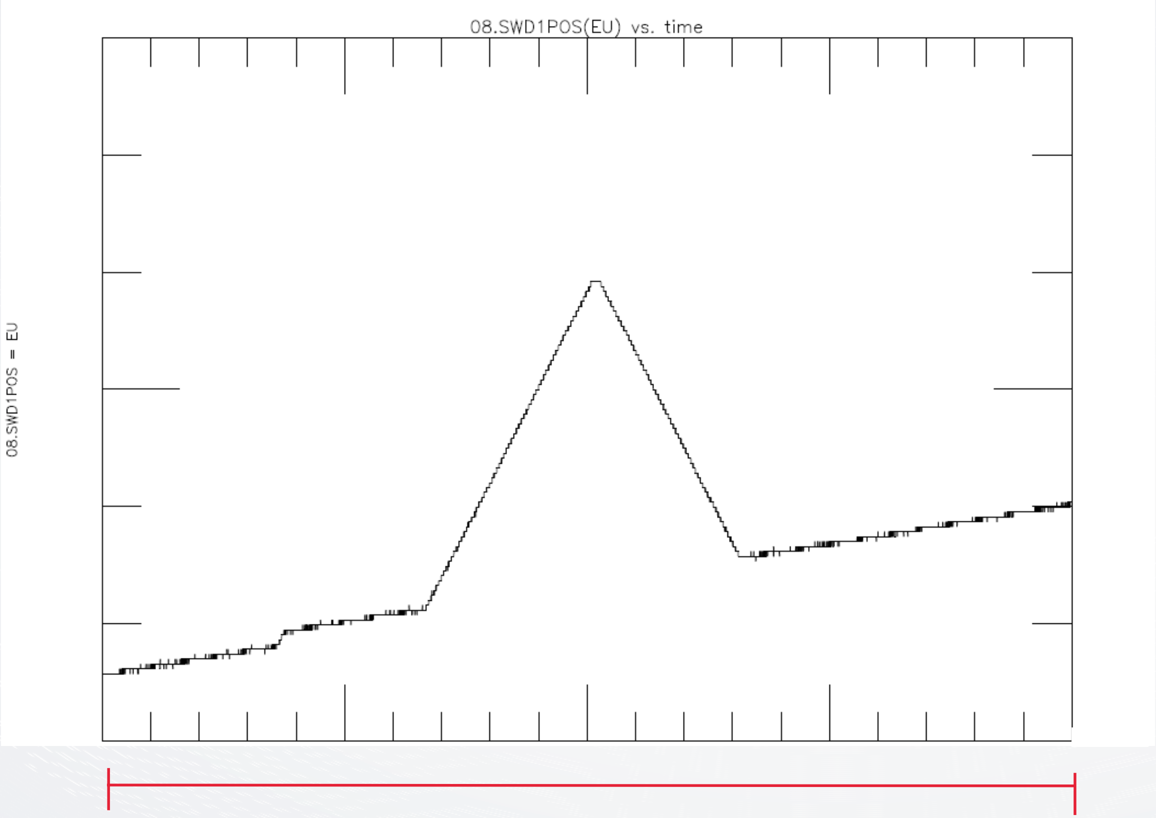
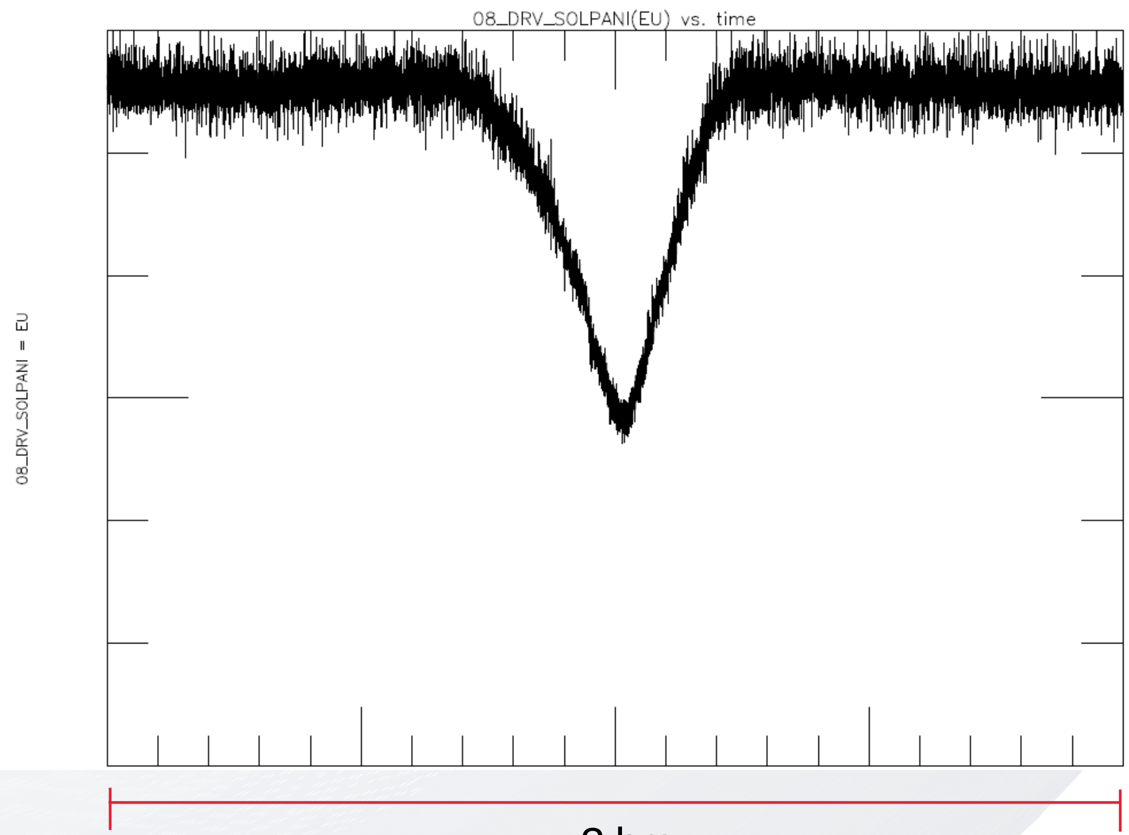
Solar Wing Position



3 hrs

Solar Wing Current



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End of Mission Planning

Guiding Documentation

Primary sources for TDRS-8 End of Mission Planning

- NASA Debris Management Documents
  - NPR 8715.6B – NASA Procedural Requirements for Limiting Orbital Debris and Evaluating the Meteoroid and Orbital Debris Environments
  - NASA-STD-8719.14A – Process for Limiting Orbital Debris
- TDRS Documents
  - Deorbit Maneuver/Shutdown
  - TDRS-1 and TDRS-4 EOM heritage
    - Provides conceptual framework for F8 EOM activities

Moving to Supersync Orbit

- The target altitude will be an orbit with a perigee of 350 km above GEO and an eccentricity of 0.003, or less. The calculated lowest perigee to meet requirements is 303 km above GEO.

Limitations & Considerations

Thruster Constraints

- 10 second burn duration – East/West thrusters
  - Time constraint introduced after the failure of the E2 thruster on TDRS-10.
  - This constraint was implemented on other Boeing 601 satellites.
  - Discussions have been taking place about relaxing this constraint.
  - 30 minutes minimum between any continuous burn (> 2 seconds).
- 50 second burn duration – North thruster pairs
  - Physically constrained by Propellant Management Device (PMD).
  - Constraint on time between burns (2 hours if depleted sponge).

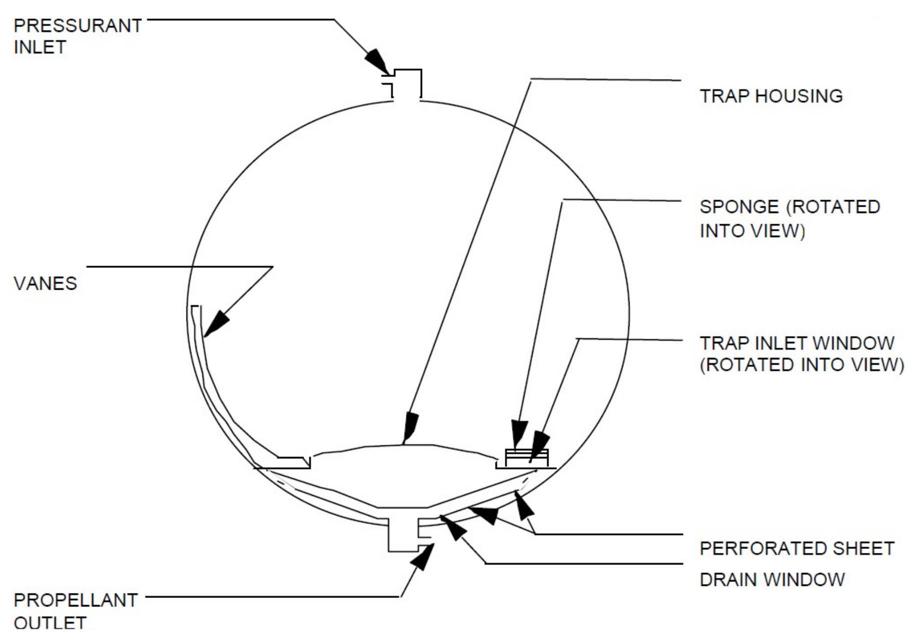

FIGURE 7-19 PROPELLANT MANAGEMENT DEVICE COMPONENTS

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Limitations & Considerations (cont.)

Power Management Considerations

- Will vary depending on what failure/scenario ultimately leads to EOM.
  - Must assume that any fault could ultimately be the cause of EOM.

Limited ground visibility window once supersync maneuvers begin.

- Constrains timeline for orbit raising maneuvers and final passivation activities.
- A significant amount of fuel depletion will likely need to occur prior to orbit raising.

Integrated End of Mission Plan (IEMP) Development

1. Payload Off/TT&C Commanded to S-Band
    - Straightforward methodology using established procedures.

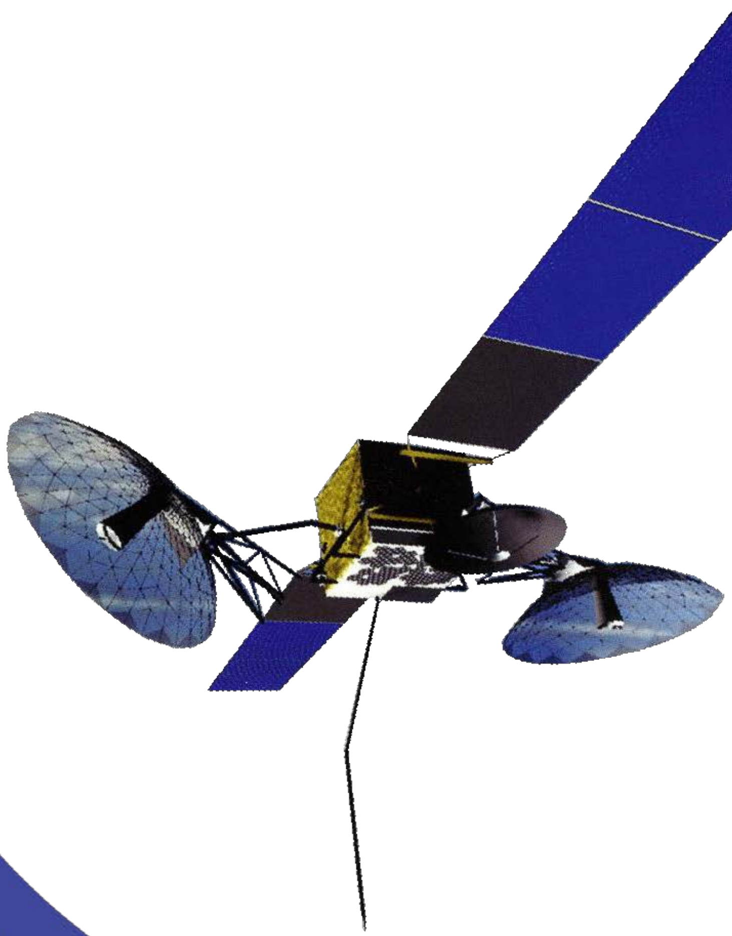
2. Initial Fuel Depletion
    - Currently plan to use north thruster burns, which may be time consuming.
    - Several techniques are currently under consideration, including various thruster configurations as well as propellant banking.

3. Super-Sync Maneuvers
    - Current plan is to perform burns using the west thrusters (more that 100 burns may be needed).
    - Other maneuver techniques under review, including tip-burn-tip and sun pointing maneuvers.

4. Final Fuel Depletion
    - Will require a fuel depletion technique that accounts for the possibility of bubbles in the propellant that could cause thrust imbalances.
    - Will likely be the most challenging phase of EOM.

Integrated End of Mission Plan (IEMP) Development (cont.)

5. Initial Electrical & Power Subsystem (EPS) Passivation
   - Power off all payload and thermal units and disable batter charging.
   - Straightforward process utilizing established procedures.
6. ACS Passivation
   - Power down gyros and Momentum Wheel Platform Assembly.
   - Power off Earth Sensor Assemblies and Spacecraft Control Processors.
7. Final EPS & TT&C Passivation
   - Power down Telemetry streams.
   - Disable Commanding.



Path Forward

Path Forward

- Research, simulate, and test strategies to extend the serviceable life of TDRS-8 in the event that additional power subsystem failures occur.
- Develop/refine emergency response procedures in anticipation of future power subsystem failures.
  - Train spacecraft engineers and operators to execute contingency procedures in a simulator environment.
- Select fuel depletion and supersyncing methodologies and document these in the IEMP.
  - Develop mature draft of IEMP.
- Continue collaboration with Boeing COSC to refine models and address major areas of concern.

QUESTIONS?

FOR MORE INFORMATION, VISIT:

SPACENETWORK.GSFC.NASA.GOV