AEROSPACE
Assuring Space Mission Success

Applying the "Test Like You Fly" (TLYF) Process To Flight Software Testing

Julie White
Senior Project Engineer
Enterprise Mission Assurance
Corporate Chief Engineers Office
(310) 416-7229
Julia.D.White@aero.org

Lindsay Tilney
Senior Project Leader
Software Systems Acquisition
Software Systems Assurance Department
(310) 336-7104
Lindsay.G.Tilney@aero.org

“Like You Fly” (LYF) Is Mostly About the Software

The TLYF Process was created based on lessons learned from a large number of mission failures

- Many of those failures resulted from issues that were either software specific, software – hardware interaction issues, software – software issues, or software – people/ process issues
- LYF tests run on testbeds and on flight vehicles predominantly discover software-related issues
- This presentation is intended as a very brief overview of how to apply the TLYF process to software testing

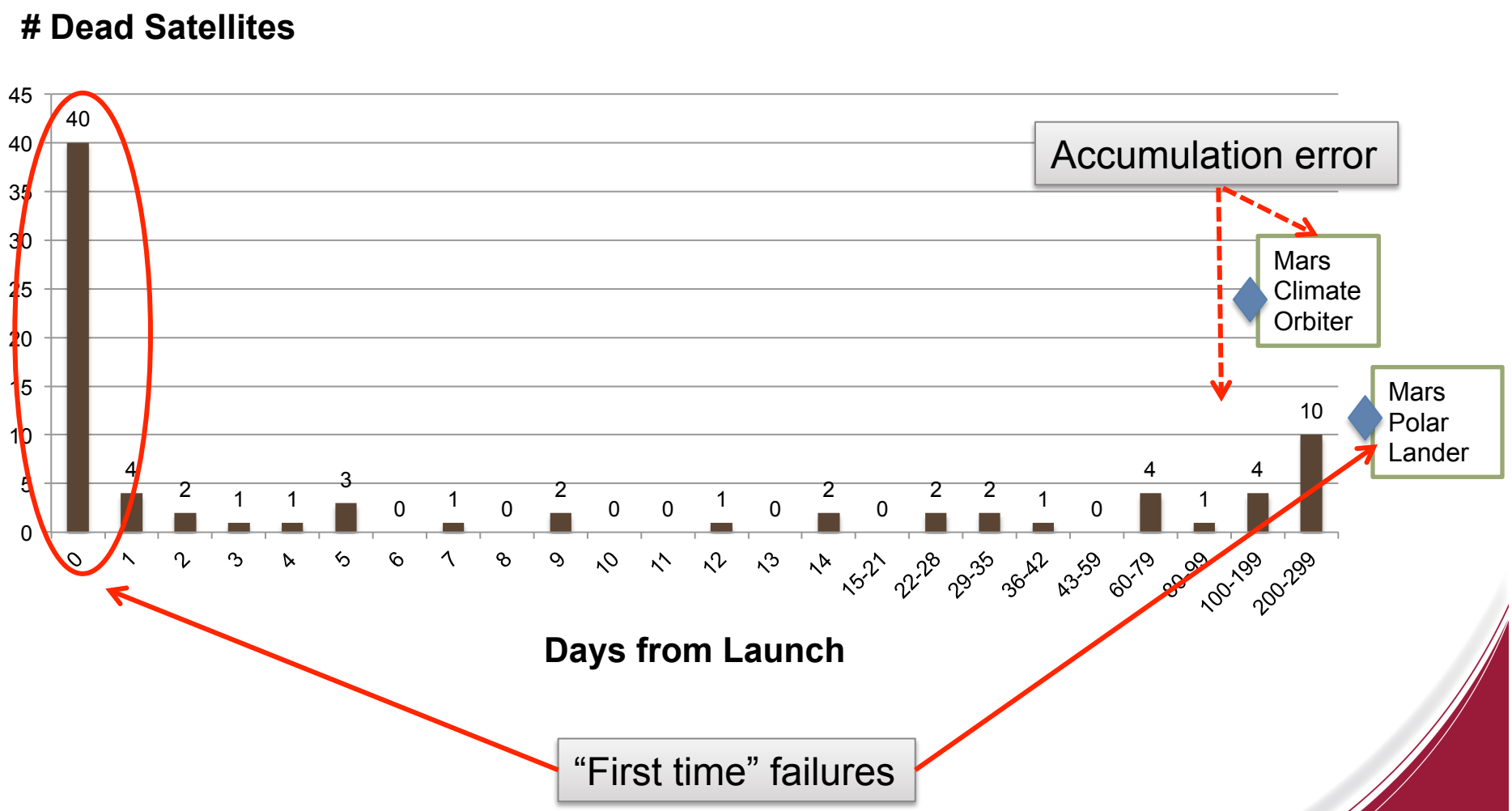
Basic Principles & Tenets of the TLYF Process

- **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**
  - *TLYF complements but does not replace other forms of perceptive testing (e.g., environmental, stress, performance and functional testing)*
- **Fourth**
  - *When unable to TLYF, manage the critical fault risk*

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

Early On-Orbit Failure Time Distribution

Many (most? all?) of the earliest losses are TLYF escapes

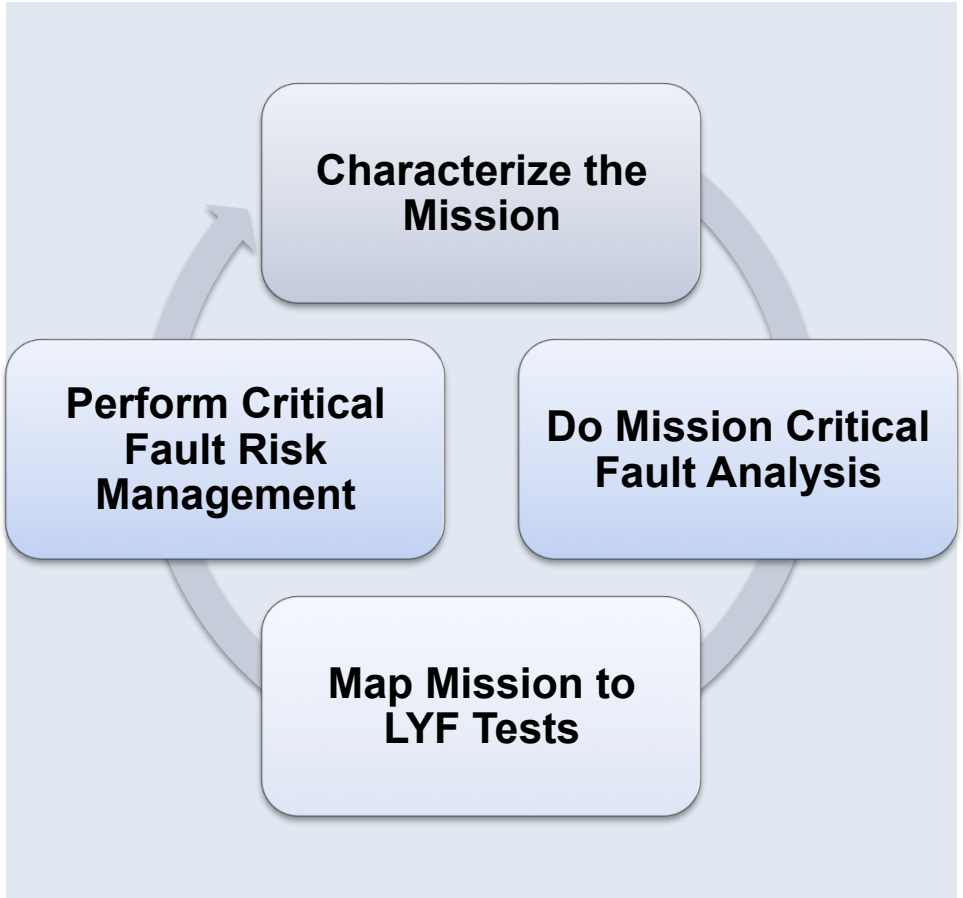


Losses Prior to 100 Days Are Frequently Test Escapes

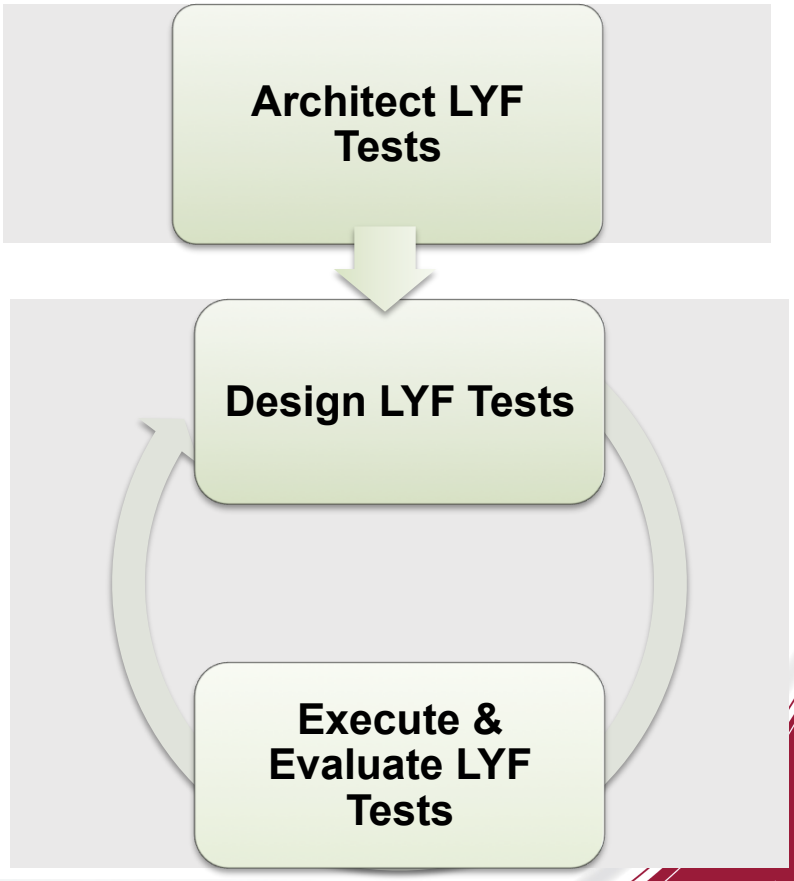
TLYF Implementation Process

An Interactive Dual Disciplined Process

Systems Engineering



Test Development



This is first and foremost a systems engineering process

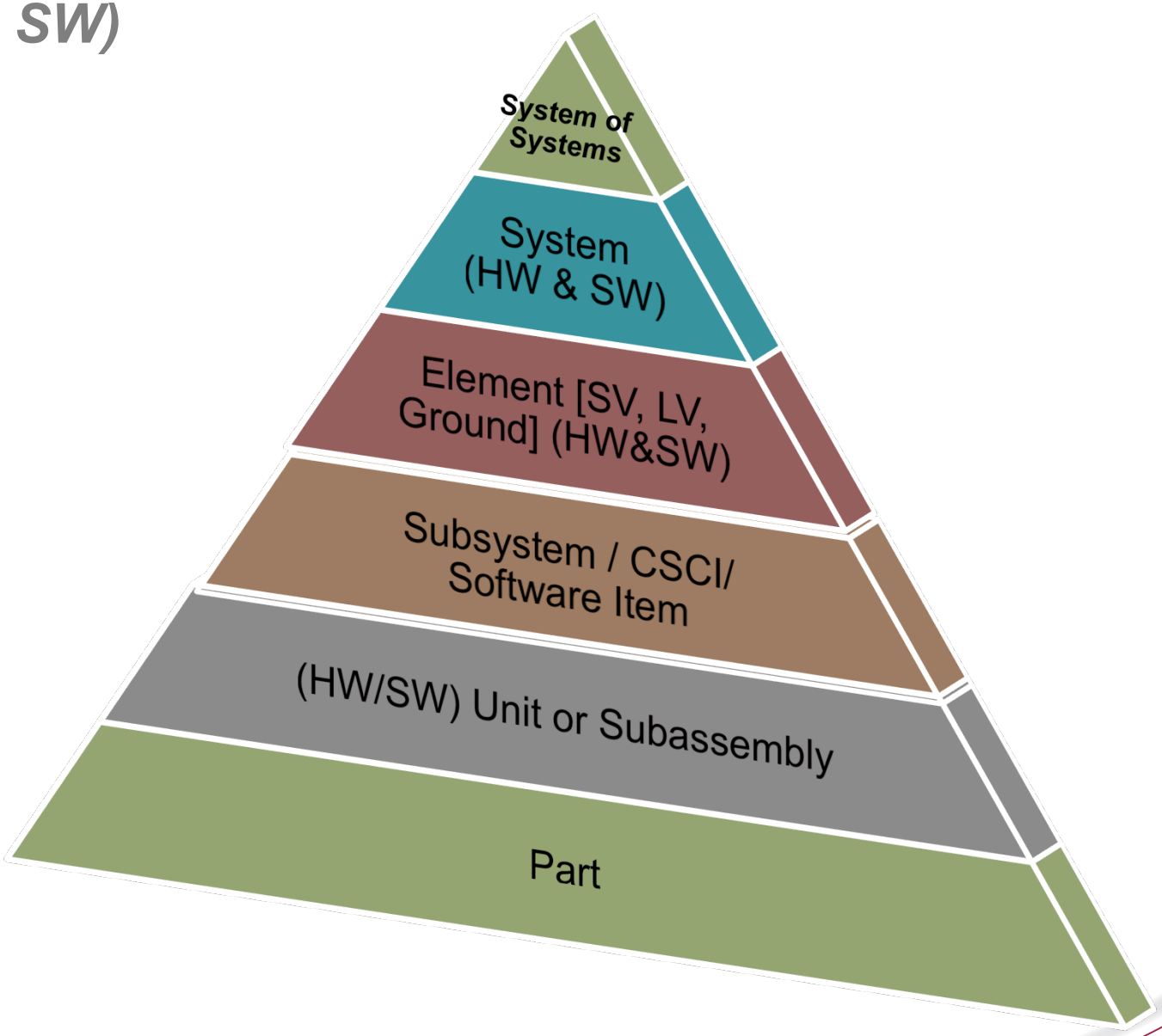
Pyramid Test Philosophy

Allocation of LYF tests to various levels of is key part of "Map Mission to Test" step

- **Physical Integration and Test Pyramid**
  - *Tests are performed at all levels of integration of the hardware and software, ending with the final configuration of the SV in the factory with the operational SW.*
  - *Includes levels of hardware integration, software integration, and combined hardware and software integration.*
  - *The integration pyramid for TLYF has two additional, higher levels: the system (SV + ground system); and system of systems (SOS).*
- **Mission Level Pyramid**
  - *Shows the progression of mission integration complexity.*
  - *Complexity increases from basic mission activities, through mission threads, mission scenarios, up to a full mission phase.*
  - *These levels are derived from timelines and are used in the creation of LYF tests*
- **Supplier Pyramid**
  - *Provides a recommended flow for applying mission operations requirements down the supply chain with an associated validation of that usage in the results from a LYF test.*
  - *The LYF test at each level demonstrates readiness to demonstrate mission activities at the next higher level of integration.*
  - *Tests along the supplier chain are necessary as either risk reducers prior to the higher level tests, or being the most perceptive for certain kinds of flaws that can only be observed in supplier test facilities with special test equipment.*

Failure History Points to Three Pyramids for Allocating LYF Tests

Progression of Integration Level Tests
(HW & SW)



Progression of Mission Level Tests

Provides Context for Injecting LYF Tests

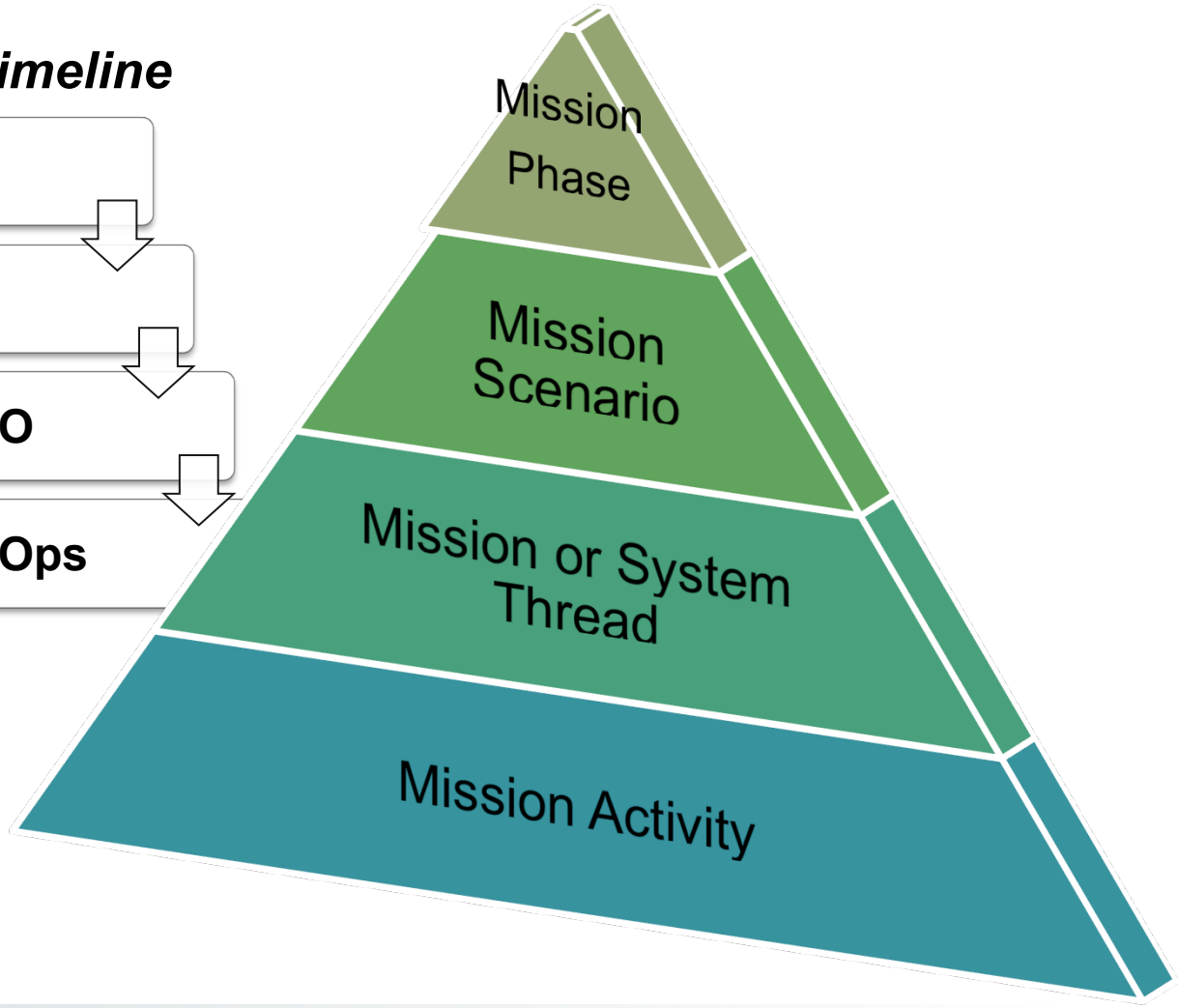
SV Mission Timeline

Launch

Initialize

Satellite C/O

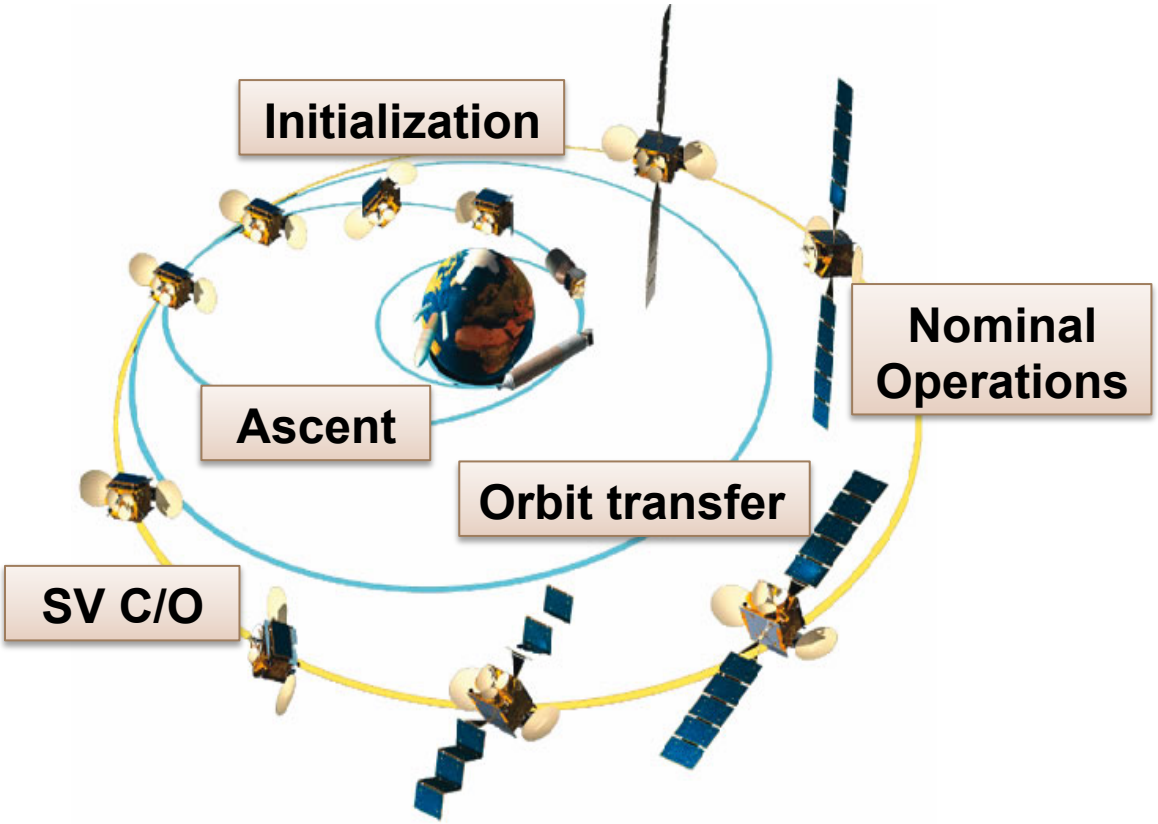
Nominal Ops



Learned from Mission Failures!

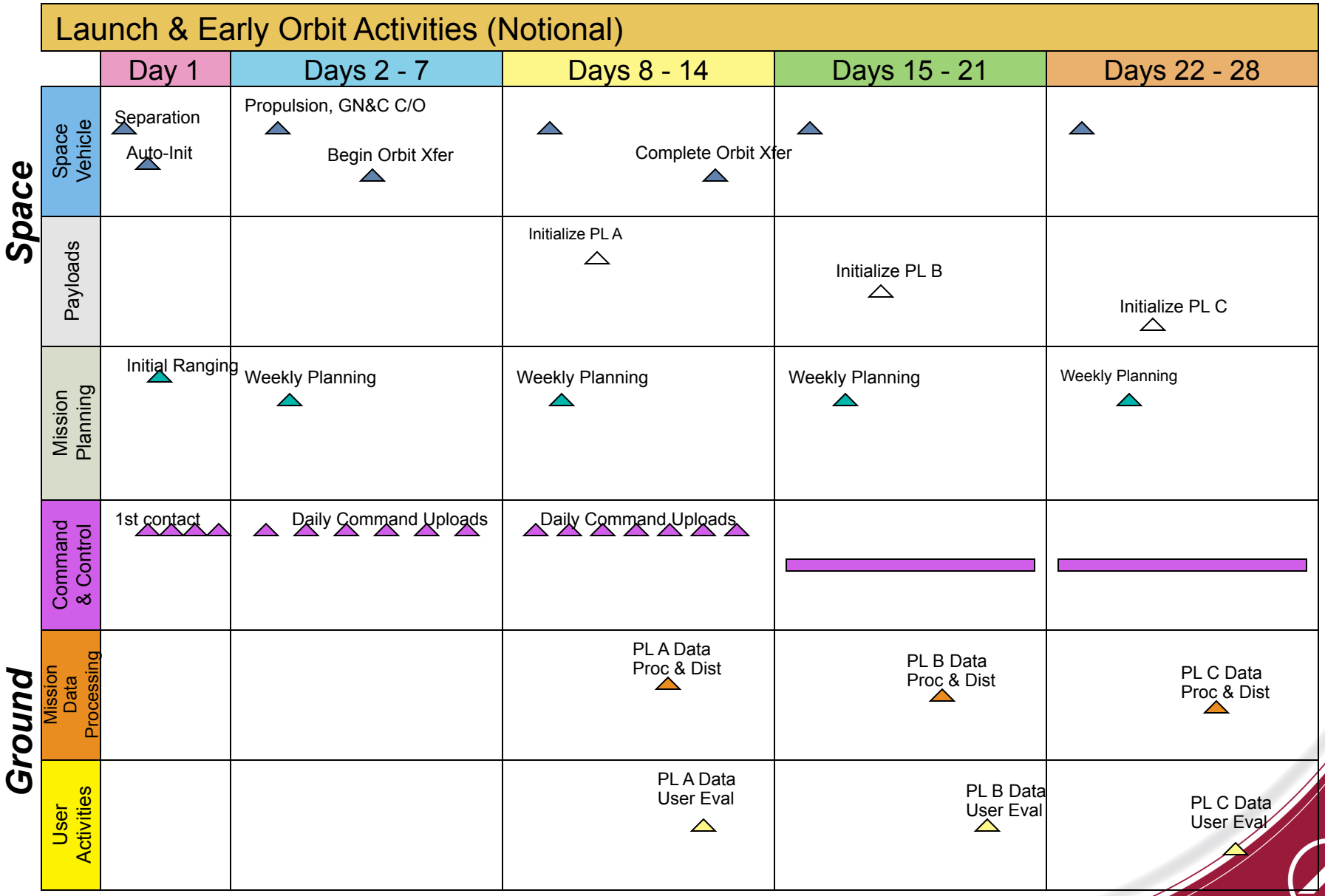
Mission Phases

Characterizing the Mission According to Mission Phase Objective



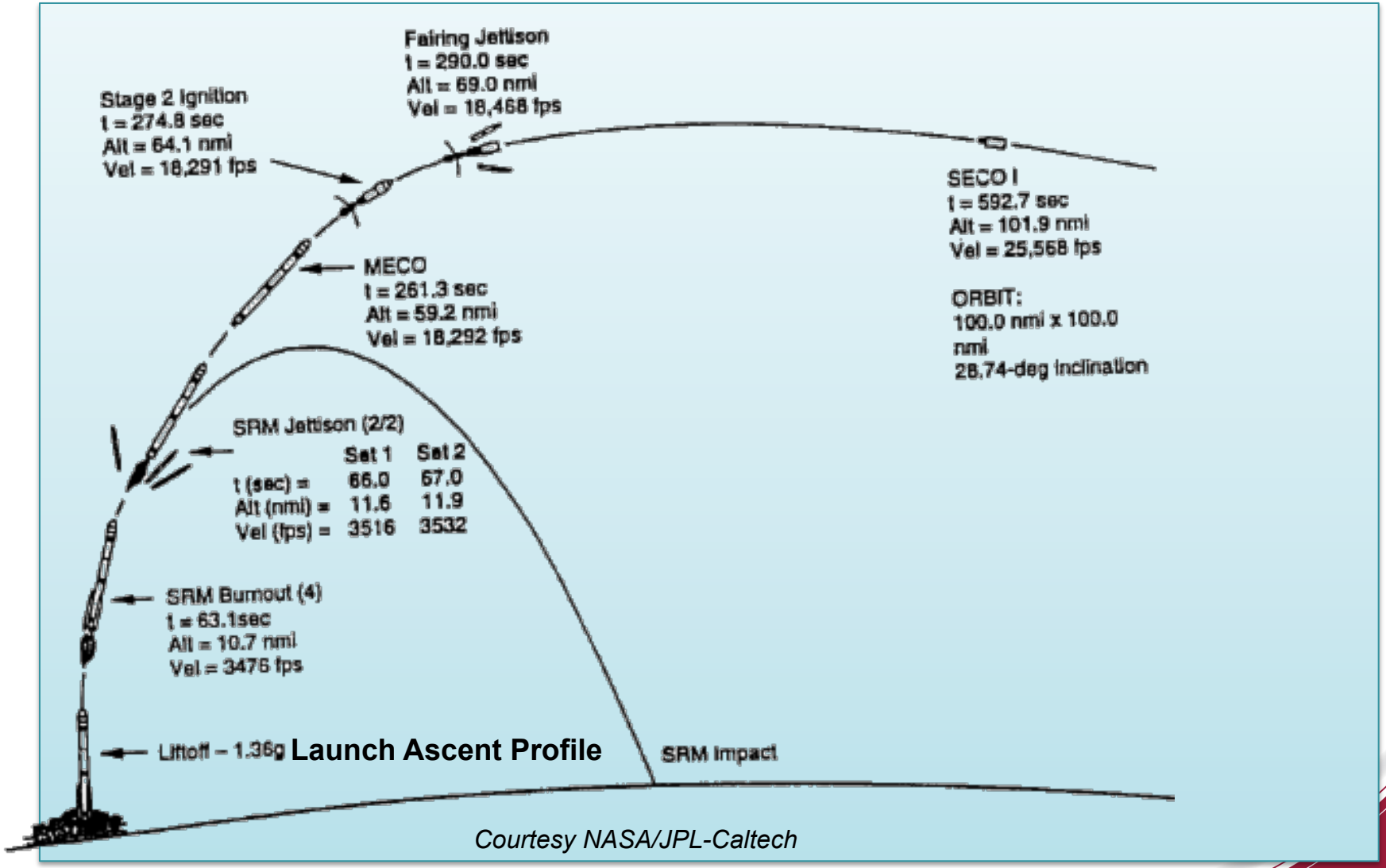
Phase
Launch / Ascent
Orbit Transfer
Initialization
SV Checkout
Nominal Operations

Time Dimension of a Mission



Ascent Phase – Launch Events

Example



Launch Ascent Profile

Courtesy NASA/JPL-Caltech

Ascent First Time & Mission Critical Events & Activities

Example - Space Vehicle and Launch Vehicle

Ascent (Space Vehicle)

Timeline	Critical Event
Prelaunch	Spacecraft computer unit (SCU)
	Database upload
	SW patch upload
	Initialize configuration for launch
	Switch to internal power
T + 0	Launch signal for SCU timer
T + 837 sec	Turn on SGLS transmitters
T + 58 min	Separation

Ascent (Launch Vehicle)

Timeline	Critical Event
Prelaunch	Initialize configuration for launch
T + 0	Liftoff
T + 82.5 sec	GEM jettison
T + 264 sec	Main Engine Cutoff
T + 277.5 sec	Second stage ignition
T + 281.5 sec	Fairing jettison
T + 685.1 sec	Secondary Engine Cutoff
T + 58 min	Separation

Lesson From Mars Odyssey:

Do a Mission Critical Fault Analysis 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
  - *This technique has been used on subsequent planetary projects*
- 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: Integrate critical flaw analysis into TLYF process
  - *Do the "Mission Failure" Investigation Pre-Launch*
- Lesson for software engineers: bring the potential for software failures and software interaction flaws into this part of the process

Courtesy NASA/JPL-Caltech

Mars Odyssey
Feb 2002

Successful Mission!

Example: Ascent 1st Time & Mission Critical Events

Mission Failure & What Can Go Wrong

Ascent (Space Vehicle)

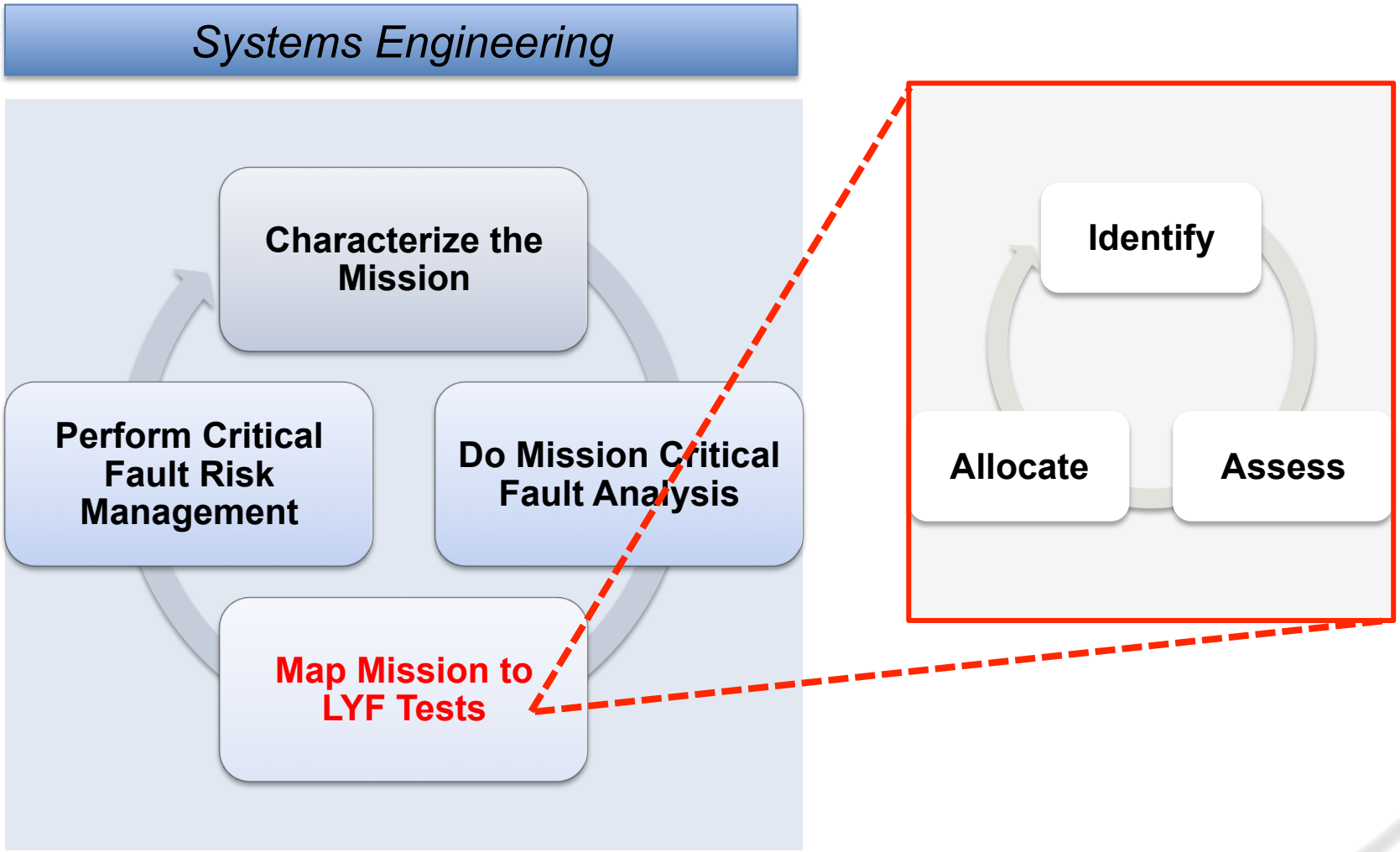
Timeline	Critical Event
Prelaunch	Spacecraft computer unit (SCU)
	Database upload
	SW patch upload ★
	Initialize configuration for launch
	Switch to internal power
T + 0	Launch signal for SCU timer ★
T + 837 sec	Turn on SGLS transmitters
T + 58 min	Separation

- **Mission Failure: SV dead on arrival (DOA) 1st contact post separation**
  - *No telemetry from vehicle*
  - *No apparent response to ground commands*
  - *No independent confirmation of appropriate configuration*
- **What Can Go Wrong**
  - *Incorrect database* ★
  - *Incorrect SW patch* ★
  - *No receipt of launch signal*
  - *SCU timer fails* ★
  - *SGLS transmitters fail to turn on*
  - *SCU failover to redundant unit* ★
  - *No receipt of separation signal*
  - *No response to separation signal*
- **How?**
  - *SCU Hardware broken*
  - *Signal timing mismatch*
  - *Software logic error*
  - *Software timing error*

★ Potential or actual FSW items

Identify, Assess, & Allocate Candidate LYF Tests

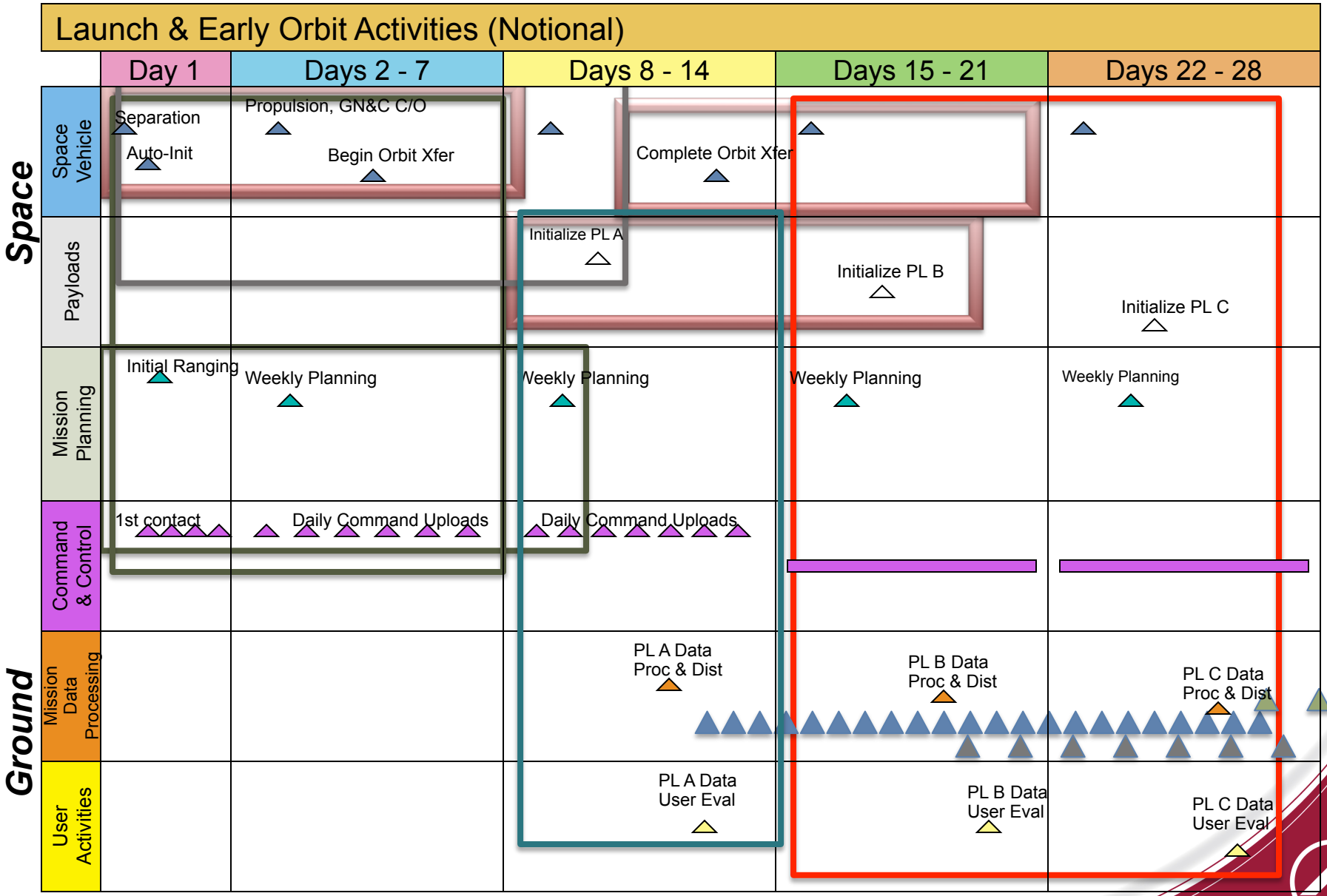
Iterative



LYF Candidate Tests are formulated within this step

Using a Mission Timeline to Identify LYF Tests

First Time / Mission Critical Events → Candidate Tests



Ascent Phase - First Time & Mission Critical Events

Example - Candidate Tests

Ascent (Space Vehicle)

Timeline	Critical Event
Prelaunch	Configure spacecraft computer unit (SCU)
	Database upload
	SW patch upload
	Initialize SV configuration for launch
	Switch to internal power
T + 0	Launch signal for SCU timer
T + 613 sec	Turn on SGLS transmitters
T + 3 hr 33 m	Separation

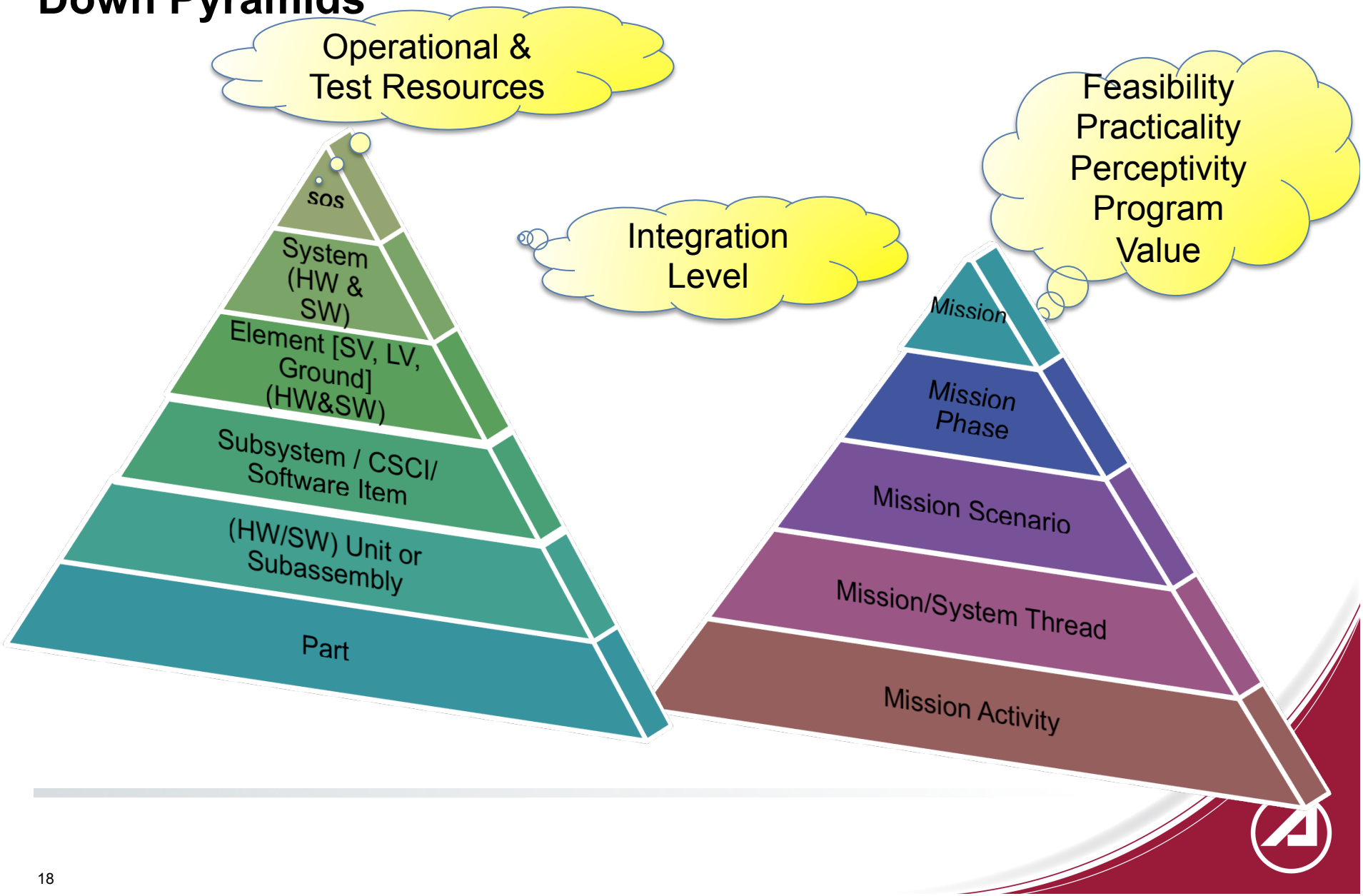
Example Ascent Phase mission objective: Have a properly working SV able to transition to next phase

- **TOCT (Prelaunch – Separation)**
  - *SV + LV + Ground*
  - *Launch base or ambient factory*
- **Ascent (T+0 -> Separation) (1a)**
  - *SV + LV*
  - *Ambient factory and/or TVAC*
  - *Software testbed (risk reduction)*
- **Ascent (T+0 -> Separation) (1b)**
  - *SV + LV*
  - *EMC chamber or antenna range*
- **Ascent w/ switch to redundant SV computer (T+0 -> Separation) (1c)**
  - *SV + LV*
  - *Ambient factory and/or TVAC or*
  - *Software testbed*

TOCT = Total Operations Chain Test

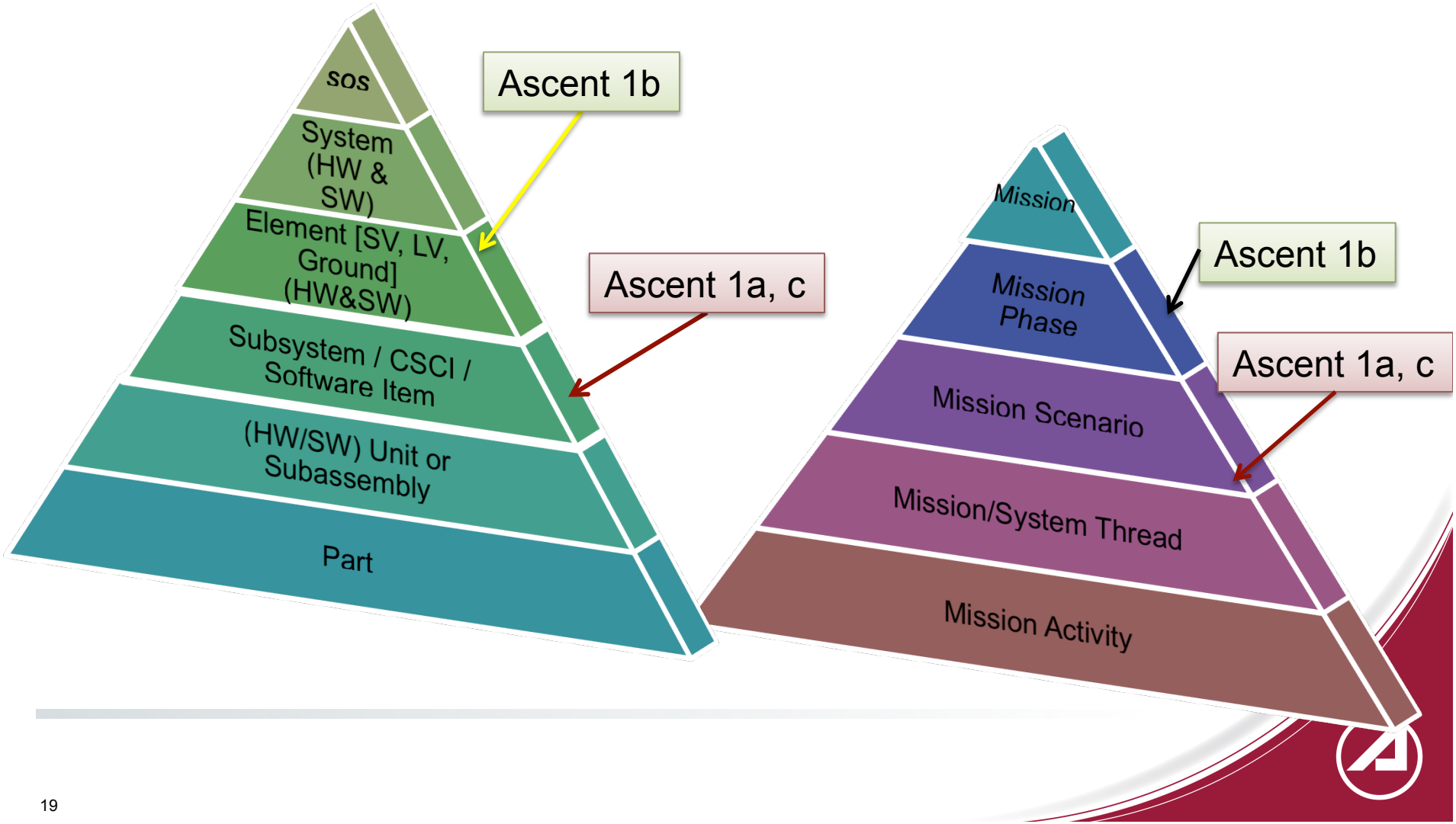
What Mission Objectives Are To Be Included?

Assess and Allocate Candidate Tests Across and Up & Down Pyramids



Allocate Ascent Candidate Tests Across Pyramids

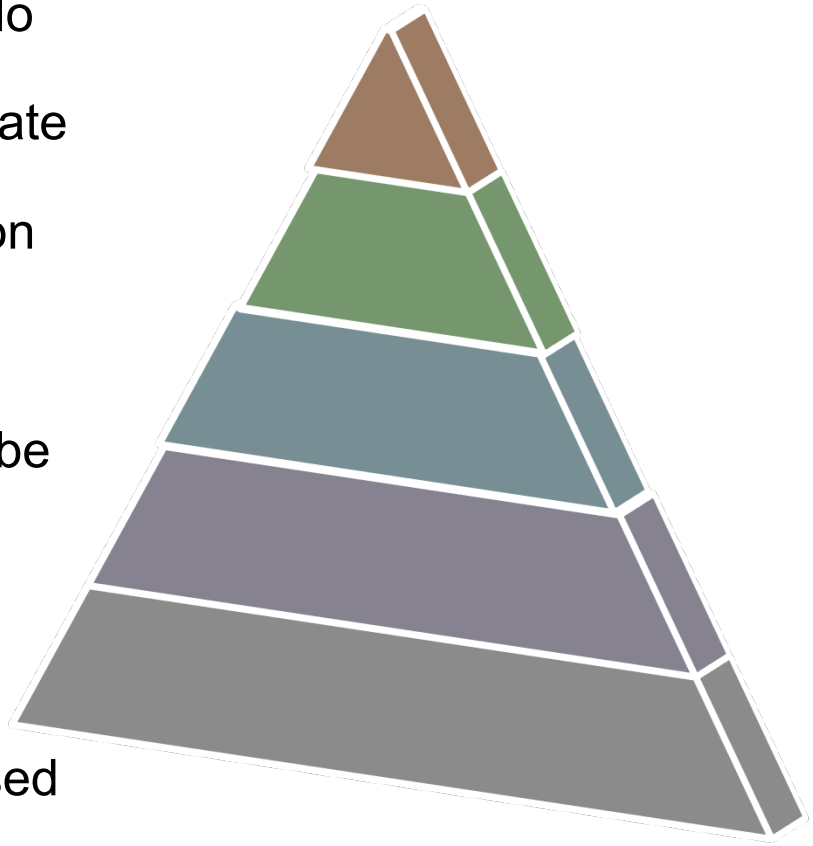
Ascent Phase Tests - Example



Specifying Test Level

Some Questions to Ask

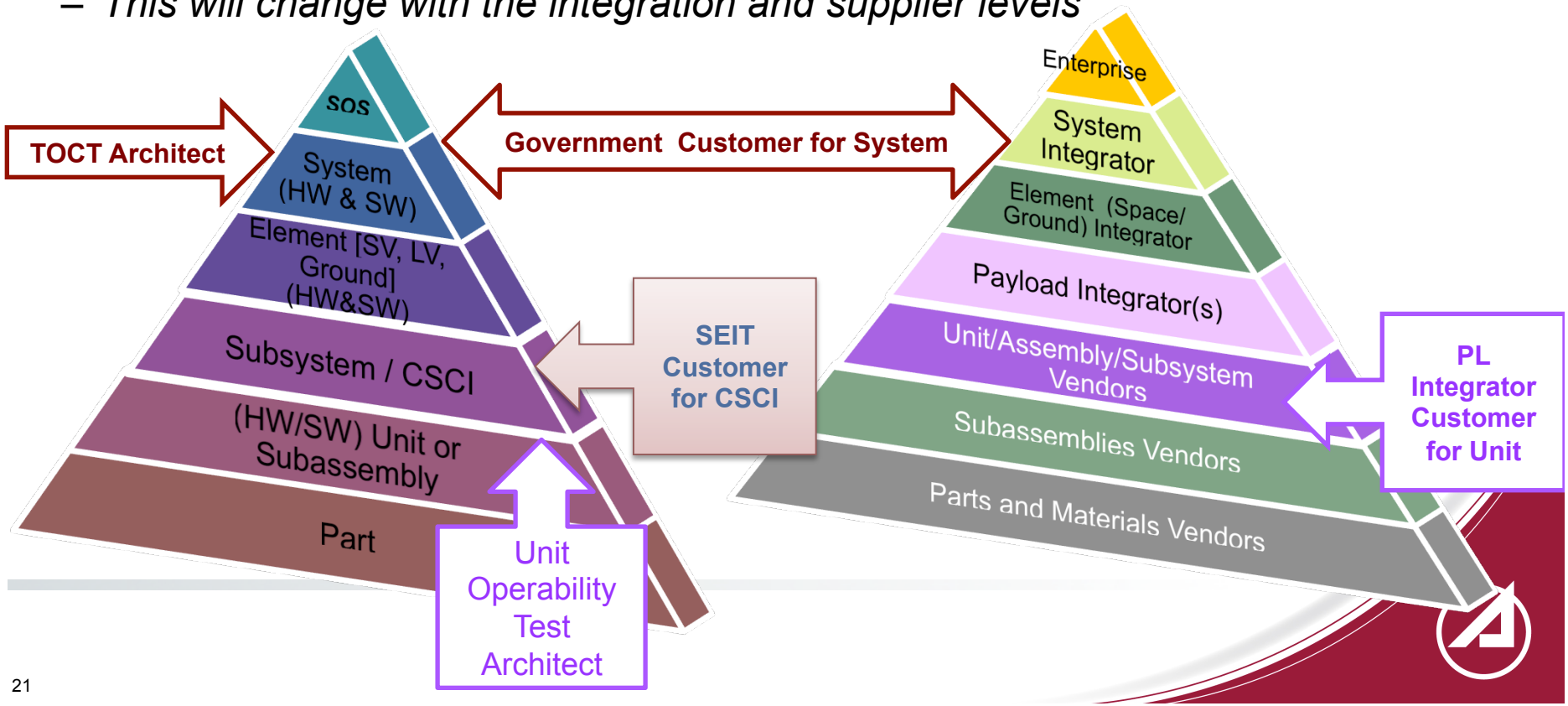
- What are the test objectives and how do they relate to the mission?
- At what level is there access to exonerate the flaw?
- What level is sufficient for risk reduction testing?
- Under which operational uses and conditions at which level?
- Which mission characteristics need to be represented?
- What mission processes are to be covered?
- What mission event/activity is being covered by the test?
- Will the test article do what it is supposed to do?
  - *What level of integration to do fault handling during operability tests?*



LYF Test Architect

What Organization Provides the Architect

- **Rule of thumb: The test architect should be in the organization requesting the test**
  - *The architect should be from the customer organization for test results*
  - *The customer will vary depending on who needs the test result*
  - *This will change with the integration and supplier levels*



Days / Weeks in the Life:
How Long Is Long Enough?

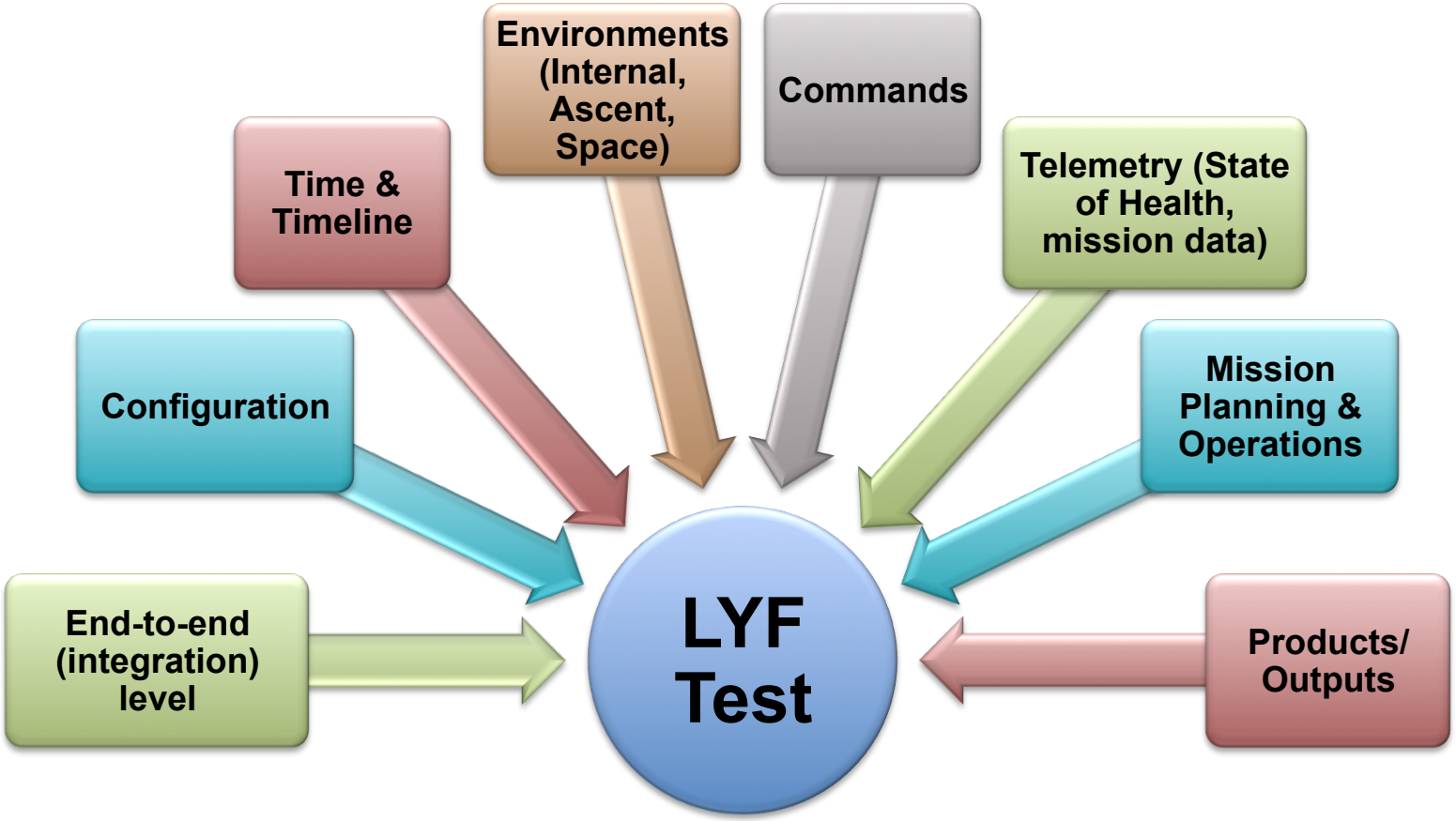
- **Short Answer:** Long enough to perform a representative timeline with all or most of the following:
  - *Extent of vehicle operational requirements (e.g., 48 autonomous operations)*
  - *All necessary and mission critical first time events, sequenced per flight and mission plans & constraints*
  - *Transitions, mode transitions, repetitive mission activities, recurring events/situations*
  - *Core mission activities (e.g., EO observations, Comm services)*
- **Another Short Answer:** Long enough to uncover threats to mission:
  - Accumulated software & firmware error growth
  - Subtle trends
  - Generate sufficient data / transactions to characterize occasional errors and out-of-family effects
  - Memory leaks
  - Buffer overflows

Time-related Questions:

- Initial condition assumptions?
- Continuous clocks?
- Test duration?
- Time jumps?
- Compressed time?
- Accelerated time?
- Triggers?

Mission Characteristics

Which Ones Are Critical to the Mission?



Which ones are necessary for the test objectives?

Example: Design an Ascent Test
Software Testbed (1c)

- **Test Cases**
  - *Nominal: LV signal timing has range of rise time -> run 3 cases: slowest, average, fastest for each signal (T+0, sep)*
  - *Off-nominal: Induce failover to redundant flight computer*
  - *Stressing: Do same test at beginning of TVAC (decreasing temperature & pressure)*
- **Initial conditions**
  - *SV configuration for launch; T+0*
- **Transition conditions**
  - *Ascent phase transition to auto-init phase*
- **End condition**
  - *T+4 hours; SV configured to acquire sun, orient antennas to earth*
- **Test design trades**
  - *Methods for inducing failover*
- **Flaw considerations**
  - *Flight computer has GIDEP re-timing sensitivity, so may need more timing cases*
  - *Hardware mis-install may lead to improper input to FSW*

Summary

- **FSW is the heart of most missions and most mission phases**
- **The TLYF Process is meant to be flowed down to subsystems, including flight software**
- **Allocation of LYF tests to FSW testing should be done for risk reduction prior to LYF tests of the flight vehicle**
- **Allocation of LYF tests to FSW testing should be done because it is**
  - ***The most perceptive level to validate the execution of a significant number of flight processes***
  - ***The most perceptive level to discover a significant number of flight flaws***
  - ***The most available setting to validate long duration mission activity sequences***
  - ***The most flexible setting for a large number of test cases***
  - ***The safest setting for certain flight activities***

Resources and References

Published

- Shelton, D. and S. Roskie, *Applying the Test Like You Fly Principle*, 20th ATS, October 2001
- Beutelschies, Guy, Jet Propulsion Laboratory, Pasadena CA, "*That One's Gotta Work": Mars Odyssey's Use of a Fault Tree Driven Risk Assessment Process*, IEEE 2001.
- White, J. D., *Test Like You Fly: Assessment and Implementation Process*, TOR-2010(8591)-6, January 2010
- Space Vehicle Test & Evaluation Handbook, Chapter 15, TOR-2011(8591)-2 Vol. 1

In Work

- White, J. D., Tilney, L. G., *Test Like You Fly: Assessment & Implementation Process for Prelaunch Mission Testing*, The Aerospace Corporation, TOR-2012(1315)-1