Study of Spacecraft Deployables Failures

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MOTIVATION

- Deployables failures still taking place at an average of 1 every two years
- Loss of mission goals and spacecraft performance
- Desire to understand what have historically been the most common modes of failure of deployables
- Role of the Space Environment on Deployment Anomalies & Failures
- How can we prevent these anomalies/failures from happening
- Share our findings with SCAF Community

YEARLY ANOMALIES DISTRIBUTION

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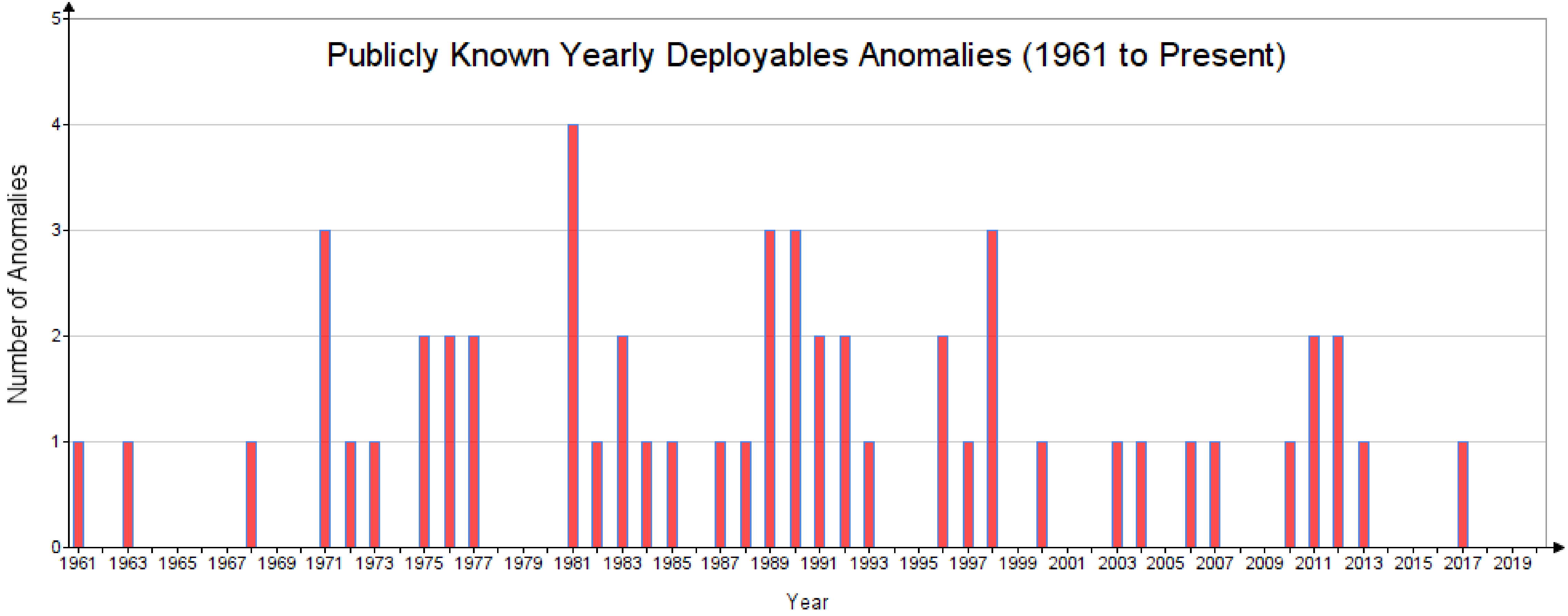

ANOMALIES BY TYPE

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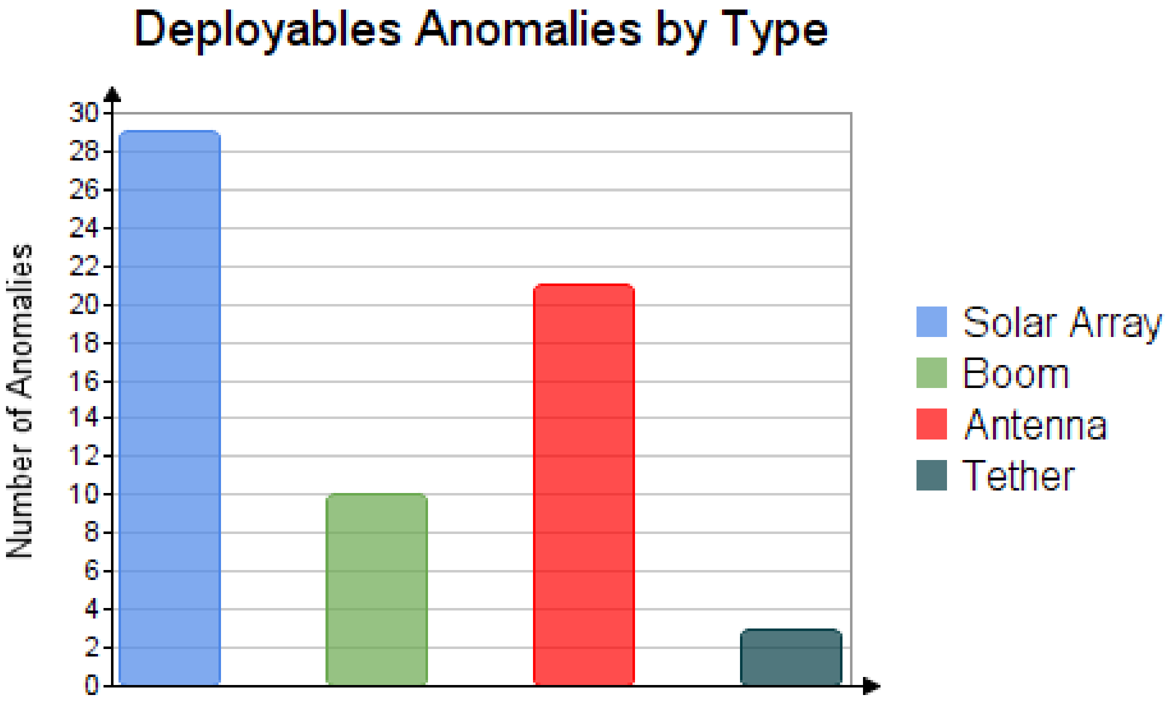

- Solar Array anomalies most common (54%)
- Antennas (37%)
- Booms (18%)

Note: Some SC had issues on more than one type of deployable.

* Based on published information. Actuals may differ.

SPACE ENVIRONMENT & DEPLOYMENT ANOMALIES, 1of 2

Two key Space Environments can affect Deployments

1. **Vacuum:**
    - Poor venting of sealed structures:
        - Honeycomb panels → explosive decompression
        - Blankets → inflation
    - Cold Welding
        - Clean surfaces of similar metal in contact and under vacuum → strong adhesion
    - Water desorption:
        - Polymers used in composites → contraction

SPACE ENVIRONMENT & DEPLOYMENT ANOMALIES, 2 of 2

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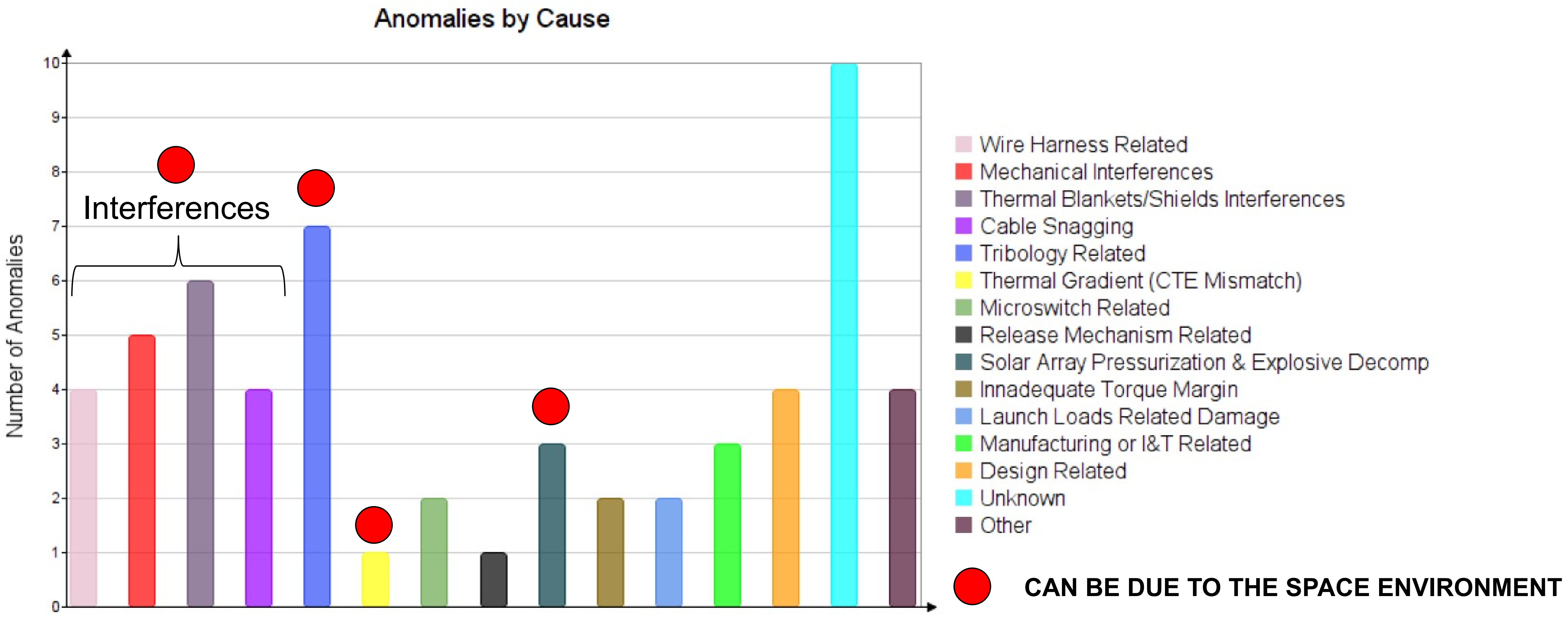
Two key Space Environments can affect Deployments

2. **Thermal:**
   - Orbital eclipse thermal extremes → approx. -173°C to +123°C for LEO (Δ=296°C)
     - SC appendages → jamming due to expansion and contraction
     - Materials selection → CTE mismatches
     - Clearances between moving parts → interferences due to thermal expansion
     - Lubricants selection
       - Cold Temps → COF increase / stiction, bearing friction, galling
       - Hot Temps → wet lubricant depletion
     - Harnesses → Increase in bending stiffness across hingeline

SPACE ENVIRONMENTAL TESTING OF DEPLOYABLES IS ABSOLUTELY CRITICAL FOR MISSION SUCCESS

MAIN ANOMALIES AND FAILURES CAUSES



* Based on published information. Actual root causes may differ.

SEVERITY

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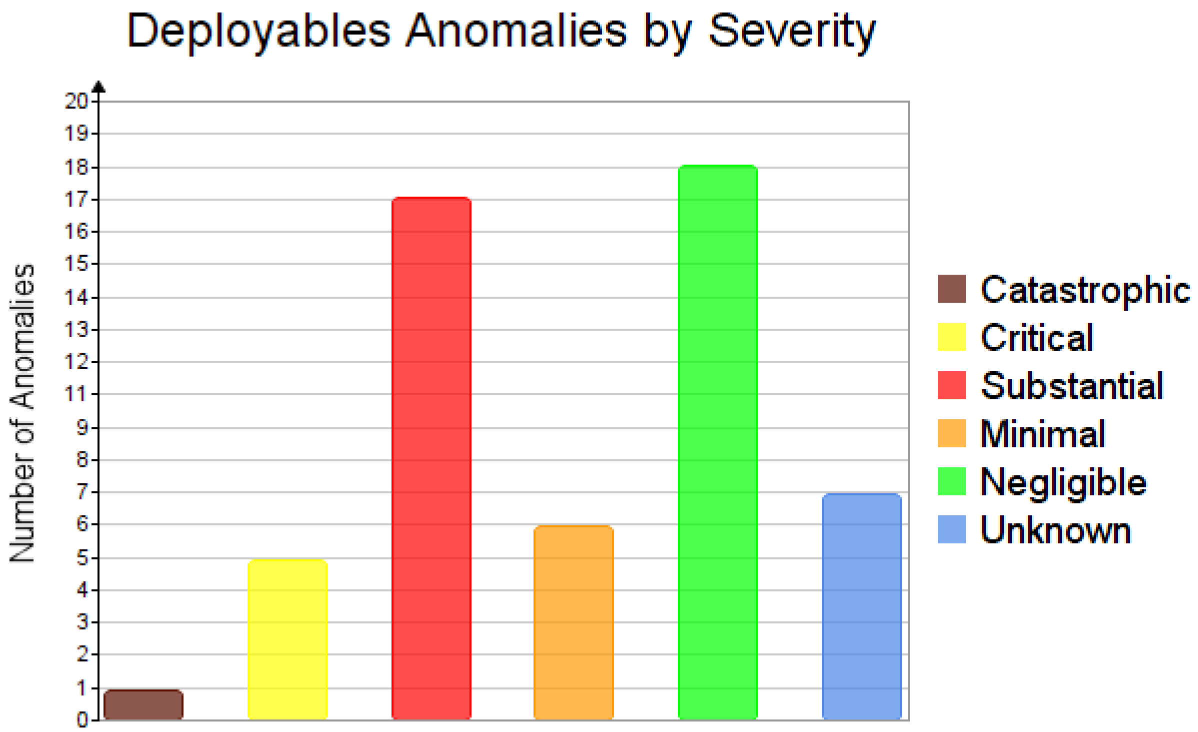

- 54% of anomalies result in some degree of mission and/or SC performance degradation (minimal, substantial, critical or catastrophic)
- 31% of anomalies results in substantial reduction of spacecraft performance and or loss of mission goals

Table 1. Failure Severity Levels

Level	Final Effect	Definition
I	Catastrophic	Loss of SC
II	Critical	Complete loss of Mission
III	Substantial	Partial Loss of Mission / SC Performance degraded
IV	Minimal	Very small loss of mission goals or SC performance
V	Negligible	No effect on mission or SC performance

* Based on published information. Actuals may differ.

INSURANCE CLAIMS

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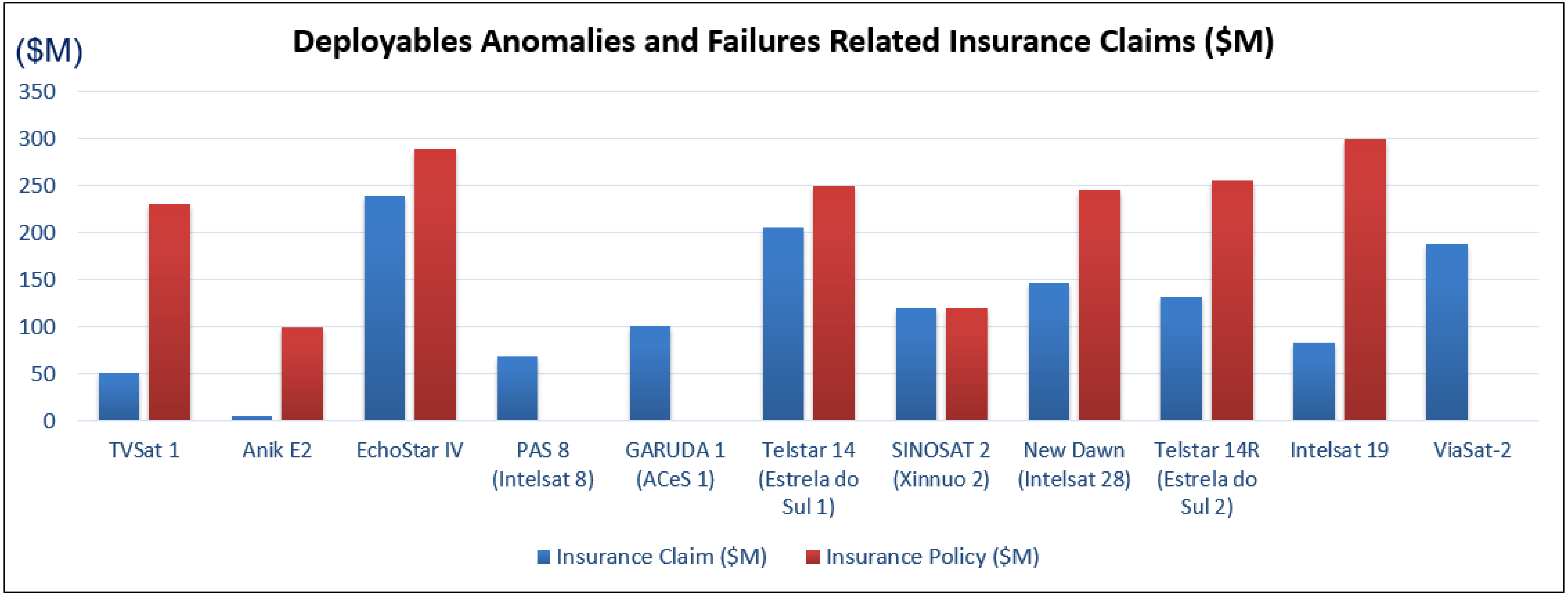

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Thermal Blankets / Shields Interferences Dawn / Intelsat 28 New

Launch Date: April 22, 2011

Anomaly #1: Ku-band antenna fails to deploy

Cause: deployment mechanisms interference with sunshield

Resolution: motor-driven deployment mechanism moved up and down to free antenna from sunshield

Anomaly #2: unable to deploy its C-band reflector antenna

Cause: antenna's spring-loaded deployment mechanism got caught in the billows of its sunshield

Resolution: Shaking of the SC unsuccessful

Consequences: Mission Life reduced by 2 years

Insurance Claim: $146M

Solid Lubricant Earth Radiation Budget Satellite

Launch Date: October 10, 1984

Anomaly: One of the Solar Arrays failed to deploy

Cause: MoS_2 exposed to excessive humidity before launch resulting in excessive bearing friction in the space environment

Trouble shooting: exposure to sun until temperature above 0 °C

TV-Sat 1

Launch Date: Nov 21, 1987

Anomaly: One of the Solar Arrays failed to deploy

Trouble shooting: Attempts to free it by spinning or shaking the satellite not successful.

Cause: Some of the hold down clips used to secure the SA panel during ground handling were not removed

Consequences: SC placed on a graveyard orbit. Total Mission Loss

Insurance Claim: $51M

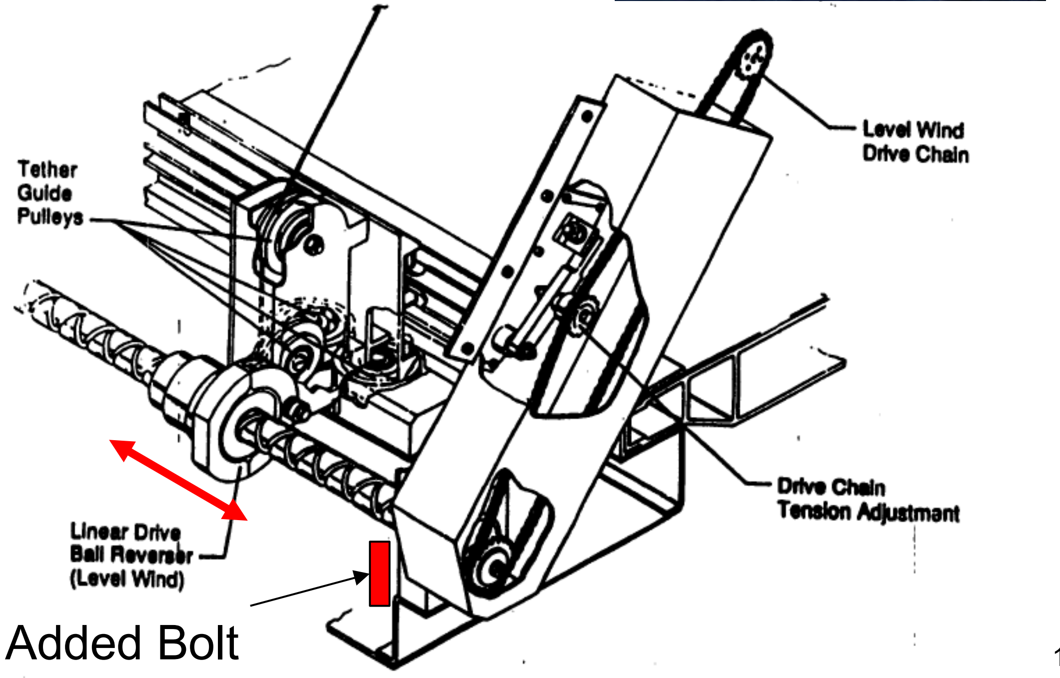
Last Minute Changes Tethered Satellite System (TSS-1)

Launch Date: July 31st, 1992

Anomaly: Reel-out mechanism jammed. Tether only released to about 256 m out of the planned 20.1 Km.

Cause: Bolt added for structural margin to address a last minute concern interfered with the reel out mechanism. Protruding bolt interfered with a traveling ball nut and thwarted satellite deployment.

Consequences: **Total Mission Loss**



Space Environment   Tethered Satellite System (TSS-1R)

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Launch Date: Feb 22nd, 1996

Anomaly: Five hours after deployment began on February 25, 1996, with 19.7 km (of 20.7 planned) of tether released, the tether cable suddenly snapped near the top of the deployment boom (within 12 m). The TSS satellite separated from the orbiter and shot away into a higher orbit

Cause: The TSS-1R Mission Failure Investigation Board established that the tether failed as a result of arcing and burning of the tether (electrical discharge through a break in the insulation), leading to a tensile failure after a significant portion of the tether had burned away.

Consequences: TSS instruments could be re-activated and produced science data for three days until battery power ran out

Partial Mission Loss

SA Explosive Decompression Telstar14, 14R, Intelsat 19

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Launch Dates: 2004, 2011, 2012

Anomaly: SA partially deployed (14, 14R) or failed to deploy (IS-19)

Cause: Inadvertent solar array pressurization and explosive decompression damaged the arrays' deployment mechanism

Consequences: all of them remained in service but with serious reductions in capacity

Insurance Claims: $205M, $132.7M, $84M
($421.7M total)

Mechanisms Failure Mars Global Surveyor

Launch Date: November 7, 1996

Anomaly: Solar Array fails to latch

Cause: input shaft of the damper sheared during SA deployment as input torque to damper was applied via a 'damper arm' which also applied a shear force the damper was not designed for.

Consequences: Aerobraking maneuvers had to be modified to put less pressure on solar panels.

New aerobraking schedule delayed reaching final polar science mapping orbit by 1 year.

Dynamic Analysis Simulations

Mars Express Issues

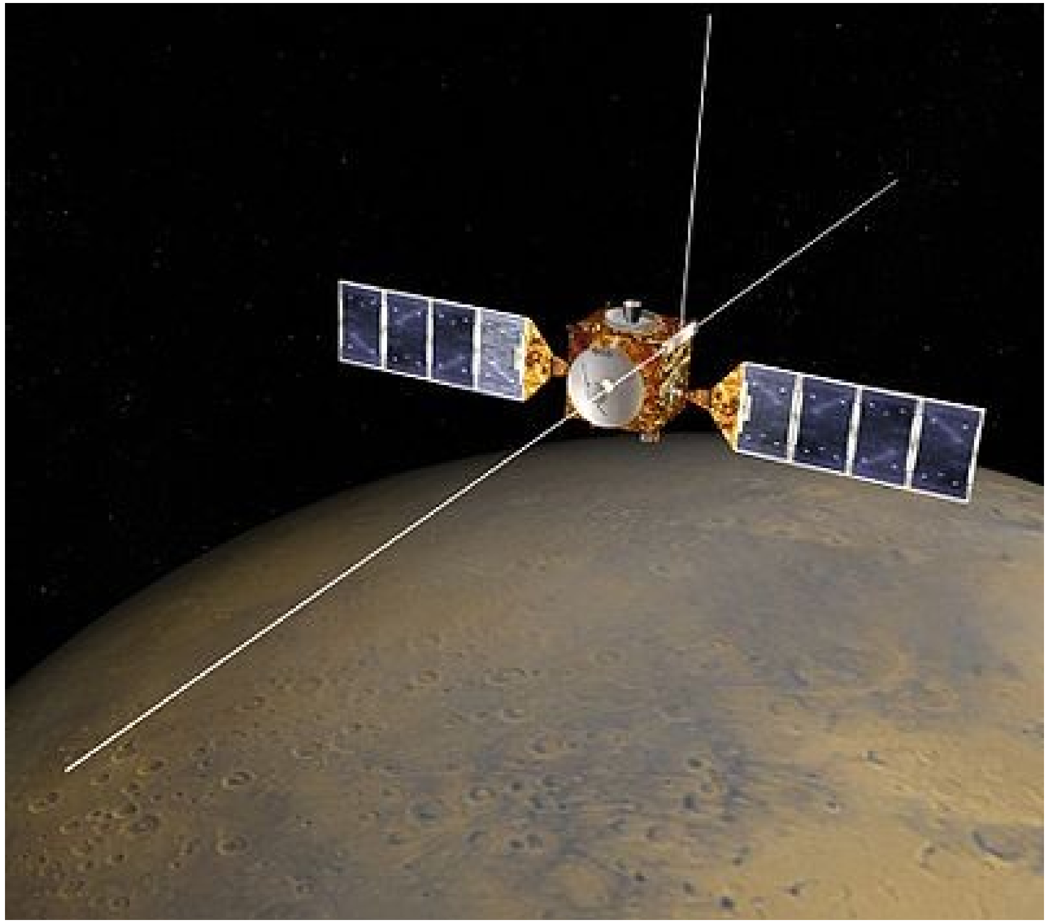
Launch Date: June 2, 2003

Anomaly: MARSIS antenna booms’ deployments delayed

Cause: Simulation enhancements on similar antenna indicated potential risk that booms could back lash and damage SC

Trouble shooting: additional contingency simulations performed to assess risks; Mitigation scenarios defined.

Resolution: 1st boom failed to deploy until after exposure to sun; 2nd and 3rd deployed successfully.



Contingency Maneuvers Anik E2

Launch Date: April 4, 1991

Anomaly: Ku-Band Antenna deployed after 2 days
C-Band Antenna did not fully deploy

Cause: Thermal blanket interference

Trouble shooting: long list of SC contingency maneuvers supported by remarkable ground team analysis and technical ingenuity

Resolution: C-band antenna deployed and mission saved

Consequences: Rescue maneuvers used a year’s worth of fuel

Insurance Claim: $5M

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Launch Date: April 23, 1967

Anomaly: Left Solar Array and backup antenna of telemetry system did not deploy; Cover of star sensor did not open due to obstruction of the undeployed SA.

Cause: SA deployment mechanism stuck

Trouble shooting: without star sensor Soyuz-1 could not maintain attitude control necessary for stabilization. Automatic and manual attempts by cosmonaut Vladimir Komarov to stabilize the SC failed. Komarov even knocked with his feet on the left side of the SC where the deployment mechanism was located.

Consequences: lack of power forced premature re-entry. Due to asymmetry of SC with just one SA opened, attitude control thrusters were not able to maintain proper orientation during braking maneuver and deviation from the nominal attitude exceeded 8 degrees. Reentry capsule descended on a ballistic trajectory and without an aerodynamic lift. Re-entry capsule crashed and burned killing Komarov.

Astronauts to the Rescue — International Space Station

Date: December 4th, 2000

Anomaly: Two rows of SA panels at the ISS Port Wing stuck together.

Cause: Snagging

Trouble shooting: Endeavour astronauts had to deploy the second of two 120ft x 38ft solar wings. The deployment which took several hours was completed, after two rows of solar panels stuck together were shaken lose by slightly retracting, then extending the arrays again.

The other solar array, the starboard wing, was deployed nonstop in about 13 minutes.

Prevention and Resolution Failures & Anomalies

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Good Practices

- Interferences
- Tribology
- Torque Margin
- Space Environment
- Launch Loads
- Assembly & Integration
- Testing
- Modeling / analysis/ simulation
- Final Stow Inspections

Pre-Flight Contingency Ops

- Computer simulations of contingency and worst case scenarios

In-Space Contingency Ops

- Firing of thrusters to spin or shake the SC
- Orienting SC to sun
- Commanding motor back and forth (if motor driven)
- Inertial load maneuvers supported by dynamic simulation analysis and ground testing if deployable mockup available

FUTURE: Robotic Servicing ?

- Preliminary studies conducted at NASA GSFC

FINAL THOUGHTS

- Spacecraft Deployables anomalies are a complex problem
- Sharing of information would be very beneficial
- Collaboration between space agencies
- Public disclosures by manufacturers that have experienced anomalies
- Reference: SC Anomalies paper with full database and anomalies, details and best practices to prevent them:

https://esmats.eu/esmatspapers/pastpapers/pdfs/2021/rivera.pdf