

Achieving Mission Success Through Effective FOD Prevention

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What Do These Missions Have in Common?



STS-107
Space Shuttle
Columbia
Feb. 1, 2003

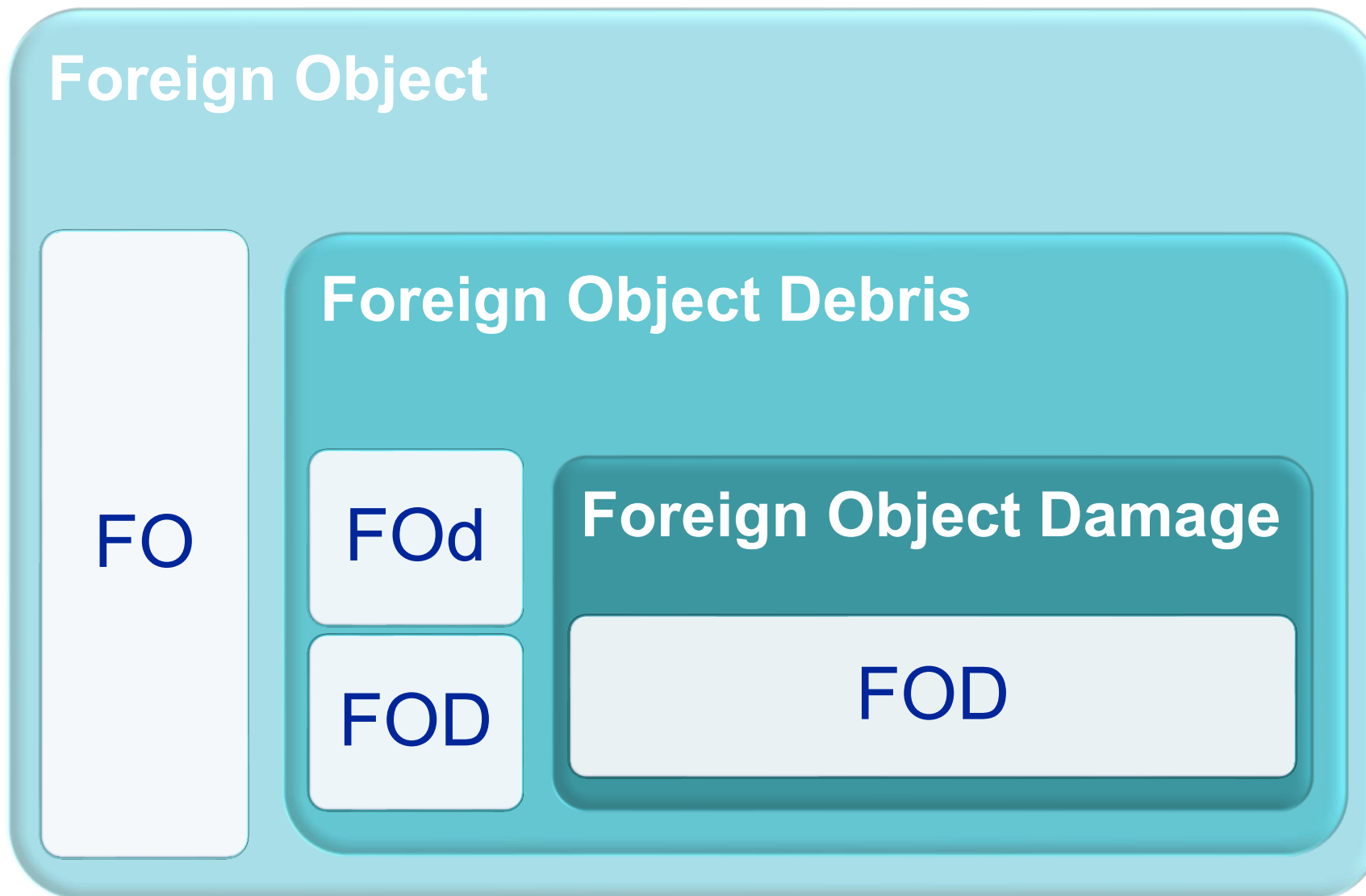


Lunar Flashlight
Launched Dec. 11, 2022



Mars
Ingenuity
33rd Flight
Sept. 24,
2022

What Is FOD?



FO: Material or objects that could enter and/or migrate into the product or system and potentially cause damage, if not removed and controlled.

Contamination is FO

Why Care About FOD and Contamination?

Safety	Illness, Injury or Death to Employees, Astronauts, or the Public
Quality	Mission Failure, Shortened Service Life, Impaired Performance
Schedule	Mission Delay, Rework
Logistics	Scheduling to Avoid Orbital Debris
Environmental	Launch Debris, Off-Planet Contamination, Sample Contamination, Habitat Air Quality
Financial	Rework, Delay, Mission Failure, Loss of Business

Who is Responsible for FOD Prevention?

Everyone involved in the design, material procurement, manufacturing, integration and launch processes are responsible for preventing FOD and contamination.

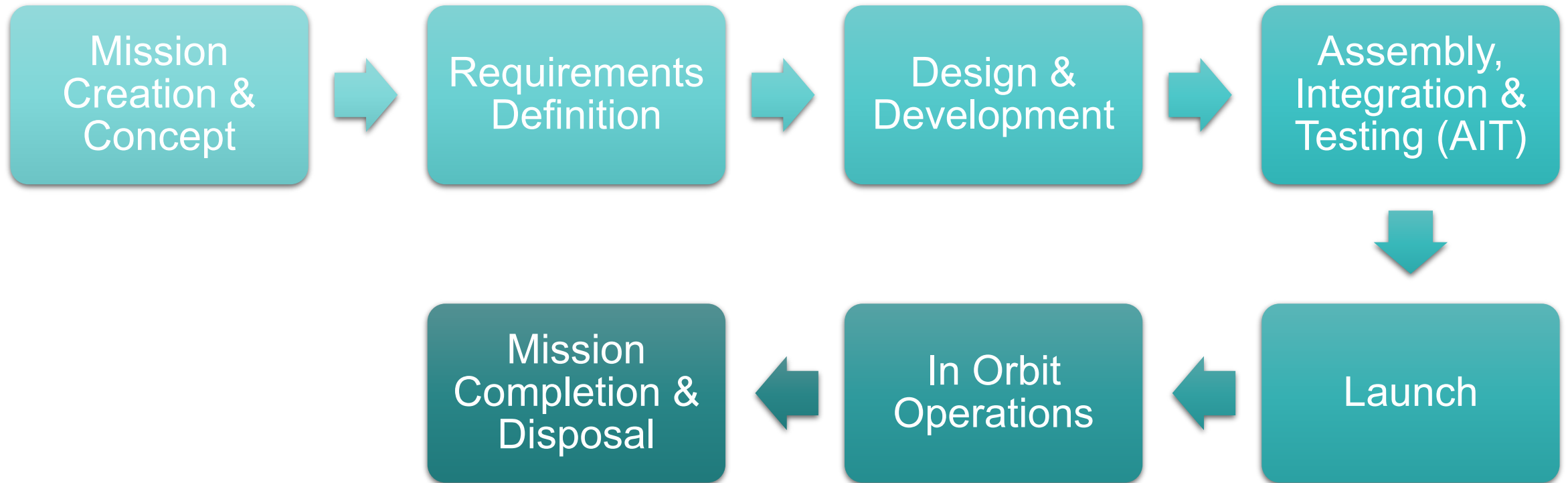
Industry Standards and Expectations

AS9100D includes “*prevention, detection and removal of Foreign Objects (FO)*” in requirements for process planning, implementation and control.

NAS-412 expects the organization to “*understand risks to product and process*” to sustain FOD prevention efforts.

AS9146 requires that FOD risks be defined and documented to establish appropriate mitigation.

FOD and Contamination Risks Must Be Considered Throughout Mission Lifecycle



Adapted from SHE 3.0 NASA Program/Project Lifecycle

NAS-412 On Risk Assessment

“The organization must understand the risks of FOD to the product or process in order to establish and sustain a robust FOD Prevention Plan. Understanding the potential source(s) of risk is key to assigning the appropriate mitigation to prevent FOD....” NAS-412 (2023) 4.12

Design, Development and Systems Engineering

Practice “Prevention Through Design”

1999 STS-93 (Columbia)

An early second stage main engine shutdown resulted in a ... under speed condition. The early shutdown was traced to a hydrogen leak ... Post-flight inspection revealed ruptures in the engine nozzle tubes caused by an impact of a loose liquid oxygen post deactivation pin...expelled during the engine start as pressure built in the liquid oxygen cavity ...

Design changes were implemented to eliminate the need for deactivation pins.

(Wikipedia, 2025)

Consider:

- Failure Modes
- Critical Characteristics
- Material Selection
- Error Proofing
- Simplifying Multi-Component Designs

Materials and Procurement

Virgin Orbit LauncherOne

Upper Stage Failure January 2023

“This is like a \$100 part that took us out,’ Hart said... It would have been relatively simple to fix,...and Virgin Orbit already decided to use a different filter on the next ... mission. However, the company, already in financial distress, filed for bankruptcy before it could launch again, its assets later liquidated.”

(Foust, J., 2024)

Consider:

- Material Selection
- Vendor Selection
- Traceability and Control
- Inspection
- Compatibility
- Change Management
- Storage Conditions

Manufacturing

1981 Atlas 76E

Excess Plastiseal blocked coolant holes causing motor failure at 19.8 seconds from liftoff 500 feet from launchpad. (Eleazar, N., 2011)

1959 Thor SM-75 IRBM

*Due to a **safety wire left in place**, the vehicle followed incorrect trajectory, ... when it was aborted, debris fell in a trailer park, cutting a trailer in half that was occupied by a mother and three children, though reported unhurt. (Eleazar, N., 2011)*

Consider:

- *PFMEA
- Training
- Work Instructions
- Manufacturing Environment
- Unplanned Activities
- Cleaning
- Inspection
- Test Conditions

*Process Failure Modes and Effect Analysis

Additive Manufacturing: Challenges and Opportunities



Consider:

- Material properties
- Raw material purity
- Build platform environment
- Finishing
- Cleaning
- NDE methods

2023 Lunar Flashlight mission failure due to clog in additive manufactured propulsion system.

“Cleaning of the lines and additional filters could have prevented the problem...the project had limited resources...(the propulsion system) was designed, integrated and tested under extreme schedule pressure.”

Assembly and Integration

1986 STS-61C

*Launch attempt scrubbed at the T minus 9 min. hold due to weather. **However, during post launch scrub operations a broken Ground Support Equipment (GSE) LOX temperature probe was found lodged in SSME #2 pre-valve post-detanking.*** (JSC Flight Safety Office, 2024)

Consider:

- Work Instructions
- Handling Practices
- Sensor Orientation
- Filters and Covers
- Cleaning
- Inspection
- Unplanned Activities

Launch and Reentry

Several other shuttle flights experienced damage to thermal insulating materials or vehicle structure prior to the Columbia Disaster including STS-27 and STS-45.



STS-107
Space Shuttle
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Feb. 1, 2003

Consider:

- Pad Debris
- Plume Effects on Vehicle and GSE
- Bird Strike Damage
- Loss or Damage of Critical Components

Space Operations

1987 Kvant-1

Trash bag outside of the docking station on Mir was discovered following failed docking attempts. (Portree, D., 1995)

1996 MIR Fire

*Solid fuel O₂ generator ignited following replacement, likely due to **latex glove contamination of lithium perchlorate canister during ground ops.** (Uri, J., 2022)*



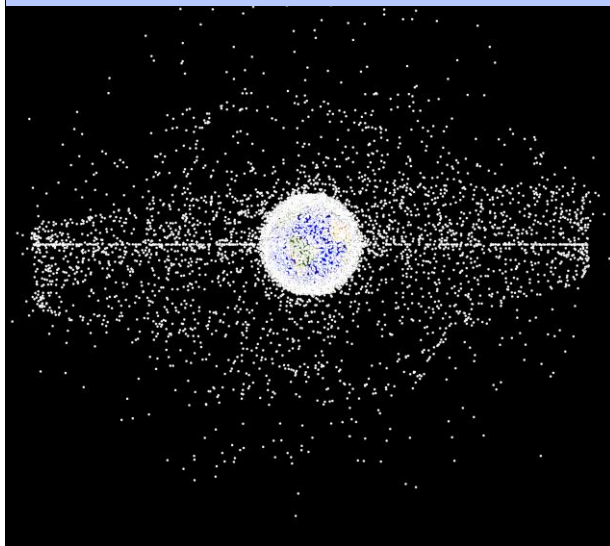
Mars Ingenuity
Sept. 24, 2022

Consider:

- Organic Buildup
- Life Support Systems
- Planetary Protection
- Sample Collection
- Detection Methods
- Bakeout and Warmup
- Zero Gravity & Vacuum
- Imported Items
- Orbital Debris

Orbital Debris – Safety, Sustainability and Logistics Concerns

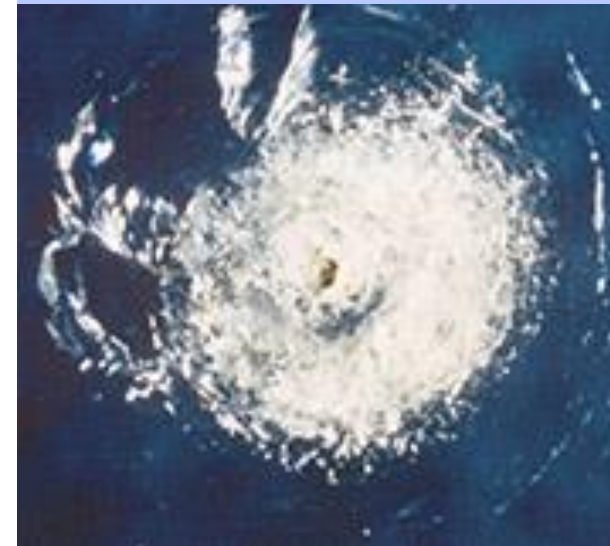
Tracking over 35,000
objects >10 cm in
diameter in orbit



Lost tools, parts, etc.
Below is a lost 2" eyebolt observed
from ISS Expedition 8



Impact Risk



Takeaways

Consider FOD Risk at Every Stage of
The Mission Lifecycle

Focus on “Prevention Through Design”

Sustainable Space Exploration
Requires Close Attention to FOD and
Contamination Prevention

FOD and Contamination Control is
Everyone’s Responsibility



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