A Systems Engineering Process to Aid in Preventing Mission Failures

Test Like You Fly (TLYF) Process

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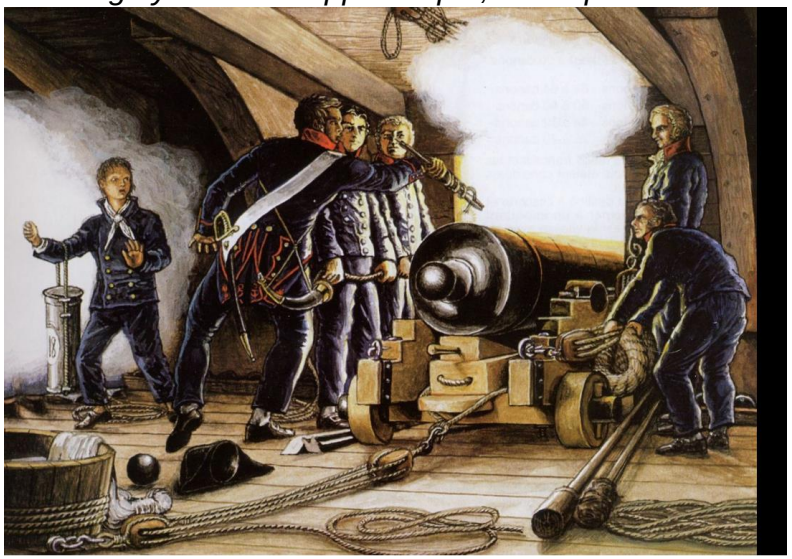
Test Like You "Fight"

Introduction of Naval Artillery – Early 15th - 16th Century

Painting by Willem van de Velde the Younger, in the public domain

Painting by Louis-Philippe Crepin, in the public domain



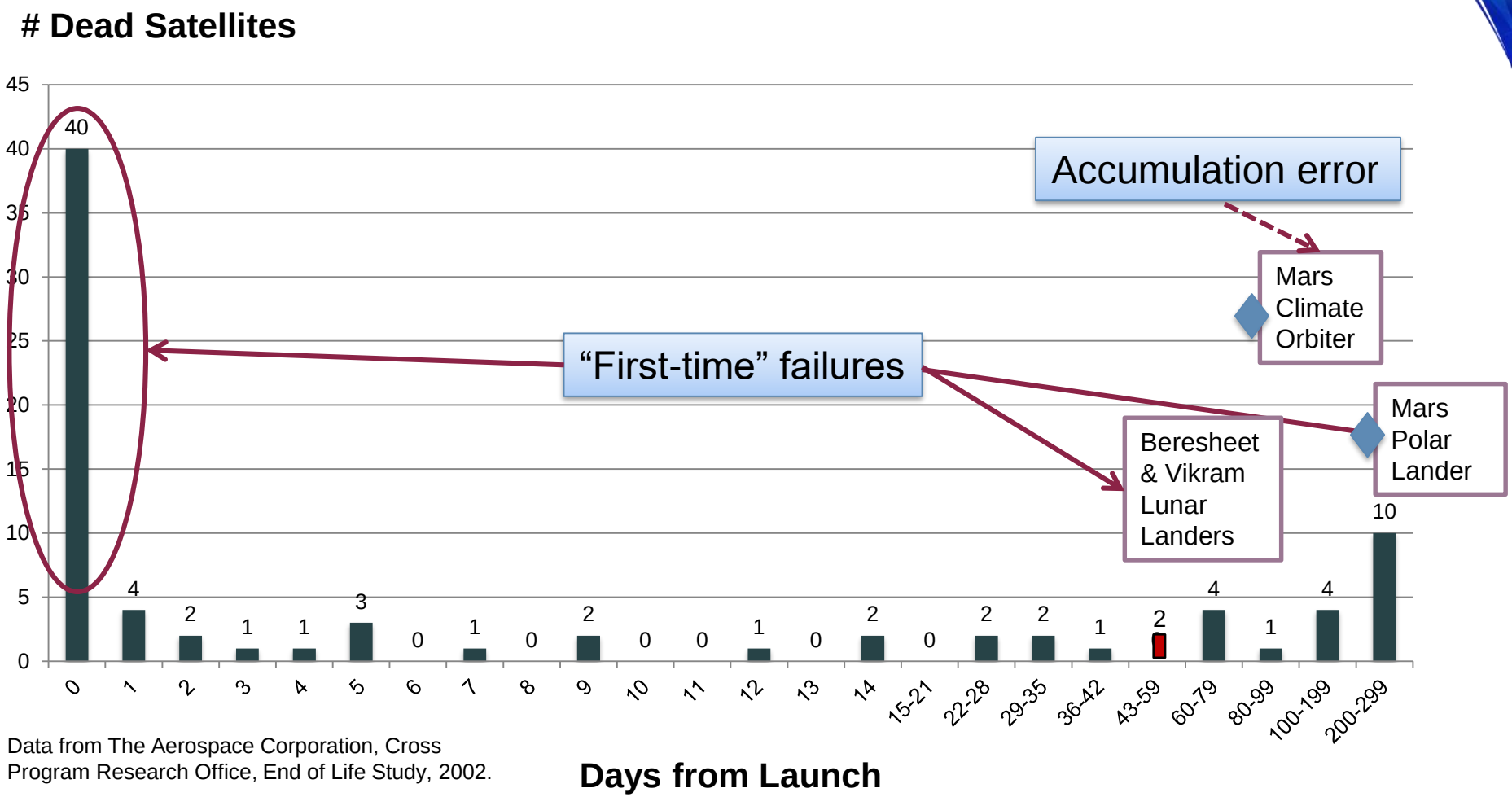
First cannons on ships fired forward and aft. Invention of the porthole allowed positioning to broadside.

The first unit permanently equipped with canons was the Nao Galicia, in 1400. Broadside cannons came much later in the century.

Addition of new technologies created the need to test complex actions and interactions PRIOR to use

Lessons from Historical Satellite Failure Data

Many of the Early Post-Insertion Losses are TLYF Escapes

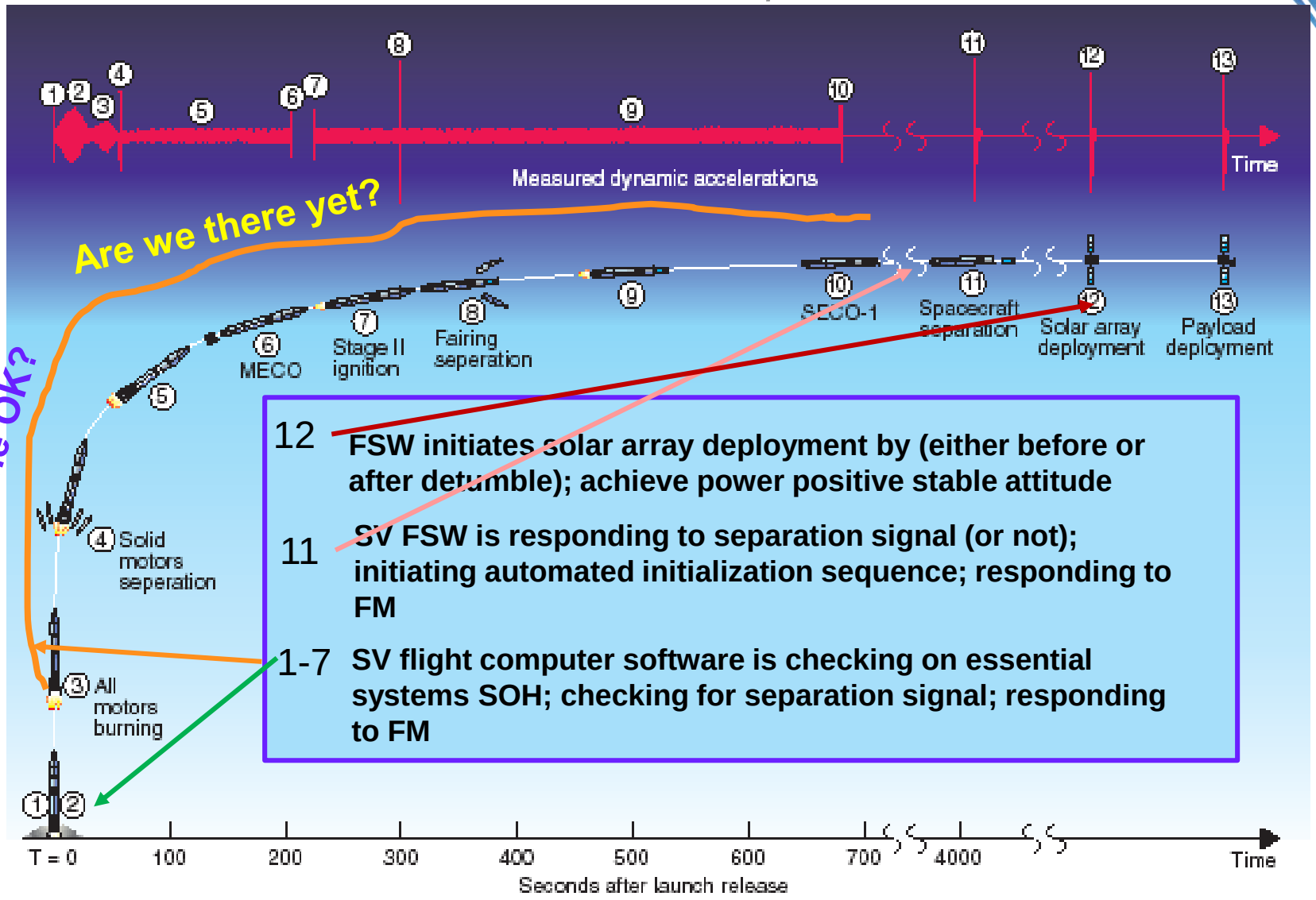


Data from The Aerospace Corporation, Cross Program Research Office, End of Life Study, 2002.

Many of the Losses Shortly After Start of Phase Are TLYF Escapes

The Test Like You Fly Process Is Mission Driven

What You Do and How You Do it Matters for Operational Based Tests



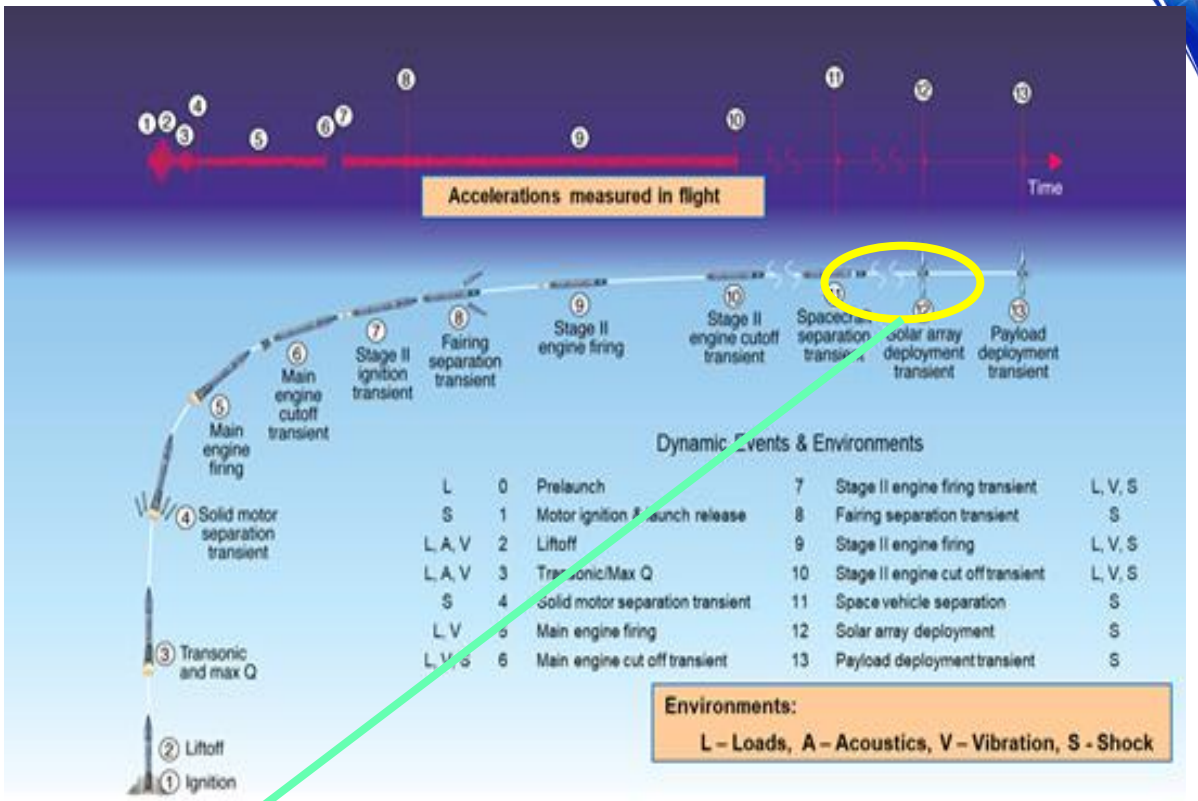
MECO Main Engine Cutoff *SECO Second Stage Engine Cutoff*

SV Space Vehicle *FSW Flight Software* *FM Fault Management* *SOH State of Health*

First Day Space System Failures

May Involve Many Elements

- **Failure to become power positive**
- **Failure to become attitude stable**
- **Failure to communicate with command & control**
- **Vehicle acquired in off nominal conditions**



Notional Functional Flow Diagram for Auto Initialization

Detumble → **Find the Sun** → **Become Power Positive** → **Orient SV for Comm** → **Initialize for Comm**

Lessons from Historical Launch Failure Data

This Is Rocket Science and It's Not Very Forgiving

Product Line	Flight #1	Flight #2	Flight #3	Flight #4	Flight #n
LV A 1	Fail	Fail	Fail	Success	End of the line
LV A 2*	Partial Success	Success	Success	Partial Fail	Success
LV B 1	Success	Fail	Success	Success	#5 Fail
LV B 2	Fail	Fail	Success	Success	#7 Fail
LV C	Fail	Fail	Partial Fail	Shutdown	
LV D 1	Fail	Success	Success	Success	
LV D 2	Success	Fail	Success	Shutdown	
LV E	Fail	Shutdown			
LV F*	Success	Success	Success	Success	#9 fail

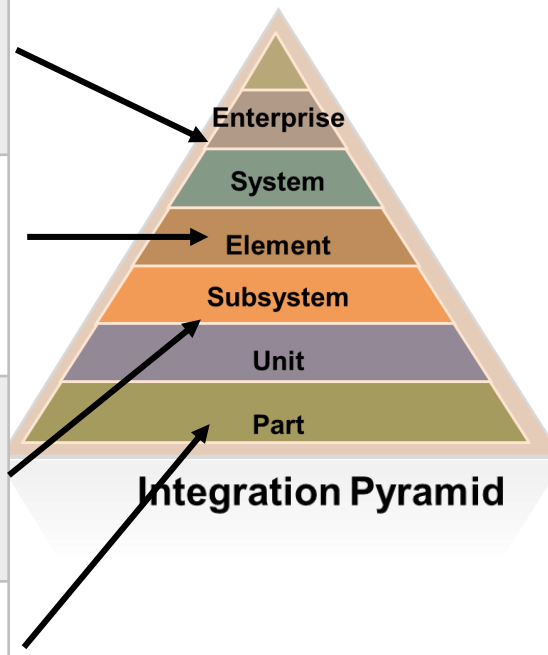
*Developed with a TLYF process

Many of the early product line losses could be TLYF escapes

Failing to Test Like You Fly

Along the System Integration Pyramid

Vehicle	Mission-Critical Anomaly & Root Cause	Integration Level of Flaw Detectability
Titan CT-2	*Failure to separate SV.* Miswire/numbering error for single payload	Integrated LV & SV
Ariane V	*Primary and secondary processor shutdown due to velocity overflow*. Inertial Reference System disabled. "Dead code" inherited from Ariane IV	Integrated Flight SW & Control Subsystem
ESEX Arcjet	*Battery explosion.* "Heritage" battery & charging system not able to sustain unique charging scheme	Payload Power Subsystem
AV-009	*Wrong orbit.* Engine fuel inlet valve did not close fully at end of first burn, resulting in overboard fuel leak during coast phase	Valve Assembly



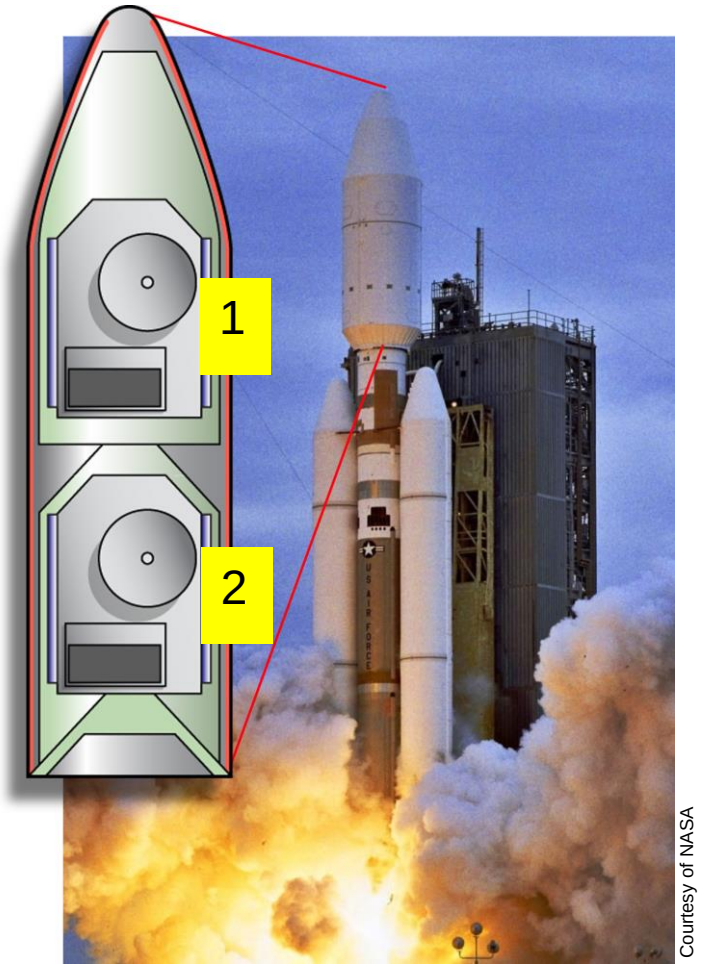
Flaws can be introduced at any level of integration and it's best to catch them there

LV Launch Vehicle

Lessons from Titan CT-2 Launch Vehicle

Assess Differences between Current & Previous Missions

- Previous mission <u>different</u> from current mission
  - *Differences not accounted for in test program*
- Payload separation error due to incorrect electrical wiring
  - *Can you count to 2 if there's only 1?*
- Lesson: Test What You Fly
  - *Heritage doesn't confirm changes & differences*
- Lesson: Test How You Fly
  - *Test across mode and phase transitions*



Courtesy of NASA

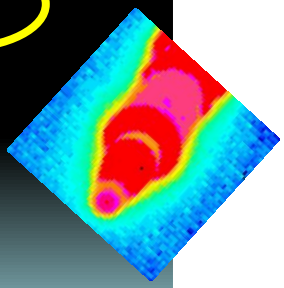
Loss of Mission

Thermal Environment Consideration

Mission Operational Consideration

Dynamics and thermal testing are analysis based and have measurable results

Operationally realistic testing is based on mission timelines and use cases. They have criteria based results



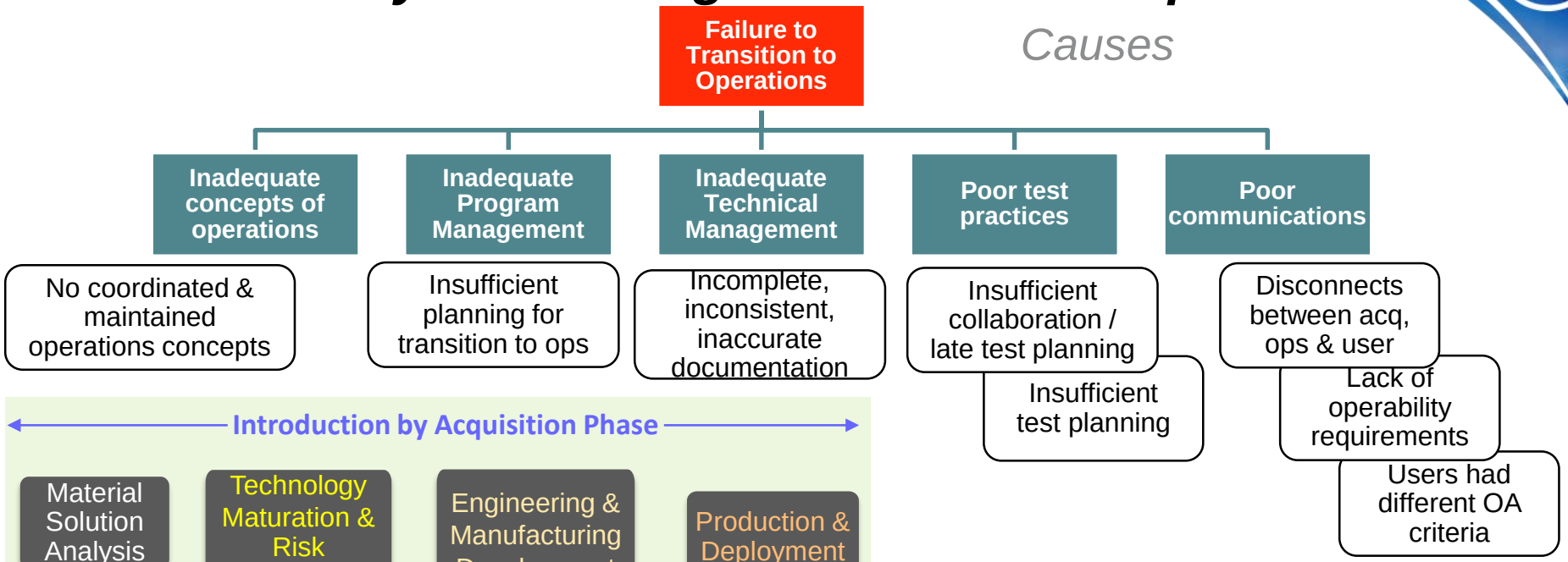
	Event	Heating Source	Cooling Environment
1	Factory / Transportation / Field	Ambient Temperature, Electronics	Convection, Air Conditioning
2	Launch Pad / Captive Carry	Ambient Temperature, Electronics	Convection, Air Conditioning
3	Initial Ascent	Fairing Temperature	Convection
4	Payload Fairing Jettison	Solar, Free-Molecular Heating, Earth IR, Albedo	Space Environment
5	Transfer Orbit, Park Orbit	Solar, Earth IR, Albedo, Electronics	Space Environment
6	On-Orbit	Solar, Earth IR, Albedo, Electronics	Space Environment

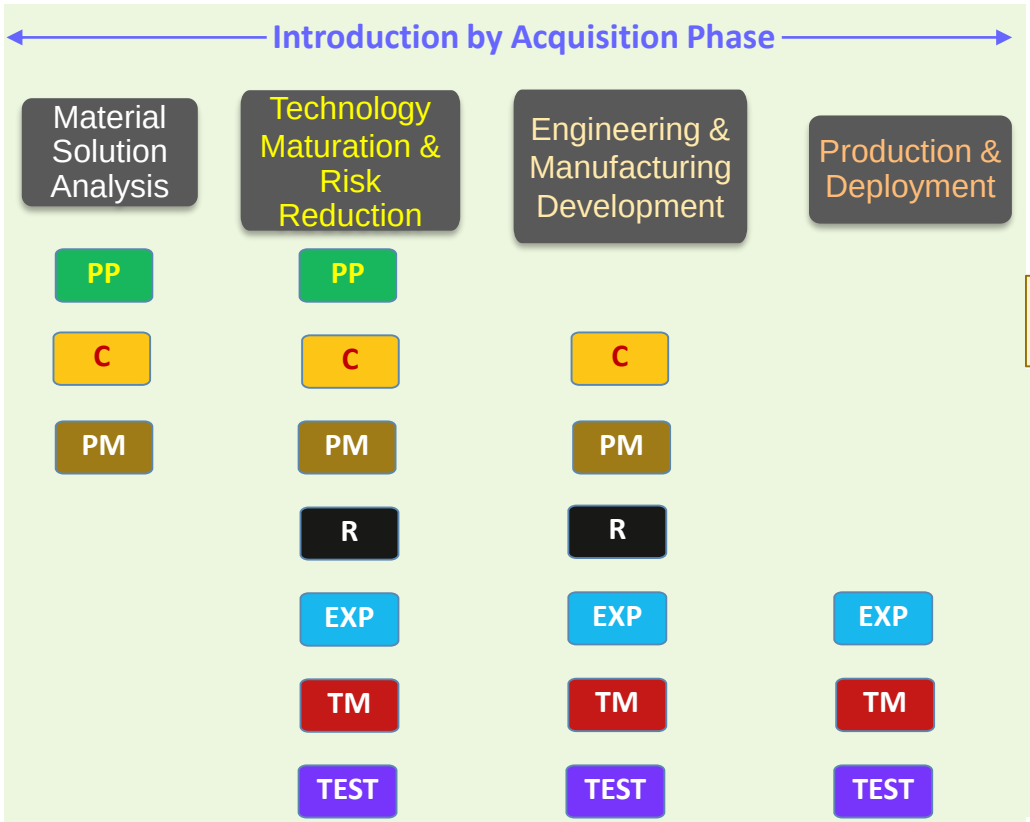
Photo courtesy of NASA

Primary thermal control is a balance between environmental and equipment heating with cold space

Mission operations is a time driven set of activities and information transfer between a satellite and ground

The Goal of Systems Integration: Mission Operations





From TOR-2018-0669, Development Test / Operational Test Transitions to Operational Acceptance Lessons Learned

- Program Planning
- CONOPS
- Program Management
- Requirements
- Expectations Management
- Technical Management
- Test Processes / Execution

Lessons from Mars Polar Lander*

Test What You Fly

- **Faulty touch down sensor logic caused vehicle to crash**
- **An operationally realistic test had been run, a hardware problem was detected and repaired**
- **<u>Lesson</u>: Test What You Fly**
  - *A repaired item is a different entity than the pre-repair item*
- **<u>Lesson</u>: Test How You Fly**
  - *Test across a range of initial conditions*
  - *Test across mode and phase transitions*

Mars Polar Lander

Courtesy of NASA/JPL-Caltech

Loss of Mission

****Report on the Loss of the Mars Polar Lander and Deep Space 2 Missions, JPL Special Review Board, March 22, 2000.***

Lessons from Mars Climate Orbiter*

Identify LYF Tests for Ground/Space Interactions

Mars Climate Orbiter

Courtesy of NASA/JPL-Caltech

- **English-metric units mismatch error**
  - *Ground software was deemed "non-critical"*
- **Lesson**: Anything that touches/interacts with critical flight equipment and processes is itself, by definition, "critical"
- **Lesson**: Understand the end-to-end flow of interactions and transactions
- **Lesson**: Understand the potential paths to failures from handoff errors

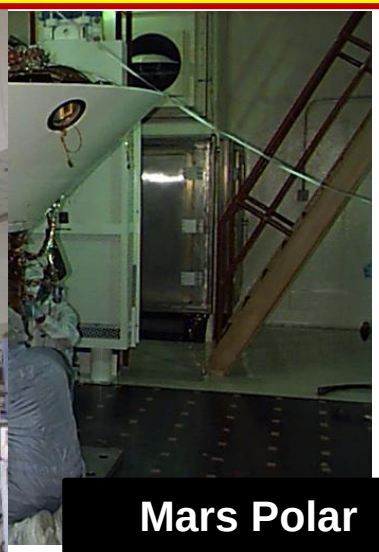
Loss of Mission!

***** *Mars Climate Orbiter Mishap Investigation Board Phase I Report, November 10, 1999.*

Lessons from the Mars Program

Two Failed Missions

Mars Climate Orbiter
Sept 1999



Courtesy of NASA/JPL-Caltech

Mars Polar
Lander
Dec 1999

Test Like You Fly

Communicate!

What could possibly go wrong?

Team sport

Think ahead

- **Failure review board findings**
  - *Project-level decisions should be made with full representation by all project elements with expertise relevant to the decision issue*
    - …future projects must review their operational scenarios and mission timelines for consistency with their Mission Plans and to determine the necessary planning is in place to support their risk management strategies

Recommendations…

- *Increase the amount of formal and informal face-to-face communications with all team elements,… especially for those elements that have critical interfaces*
- *a systematic assessment of all potential failure modes*
- *Utilize established risk management tools such as fault-tree analysis and FMECA*

FMECA Failure Modes, Effects, and Criticality Assessment

Lesson From Mars Odyssey*

Do a Pre-Mortem During Design Phase

- **Mars Odyssey, the next Mars mission to follow the two Mars failures in 1999, pioneered a method of holding the "failure review board" prior to launch**

What could possibly go wrong?

- **Method puts the focus on identifying flaws that can kill or severely wound the mission**
- **Use those revelations to focus the test program to validate or exonerate the existence of those flaws**
- **Lesson: Do the "mission failure" investigation pre-launch**

Courtesy of NASA/JPL-Caltech

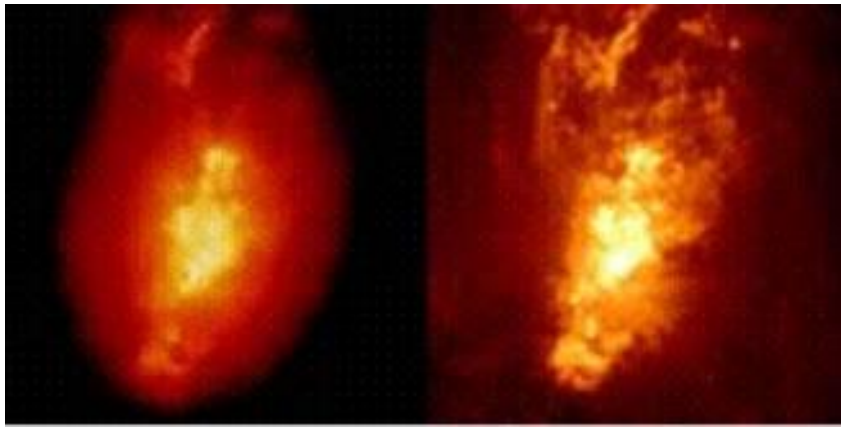
Mars Odyssey February 2002

** Beutelschies, "That One's Gotta Work"* IEEE, 2001*

Successful Mission!

Lessons from Hubble Space Telescope

Everything You Wanted to Learn about TLYF



Courtesy of NASA/Space Telescope Science Institute (STScI)

Before *After*

Test Like You Use

- **Lesson:** Conduct end-to-end tests of integrated equipment
- **Lesson:** Critical fault-related risks that cannot be exonerated should be identified and elevated

Communicate!

Courtesy of NASA/Space Telescope Science Institute (STScI)

Think ahead

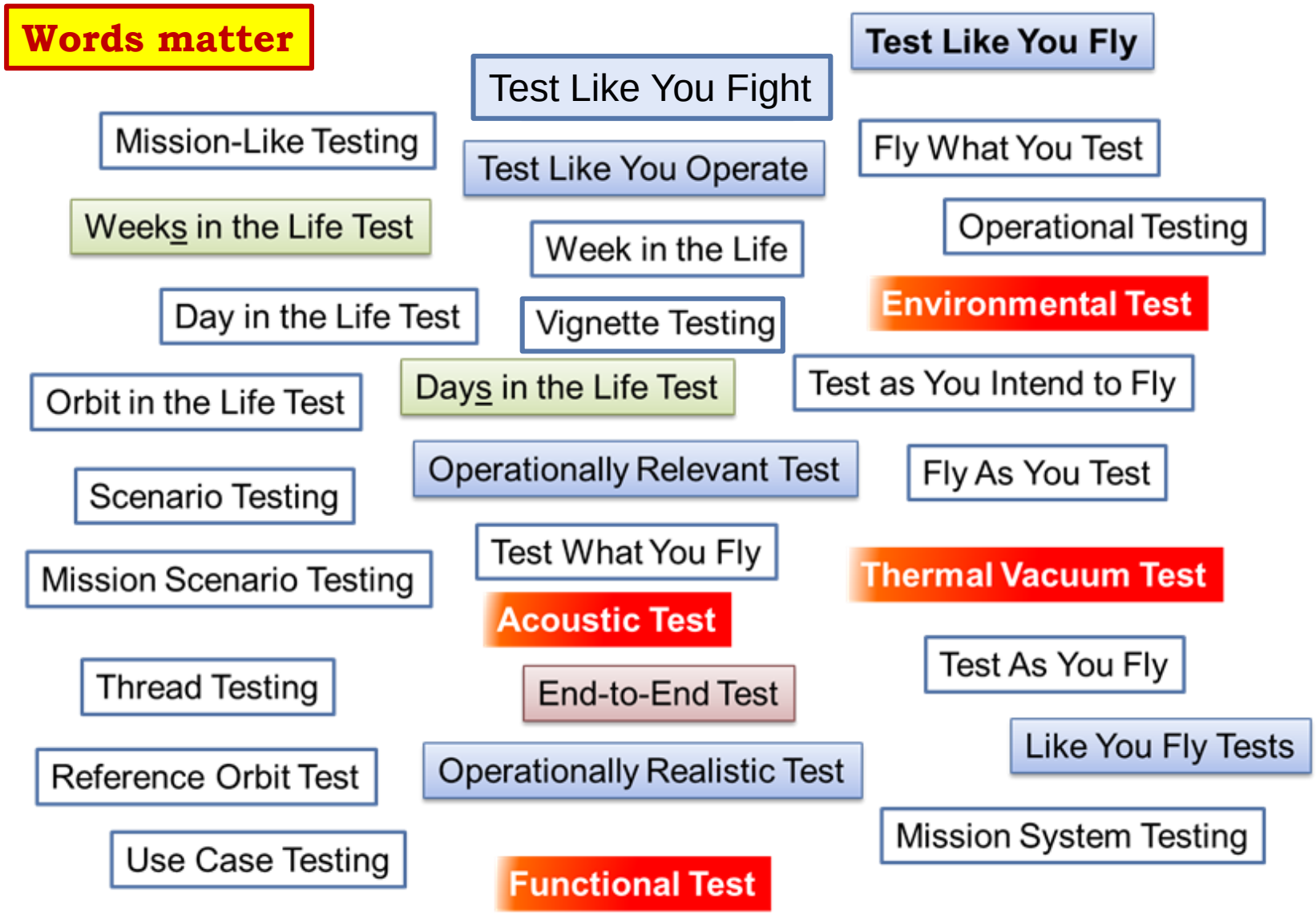
Lesson: Identify and mitigate risk*

"The Project Manager must make a deliberate effort to identify those aspects of the project where there is a risk of error with serious consequences for the mission. Upon recognizing the risks the manager must consider those actions which mitigate that risk."

Initial Severe Degradation to Mission

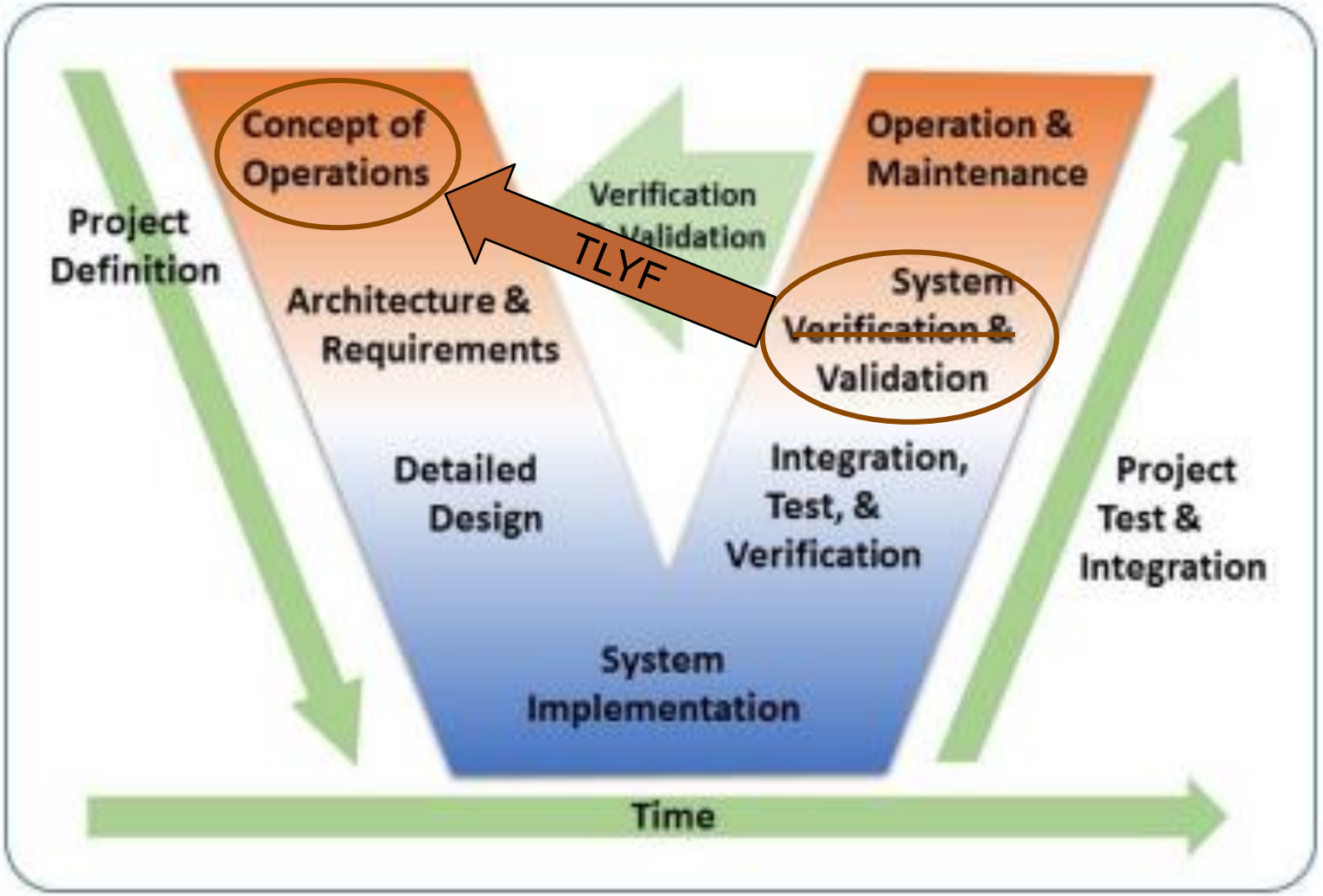
The Hubble Space Telescope Optical Systems Failure Report, NASA, November, 1990

"What we have here is a failure to communicate"



Tests Aimed at Validation of Concepts of Operations

Test Like You (Fly, Operate, Use, Fight)



Systems Engineering Junior Handbook, The International Council on Systems Engineering LA Chapter, 2015, version 1.0

Guiding Principles for Operationally Realistic "Like You Fly" Testing

- **First**
  - *The system should never experience expected operations, environments, stresses, or their combinations for the first time during the mission**
- **Second**
  - *Do not subject the system to potentially damaging situations*
- **Third**
  - *LYF testing complements but does not replace other forms of perceptive testing (e.g., environmental, stress, performance, and functional testing)*
- **Fourth**
  - *When unable to test mission-critical fault paths in an operationally realistic manner, manage the critical fault risk*

Murphy is alive & well & working overtime on your program!

** D. Shelton, S. Roskie, Applying the Test Like You Fly Principle, 20th Aerospace Testing Seminar, USAF/The Aerospace Corporation, Manhattan Beach, CA, October 2001*

Test Like You Fly—The Implementation Process

Definition

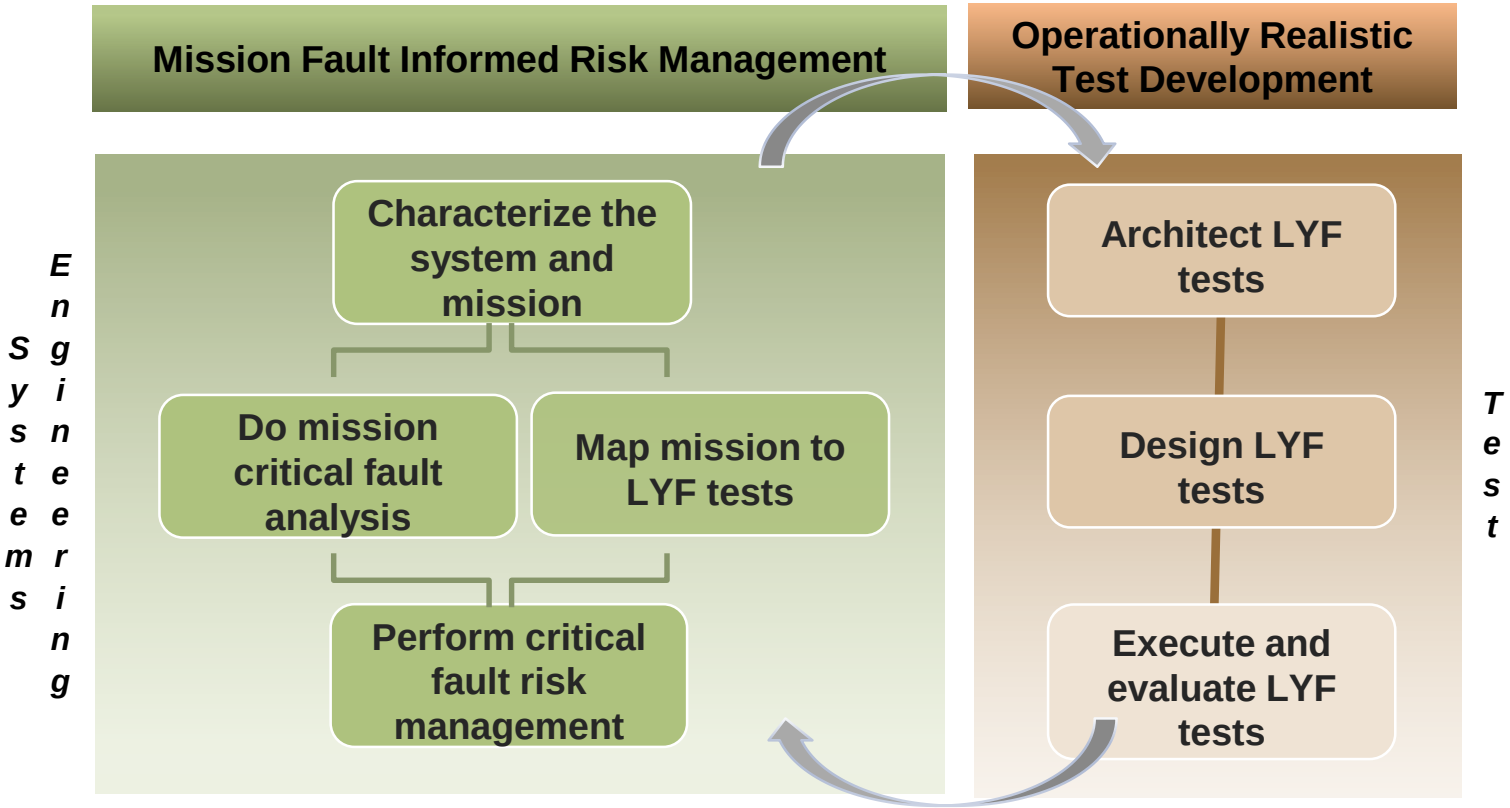
- *Test Like You Fly* is a prelaunch/pre-operational systems engineering *process* that translates mission operations concepts into perceptive operationally realistic tests to detect latent mission-critical flaws and assesses the risk of missing those flaws when it is not feasible to do those tests or adequately represent key mission characteristics while executing such a test
  - *The TLYF process is a comprehensive approach to **validate** a system's capability to perform the mission prior to launch or fielding*
  - *The TLYF process goes beyond the test domain; it also relies heavily on systems engineering disciplines*
- "Like You Fly" testing is a method to find flaws in the actual system to ensure its ability to perform the mission post-launch

The TLYF process results in operationally realistic "like you fly" (LYF) tests that address potential mission-critical flaw paths and contributors

TLYF Process Implementation

Systems Engineering and Test Development Interaction

The TLYF Process will be taught on August 17-18 4 – 6 pm Pacific. Hosted by INCOSE-LA. *Registration Link:* http://events.r20.constantcontact.com/register/event?oeidk=a07eh6kmtkz6b52317e&llr=l4ihvgeab



The TLYF Process has both System Engineering and Test aspects

** TOR-2014-02537-REV A - The Test Like You Fly Process Guide for Space, Launch, and Ground Systems, Julia D. White and Lindsay G. Tilney, September 30, 2016*

Backups

TLYF Pyramids

Allocating Operationally Realistic Tests