National Aeronautics and Space Administration

# NOAA-17 Breakup Engineering Investigation

Spacecraft Anomalies and Failures (SCAF) Workshop 2024

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# Agenda

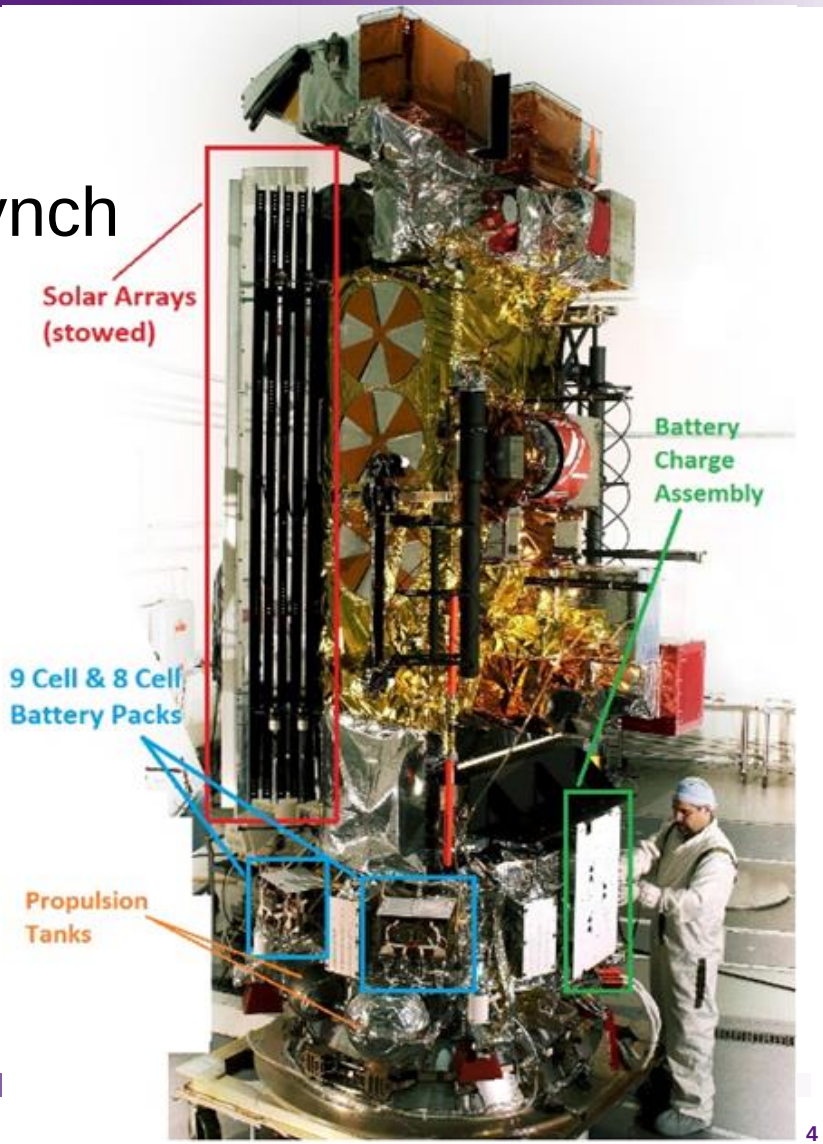
- Introduction
- Investigation
  - Source for the Debris
  - Likely Initiating Event
  - Findings
- Summary

# Introduction

- The NOAA-17 Spacecraft operated successfully for 11 years, then was decommissioned and passivated to the extent possible
- March 10, 2021: Spacecraft broke up almost 8 years after being passivated
- Localized event, not a complete breakup
- Similar to other events (NOAA-16, DMSP F11, DMSP F13)
- Engineering Investigation Board (EIB) was created at the request of NOAA
- This paper summarizes the very detailed 44-page EIB report
- To date, 114 objects have been cataloged, 109 of which are still in orbit

# NOAA-17 Overview

- Polar weather satellite
- Launched on 6/24/2002 to approx. 800 km Sun-synch
- Very similar to DMSP Block 5D3 design
- Mass is 1430 kg in orbit
- Operated nominally until 2013, when it was passivated
  - 4.98 kg hydrazine remained after isolation
  - Nitrogen cold-gas propulsion system was nominally depleted before decommissioning
  - Two batteries isolated, one left connected to the discharge path



# Fleet History

- Two designs for each of two customers (NOAA and DMSP)
  - Block 5D2 Family: 15 spacecraft
  - Block 5D3 Family: 10 spacecraft
  - 19 of the 25 have been decommissioned to-date
- Four of these spacecraft have experienced significant debris shedding

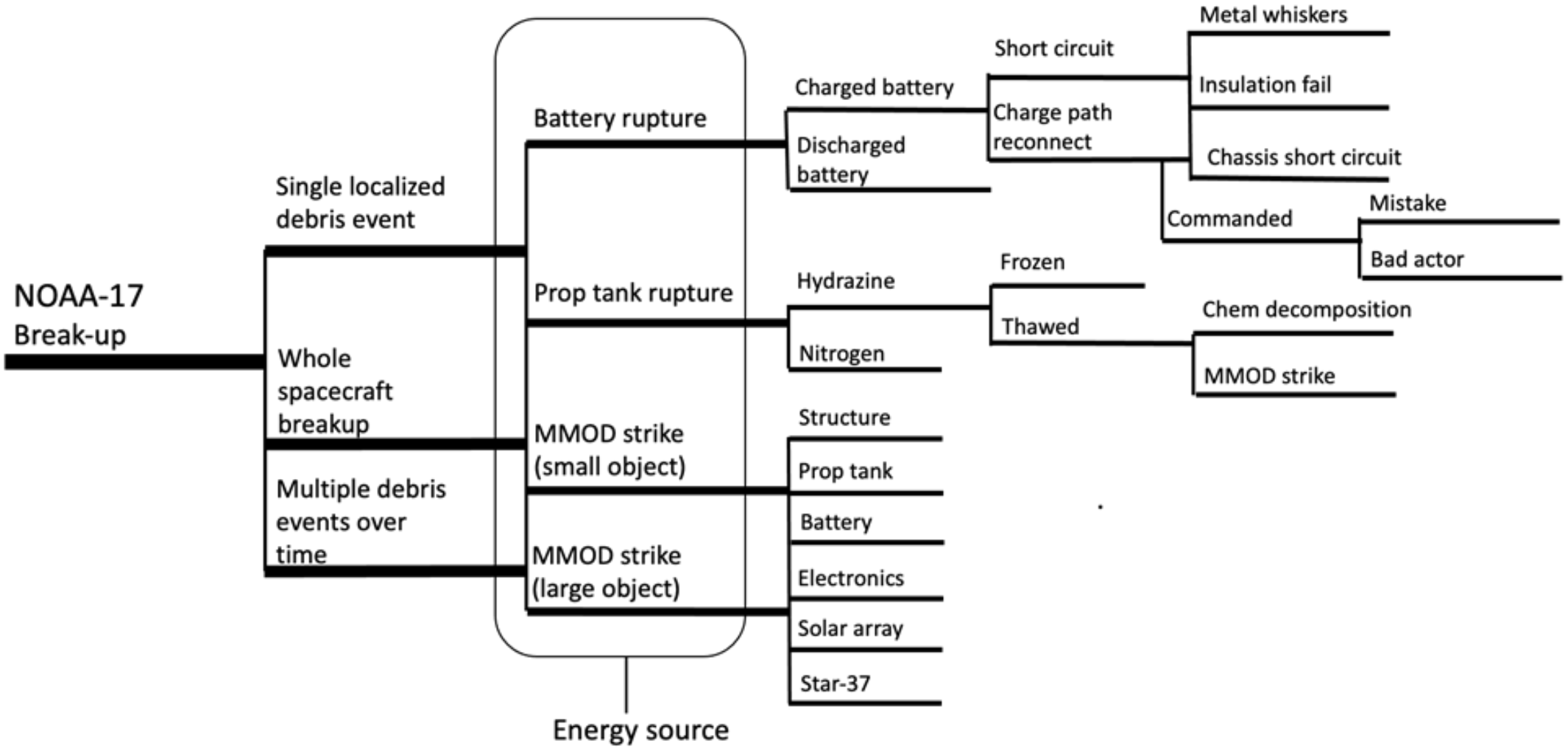
| Spacecraft | Design Family | Objects Detected/Tracked |
|---|---|---|
| DMSP F11 | Block 5D2 Family | 85 |
| DMSP F13 | Block 5D2 Family | 236 |
| NOAA-16 | Block 5D3 Family | 458 |
| NOAA-17 | Block 5D3 Family | 114 |

Tracked objects are assumed to have ~10 cm threshold size

# Investigation

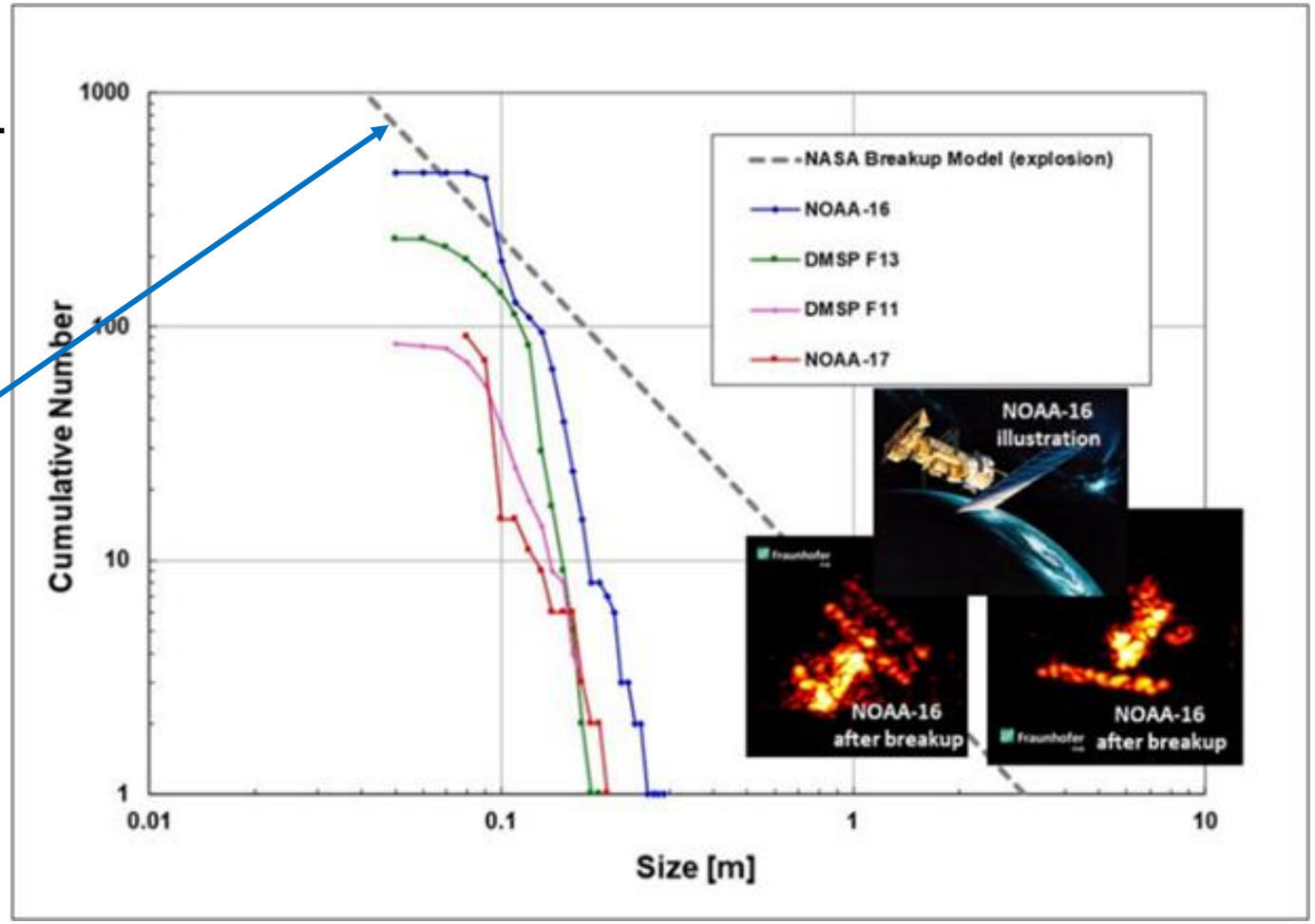
- No clear cause ‘jumped out’ based on the evidence
- Fault Tree used to associate potential causes with the observed breakup
  - Evidence, observations, and logic used to categorize potential root causes as Impossible, Unlikely, Possible, or Probable
- Identification of the Likely Debris Source
  - Debris size distribution
  - Debris orbit distribution
  - DMSP F13 history
  - Debris Area to Mass Ratio
- Examination of Potential Initiating Events
- Findings: list of possible but unlikely initiating events

# Fault Tree


NOAA-17
Break-up
Single localized debris event
Whole spacecraft breakup
Multiple debris events over time
Battery rupture
Prop tank rupture
MMOD strike (small object)
MMOD strike (large object)
Charged battery
Discharged battery
Short circuit
Charge path reconnect
Metal whiskers
Insulation fail
Chassis short circuit
Commanded
Mistake
Bad actor
Hydrazine
Nitrogen
Frozen
Thawed
Chem decomposition
MMOD strike
Structure
Prop tank
Battery
Electronics
Solar array
Star-37
Energy source

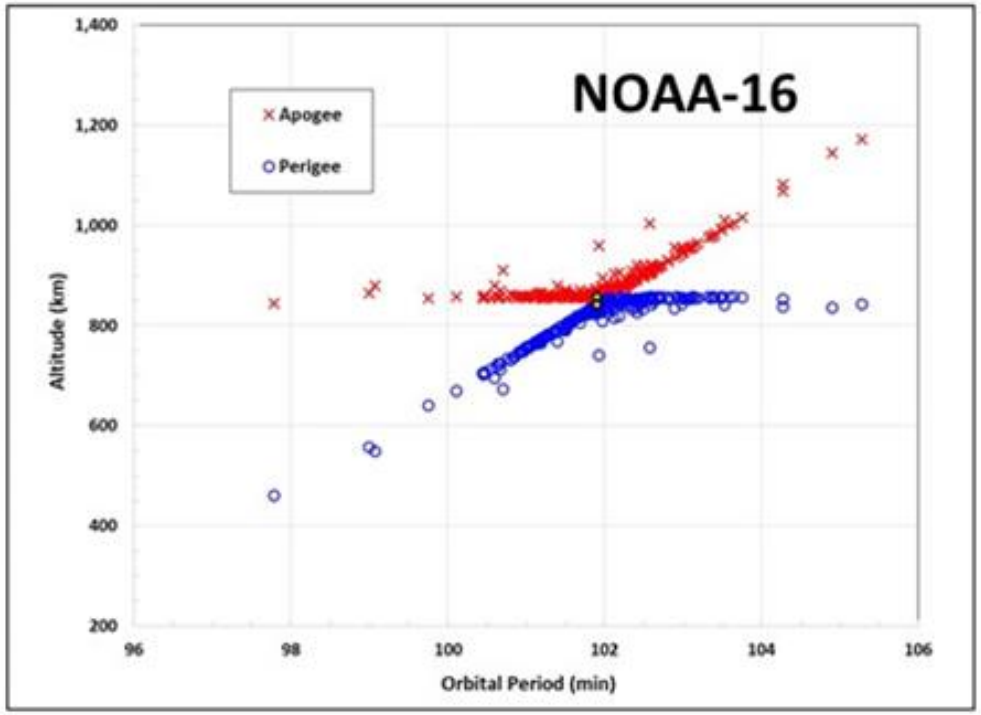
# Investigating the Likely Source of the Debris: Debris Size Distribution

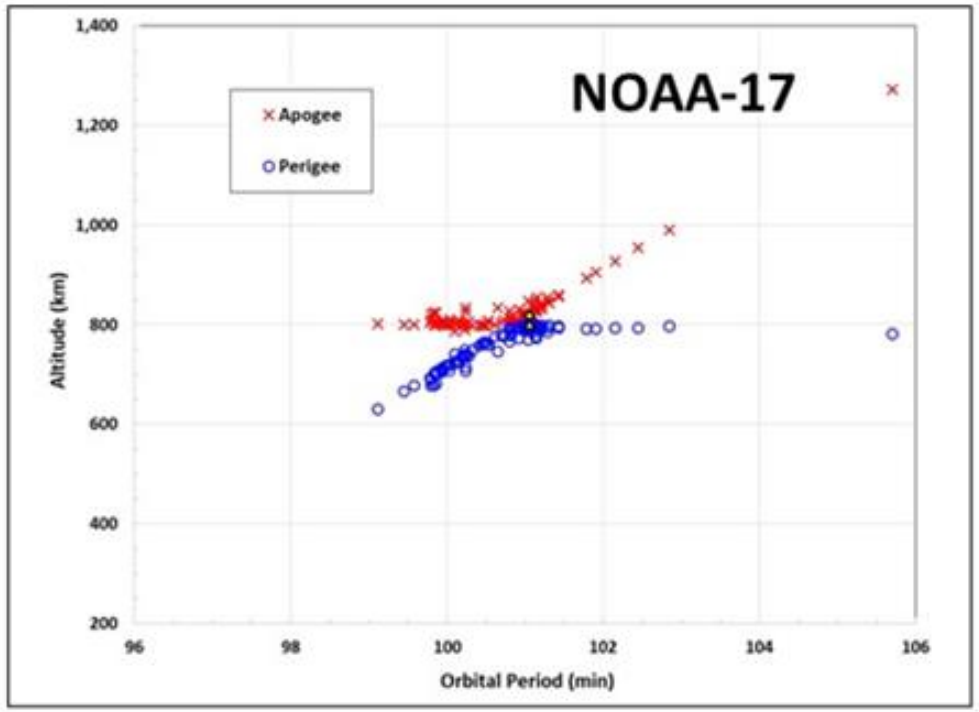
- NASA radar Size Estimation Model used along with the Radar Cross-section to determine debris characteristic length distribution
- Compared to the standard distribution for a complete spacecraft explosion: **not** consistent with an explosion
- Compared to the three similar breakups: same trends



# Investigating the Likely Source of the Debris: Debris Distribution in Orbit

- Gabbard diagrams illustrate the altitudes of perigee and apogee vs orbital period
- Suggests that the nature and the intensity of the NOAA-16 and NOAA-17 breakups were similar.  DMSP breakup diagrams also looked similar to those



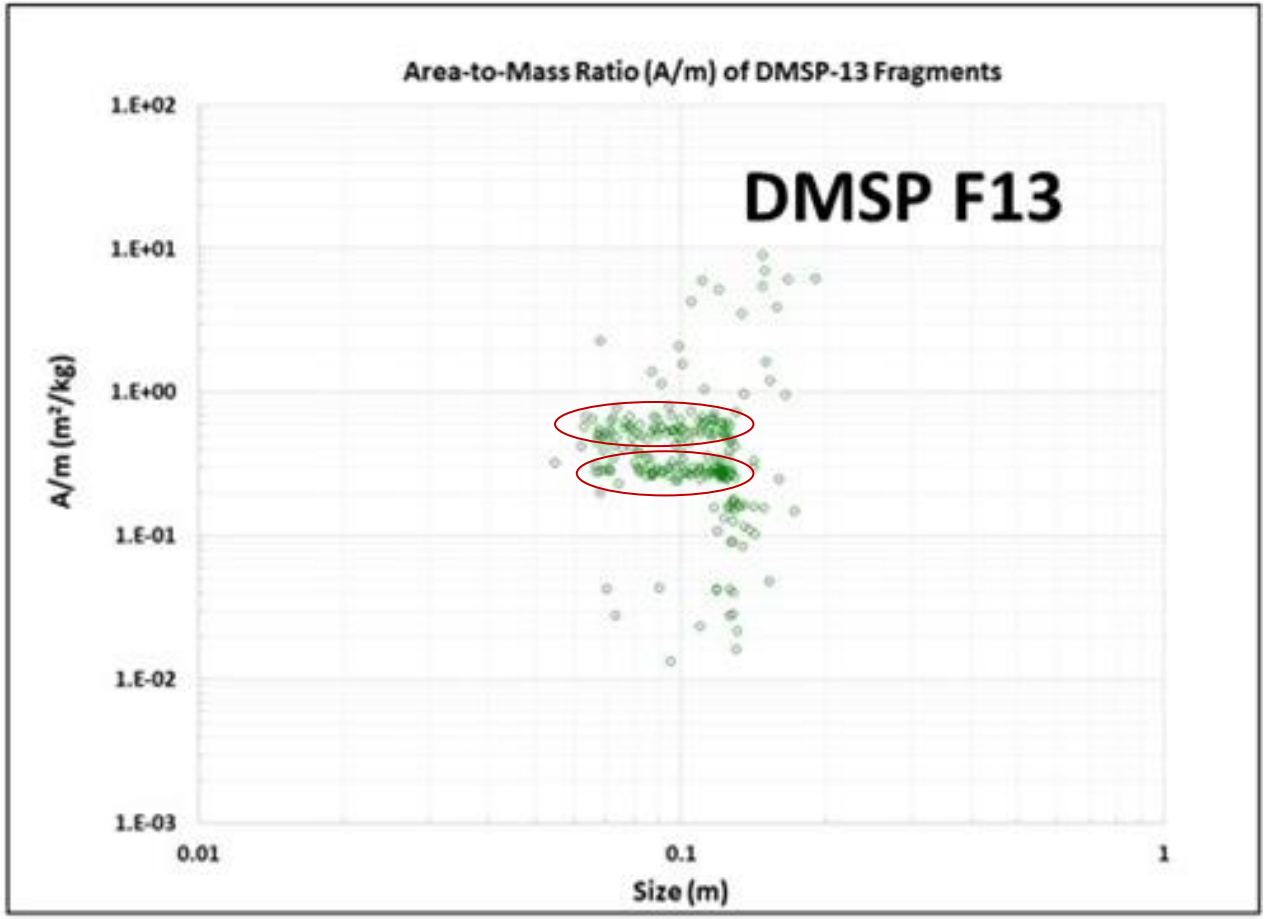



# Investigating the Likely Source of the Debris: DMSP F13 History

- DMSP F13 broke up while the spacecraft was operational
- The breakup is known from telemetry to have occurred simultaneously with a battery overcharge event
- Observed debris size distribution and orbit distribution is nearly identical for all four breakup events
- Therefore, battery rupture is believed to be the most likely intermediate cause of all four of the breakups

# Investigating the Likely Source of the Debris: Debris AMR (1 of 3)

- Area to Mass Ratio (AMR) is a key driver for long-term orbit decay
- Orbit decay history over days to weeks was used to imply an AMR for each tracked object
- Two peaks were evident for all four breakups
  - ~0.3 $m^2/kg$
    ~0.4 $m^2/kg$



# Investigating the Likely Source of the Debris: Debris AMR (2 of 3)

- Typical spacecraft components were examined for possible matches
- **Cd and Ni Battery Cell Plates match to the two peaks (0.3 and 0.4)**

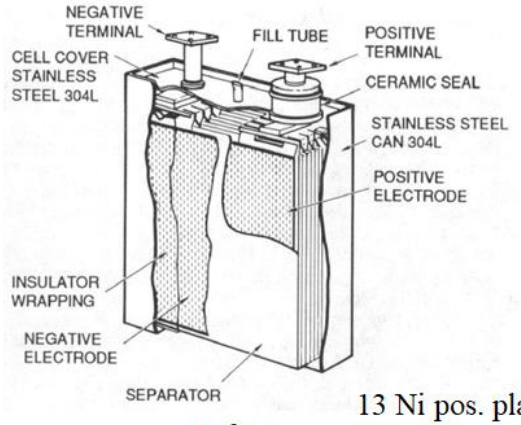
| Object | Material | Density ($g/cm^3$) | Thickness (cm) | Areal Density ($g/cm^2$) | Tumbling AMR ($m^2/kg$) |
|---|---|---|---|---|---|
| Prop Tank Wall | Ti-6Al-4V | 4.41 | 0.34 | 1.499 | 0.033 |
| 100 mil Al box wall | Aluminum | 2.70 | 0.254 | 0.686 | 0.073 |
| Battery Cell Case | 304L SS | 8.03 | 0.048 | 0.388 | 0.129 |
| **Cd Battery Cell** | **Cadmium** | **1.96** | **0.092** | **0.180** | **0.278** |
| **Ni Battery Cell Plate** | **Nickel** | **1.74** | **0.079** | **0.138** | **0.362** |
| Solar Cell | Silicon | 2.33 | 0.0254 | 0.059 | 0.845 |
| Solar Cell Cover | Fused Silica | 2.32 | 0.015 | 0.035 | 1.437 |
| Typical MLI Blanket | Kapton/Mylar | 1.42 | 0.014 | 0.020 | 2.515 |

# Investigating the Likely Source of the Debris: Debris AMR (3 of 3)

- Each battery cell contains 13 Ni and 14 Cd plates
- Battery packs (6 per spacecraft) contain either 8 or 9 cells
- NOAA-17 produced 114 tracked debris (just over 4 cells)

Cell : L: 115 mm; W : 31.5 mm, H : 165 mm, 1.62 kg


Ref. 1

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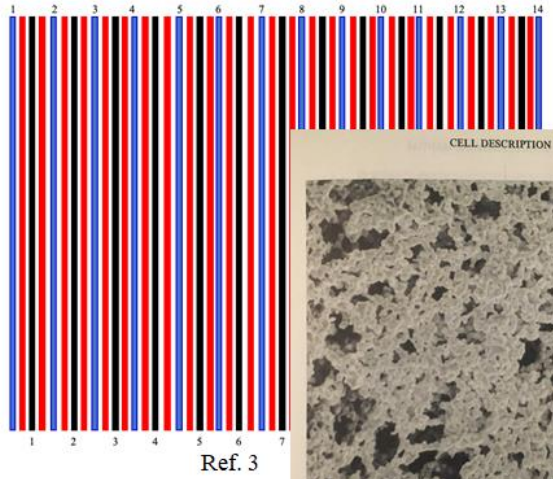


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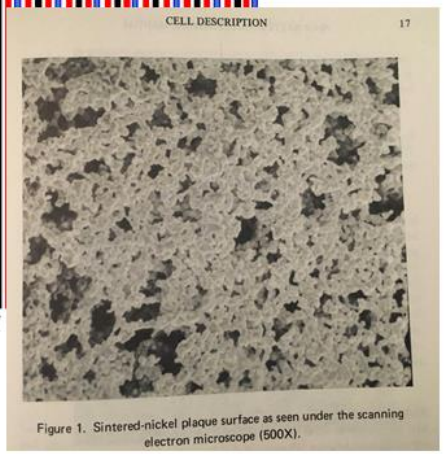



Figure 1. Sintered-nickel plaque surface as seen under the scanning electron microscope (500X).

13 Ni pos. plates (~30-45 grams)
14 Cd neg. plates (~23-35 grams)
26 separators (very thin "plastic")
Weight : 1.62 kg.

# Investigating the Likely Initiating Event (1 of 2)

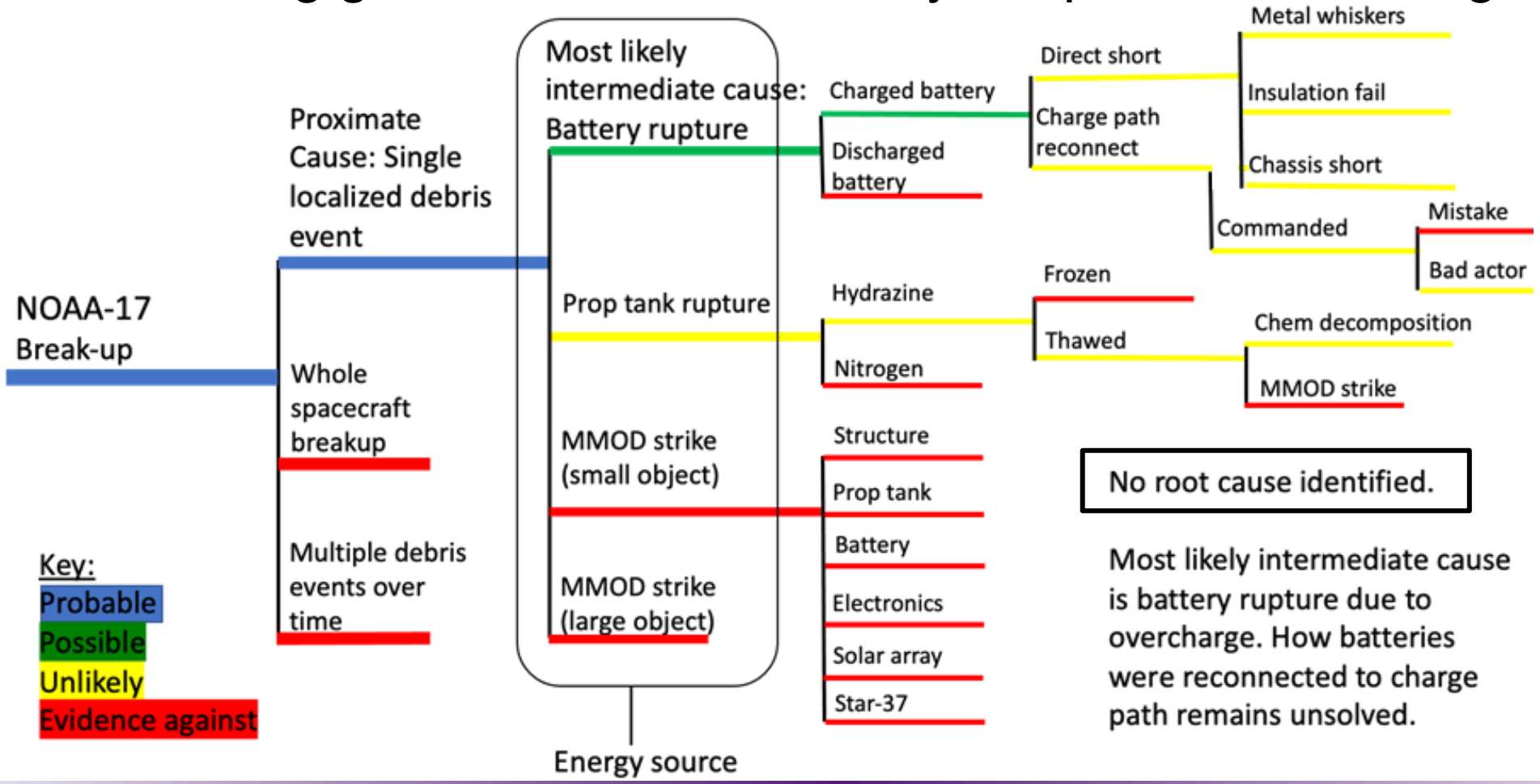
- **MMOD Strike** Initiating a Breakup
  - No tracked object seen by the US Space Surveillance Network that approached NOAA-17
  - Probability of an OD strike by almost-trackable objects is about 1 in 10,000 per year per spacecraft: **extremely unlikely**, especially considering four such events
- **MMOD Strike** Liberating Star-37 Motor Slag
  - No cases reported from exhausted motors
  - Many such motors in orbit with no widespread debris: **extremely unlikely**
- **Tank Rupture** (Hydrazine Decomposition)
  - Few objects with AMR matching Ti tank wall (0.03 $m^2/kg$ vs. ~0.3 $m^2/kg$ observed)
  - Tank rupture is considered highly unlikely as an initiating event, but proximity to the batteries and presence of isolated hydrazine means it **can't be completely ruled out**

# Investigating the Likely Initiating Event (2 of 2)

- **Battery Rupture** (Overcharge)
  - NOAA-17 is known to have been passivated at decommissioning
  - One battery still connected to the discharge path, but disconnected from the charge path
  - Reconnection to a power input needed for overcharge to occur: **three possibilities**
  - **Sneak Path**
    - Unintentional circuit path providing power to battery after passivation: **no evidence to support**
  - **Direct Short Circuit Developed Over Time**
    - Metal whiskers could grow to create a temporary switch signal, or a high power plasma: **possible, but unlikely**
    - Insulation could rub through to short power to the battery or to the chassis: **possible but unlikely**
  - **Commanded Reconnection of the Charge Path**
    - Erroneous command sent after decommissioning: numerous levels of safeguards: **very unlikely**
    - Intentional interference by a bad actor: numerous levels of security safeguards: **highly unlikely**

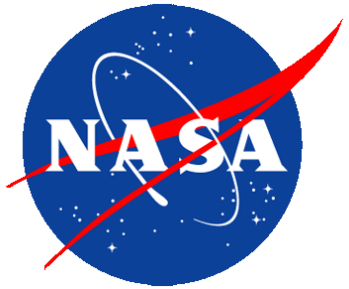
# Findings

- No clear ‘smoking gun’, but several unlikely but potential initiating events



# Summary

- NOAA-17 breakup event was found to be very similar to 3 previous events
- The four events likely shared the same debris source: a battery cell rupture
- No clear root cause for the breakups was identified that can be supported by the available evidence
- Based on the investigation, it appears all 25 of the spacecraft of related designs remain at risk of future breakups for decades to come, even if they were or will be appropriately decommissioned and passivated
- Recommendations have been provided for improved passivation, and to further the investigation
- Removal of these spacecraft from orbit should be considered




- 40 page NOAA-17 Break-up Engineering Investigation Board Final Report (public version)

https://ntrs.nasa.gov/citations/20240000154

- 10 page Summary for the 2nd International Orbital Debris Conference

https://ntrs.nasa.gov/citations/20230014958

# QUESTIONS ?