Mission Success Starts with Safety

# Understanding the Elements of Operational Reliability
# A Key for Achieving High Reliability

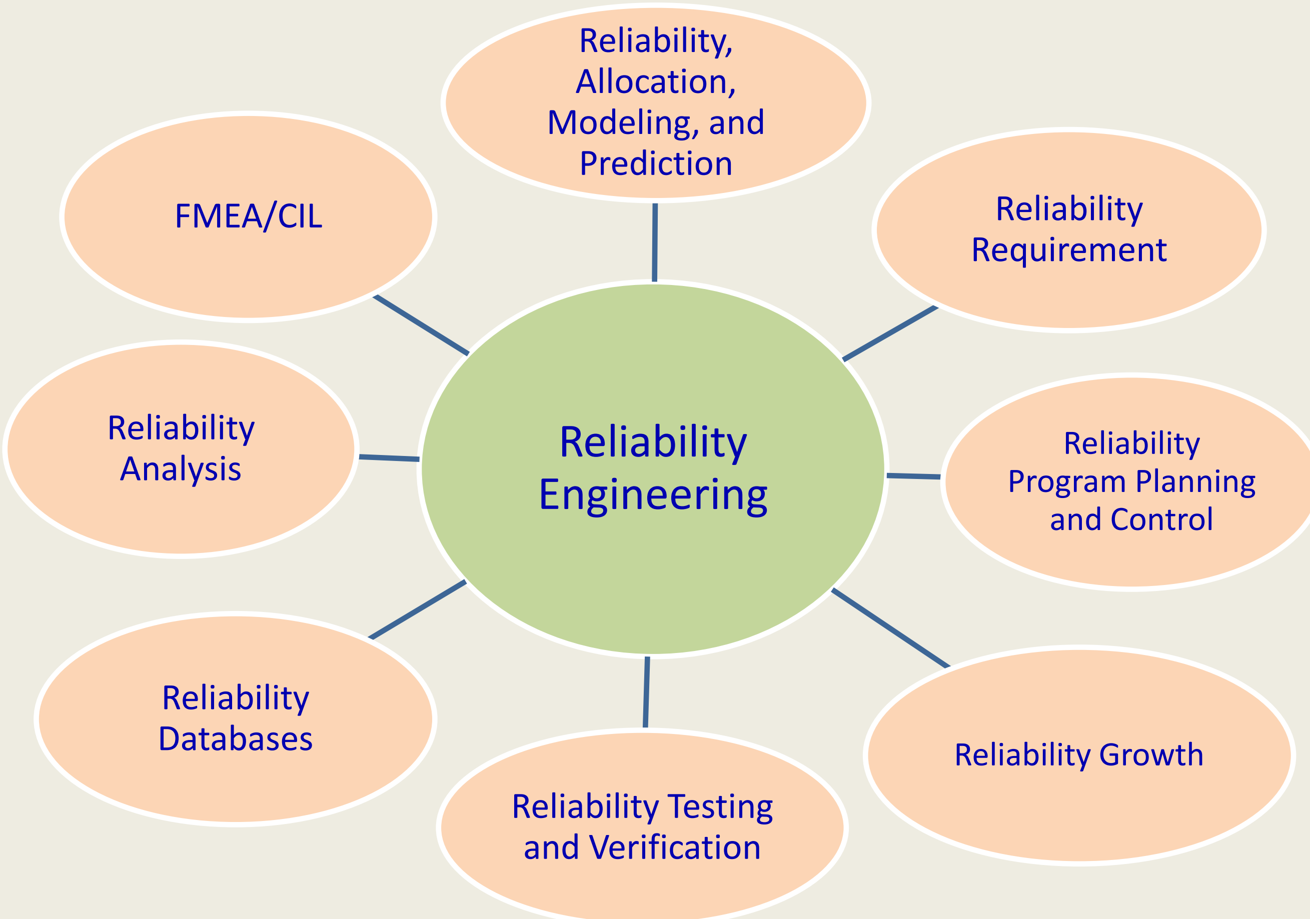
Fayssal M. Safie, Ph. D.
Marshall Space Flight Center
Huntsville, Alabama, USA

Trilateral Safety and Mission Assurance Conference (TRISMAC)
Cleveland, Ohio, October 26-28, 2010

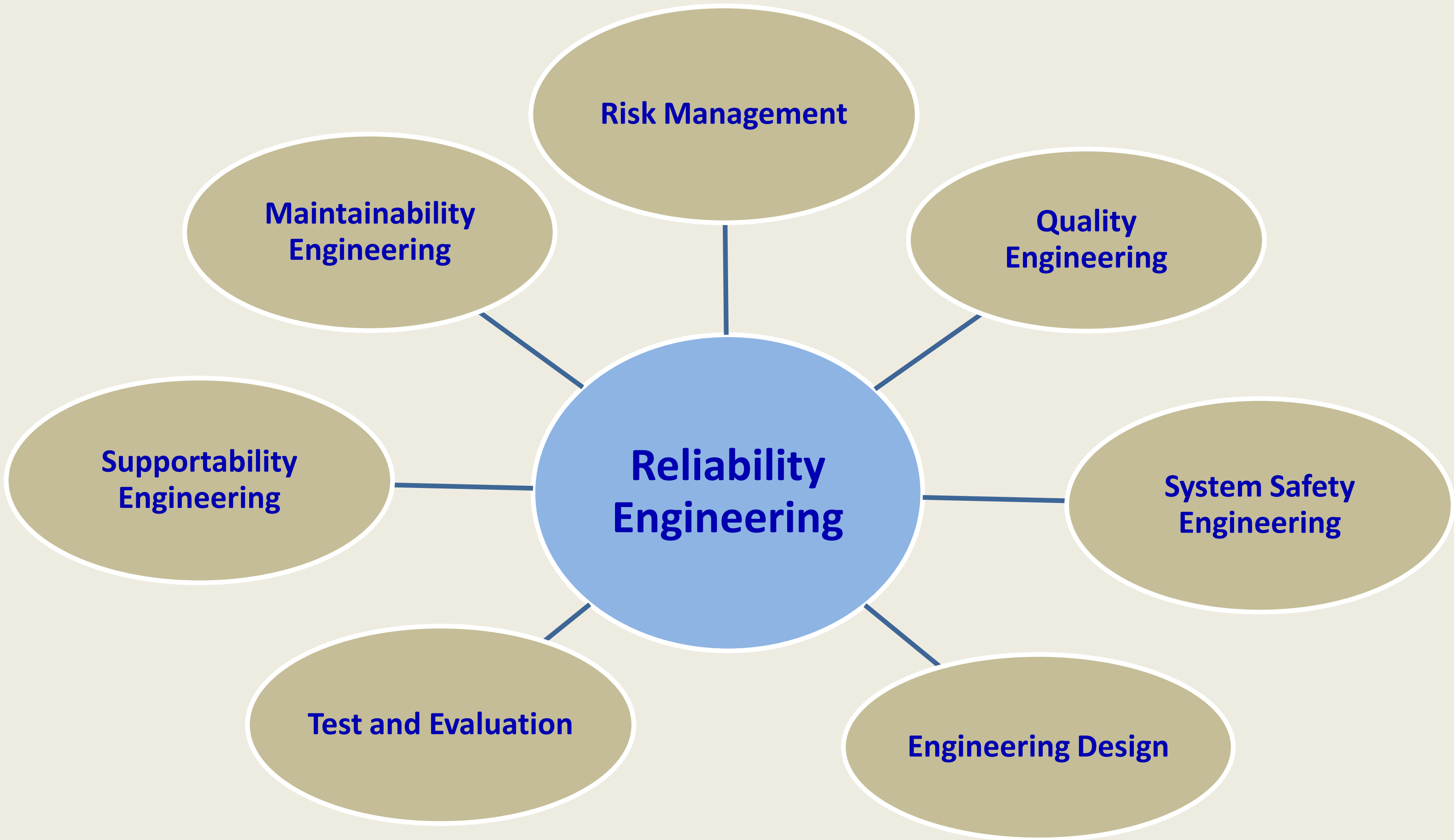
# Agenda

- Introduction
- Reliability Engineering Major Areas
    - Reliability Engineering Interfaces
- Design Reliability
- Process Reliability
- Reliability Applications
    - A Probabilistic Engineering Analysis Case Study
    - A Process Reliability Case Study
- Concluding Remarks

# Reliability Engineering Major Areas



# Reliability Engineering Major Interfaces



## Inherent Reliability versus Operational Reliability

- **Inherent Reliability** is the level of reliability inherent in the system as designed and manufactured (See design and process reliability).
- **Operational Reliability** is the reliability actually observed during operation.
- Failure occur due to weaknesses in the design, flaws in the materials, defects from the manufacturing processes, maintenance errors, improper operation, changes in operating concept, etc.
- The level of inherent reliability is determined through analysis and test (the ”actual” system or prototypes). Although the design and development team attempts to simulate the actual operating environment, it is difficult if not impossible to account for some aspects of operation.
- If the operating environment is substantively different from that defined during design, more failures or failure modes may occur than were addressed during design and manufacturing.

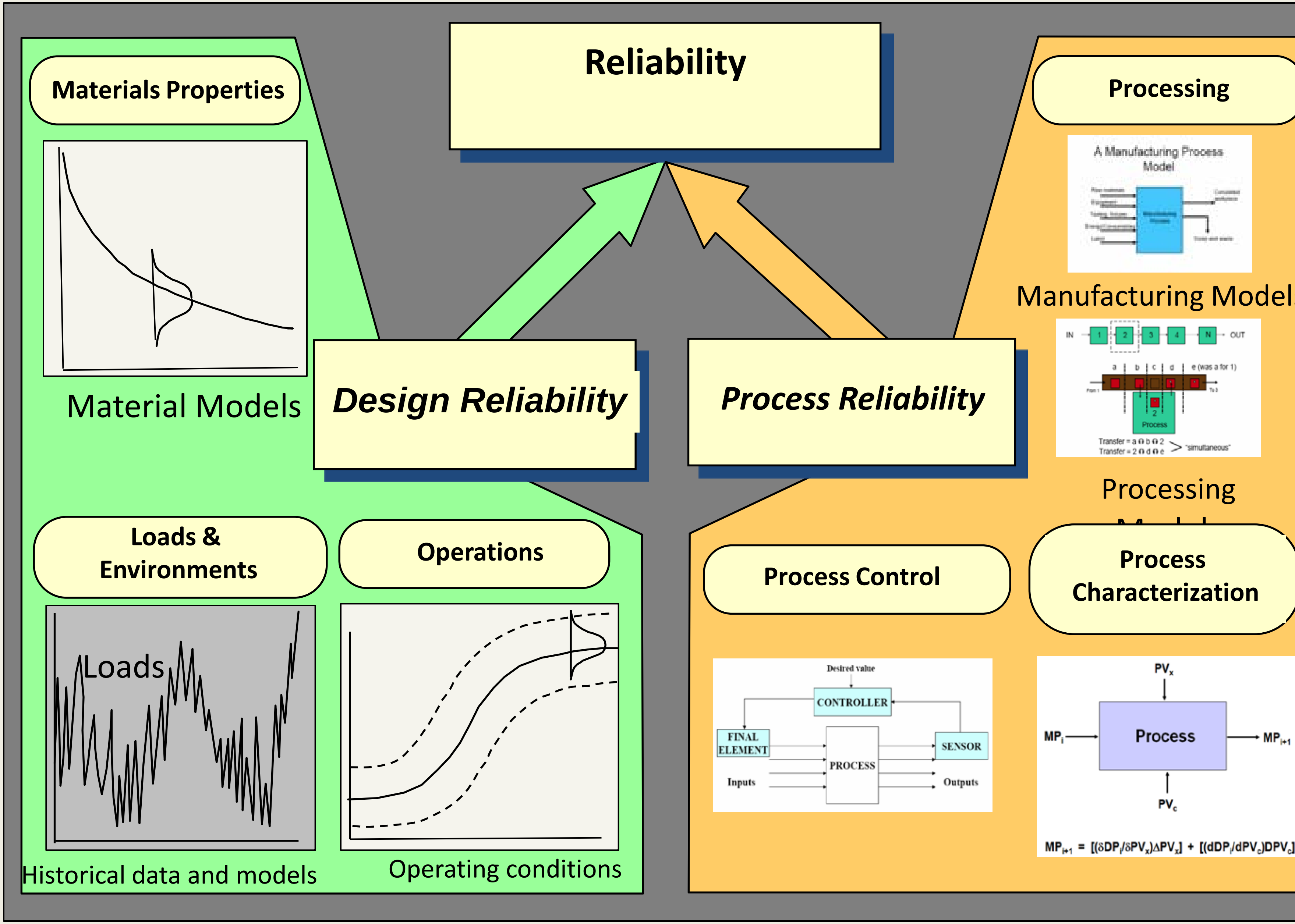
# Introduction - The Metric

**Reliability:** The probability that an item will perform its intended function for a specified mission profile.

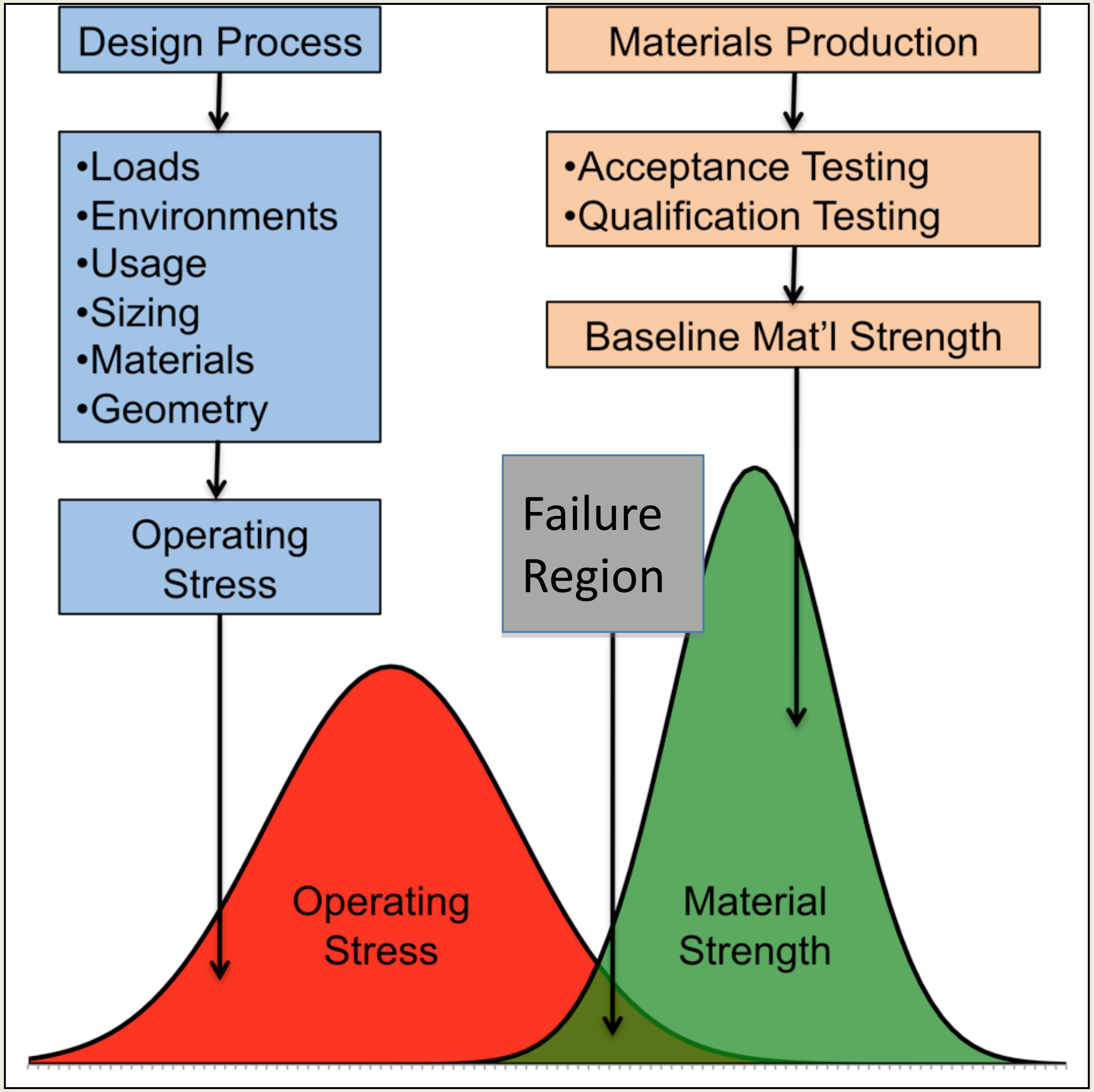
HIGH RELIABILITY MEANS:

- DESIGN IT RIGHT
  - ESTABLISH DESIGN RELIABILITY REQUIREMENTS AND DEVELOP A PLAN WHICH SHOWS HOW REQUIREMENTS WILL BE MET
  - USE QUALITATIVE AND QUANTITATIVE ANALYSIS METHODS AND TOOLS TO VERIFY THAT REQUIREMENTS ARE MET
- BUILD IT RIGHT
  - ANALYZE THE MANUFACTURING, ASSEMBLY, AND TEST PROCEDURE CONCURRENT WITH THE DESIGN PROCESS
  - USE CONCURRENT ENGINEERING TO GET EVERYONE INVOLVED UP-FRONT

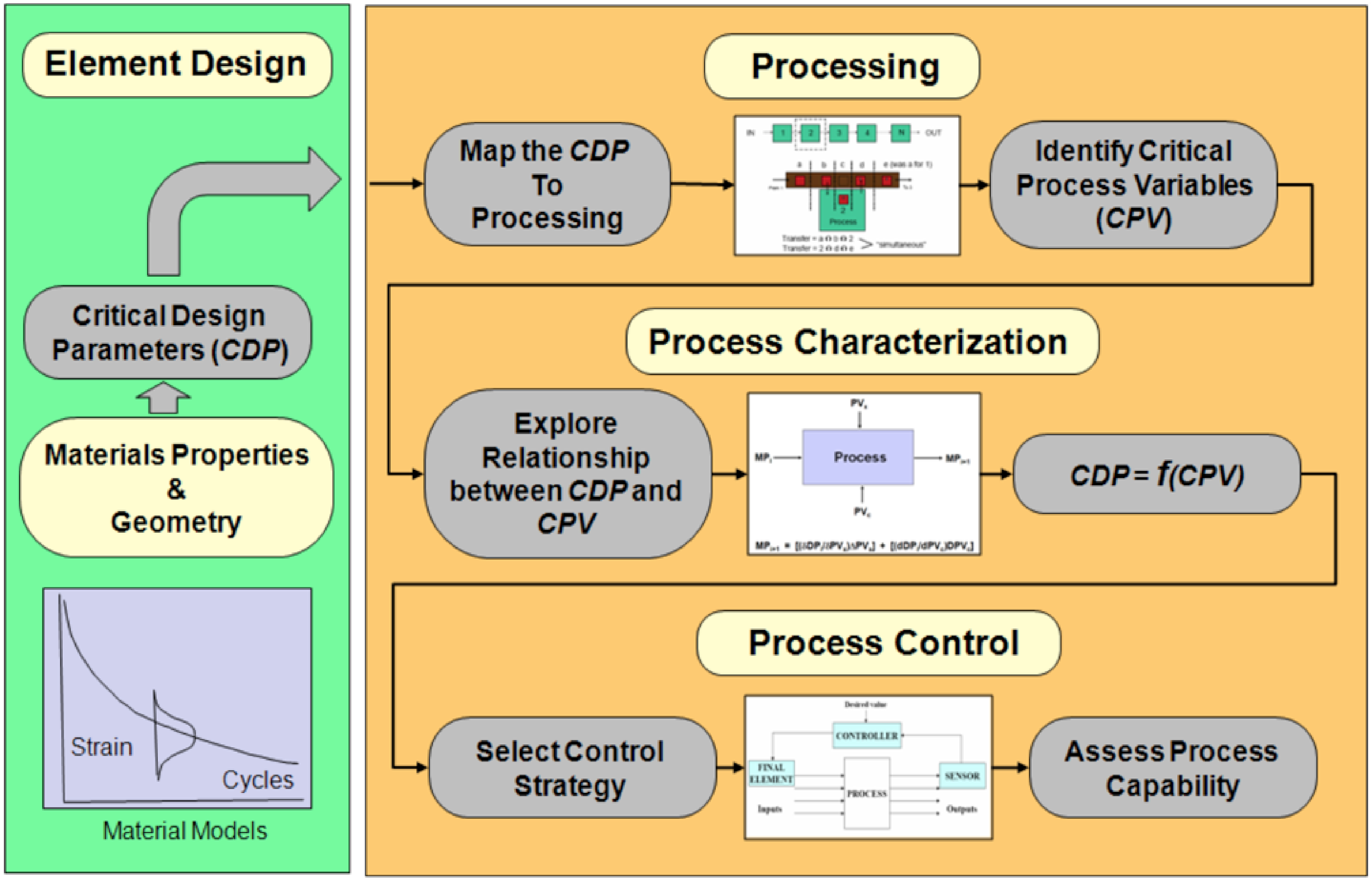
# Design and Process Reliability



# Design Reliability



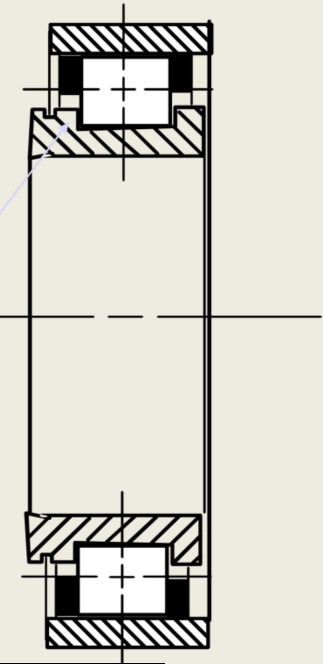
# Process Reliability



# A Probabilistic Engineering Analysis Case Study

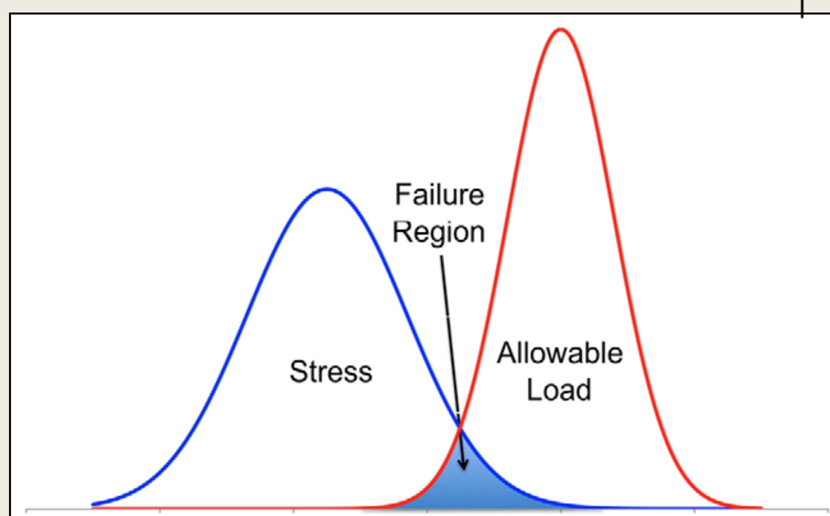
# Probabilistic Engineering Analysis

- Probabilistic engineering analysis was used in the study to predict the probability of inner race over-stress, under the conditions experienced in the test rig, and estimate the effect of manufacturing stresses on the fracture probability.
- Probabilistic engineering analysis is used when failure data is not available and the design is characterized by complex geometry or is sensitive to loads, material properties,  and environments.

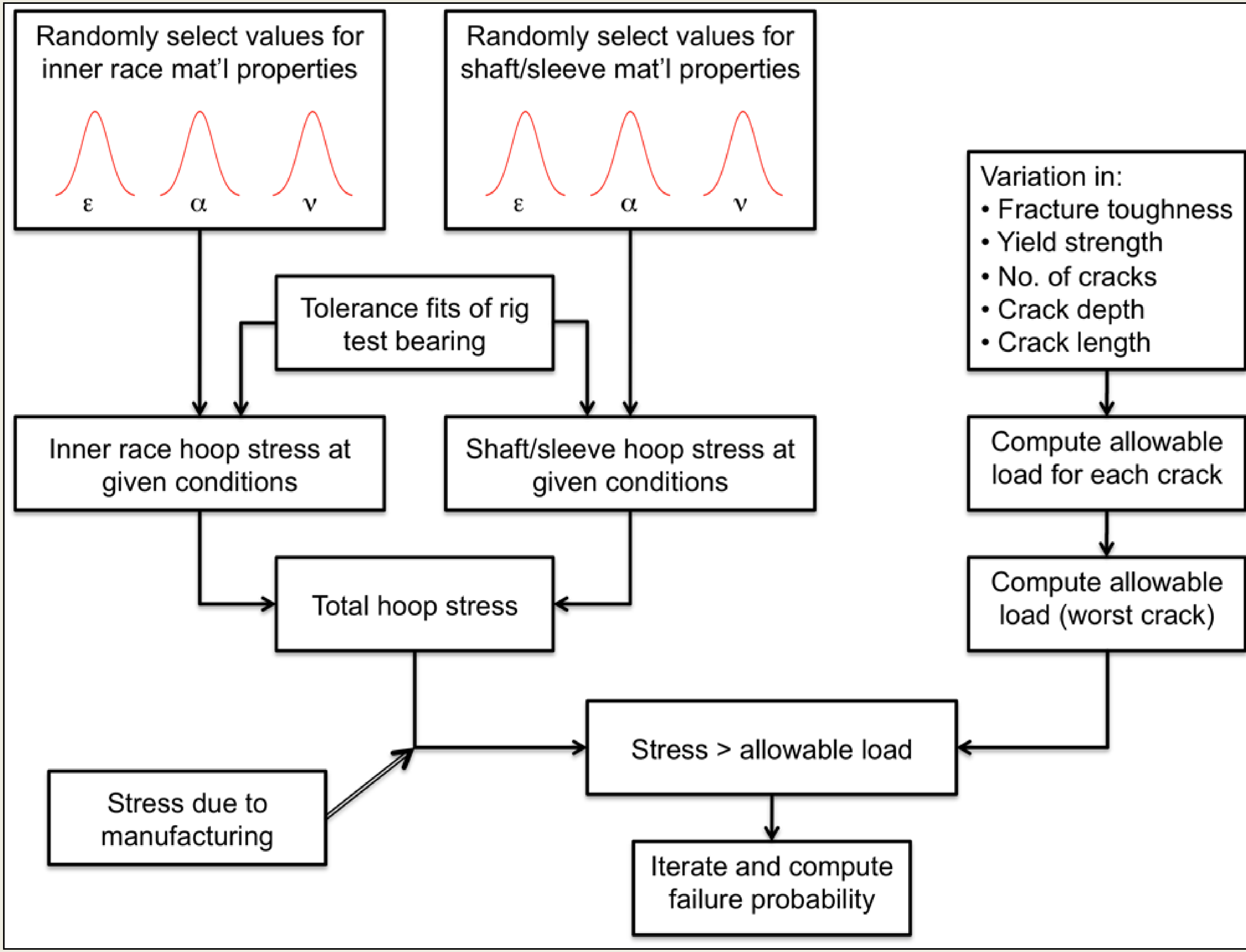



**•During rig testing the AT/HPFTP Bearing experienced several cracked races.**

**•Summary of 440C race fractures/ tests: 3 of 4 fractured**



# Turbo-pump Bearing Simulation Model



# Turbo-pump Bearing Simulation Results

| Test Failures | Race Configuration | Failures in 100,000 firings** |
|---|---|---|
| 3 of 4 | 440C w/ actual* mfg. stresses | 68,000 |
| N/A | 440C w /no mfg. stresses | 1,500 |
| N/A | 440 C w/ ideal mfg. stresses | 27,000 |
| 0 of 15 | 9310 w/ ideal mfg. stresses | 10 |

*ideal + abusive grinding

**Probabilistic Structural Analysis

**It is estimated that 50% of the through ring fractures would result in an engine shutdown. The shutdown 9310 HPFTP Roller Bearing Inner Race Failure Rate is then: 0.50 X 10/100k = 5 fail/100k firings.**

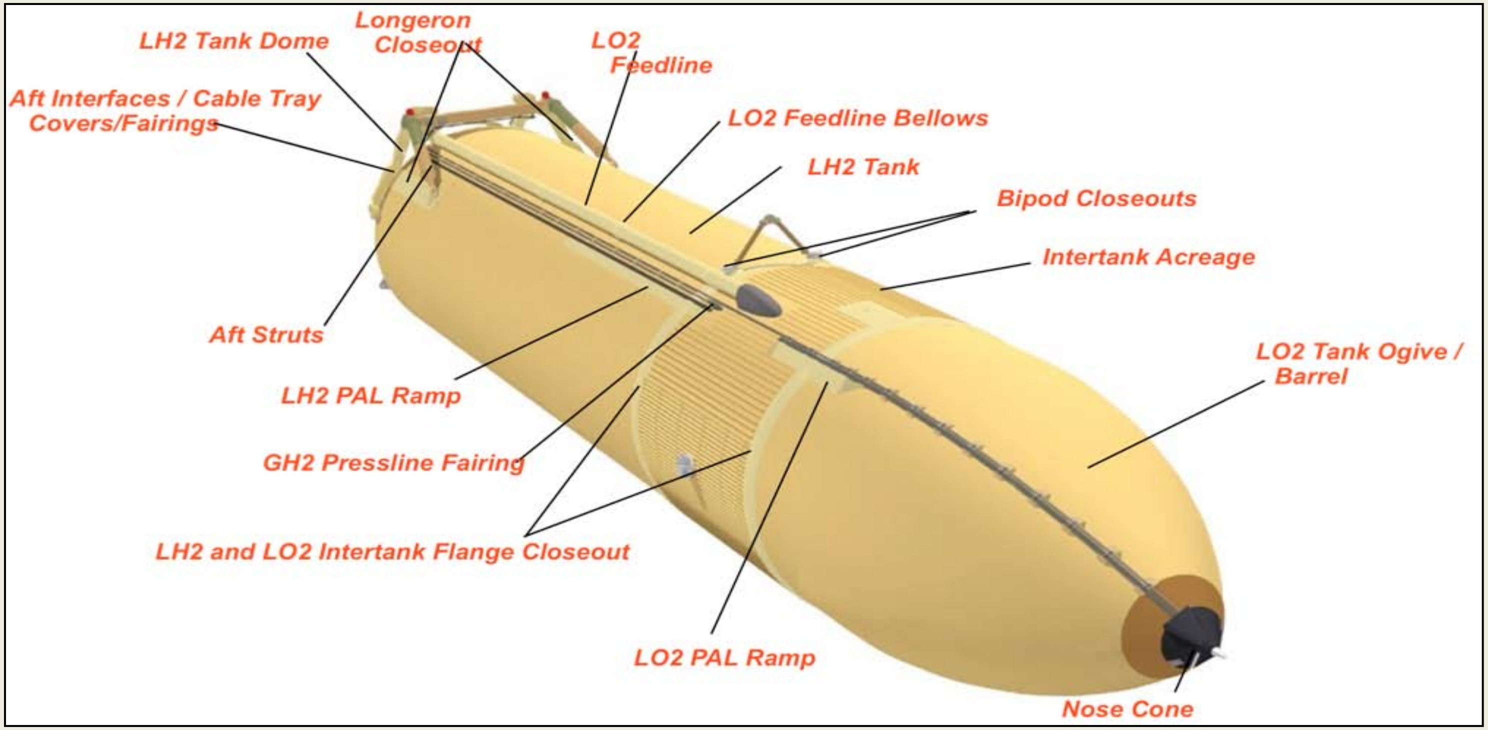
# The Message

- Probabilistic engineering analysis is critical:
  - To understand the uncertainty of the design and identify high risk areas
  - To perform sensitivity analysis and trade studies for reliability optimization.
  - To identify areas for further testing.

# A Process Reliability Case Study

# External Tank (ET) Thermal Protection System (TPS)

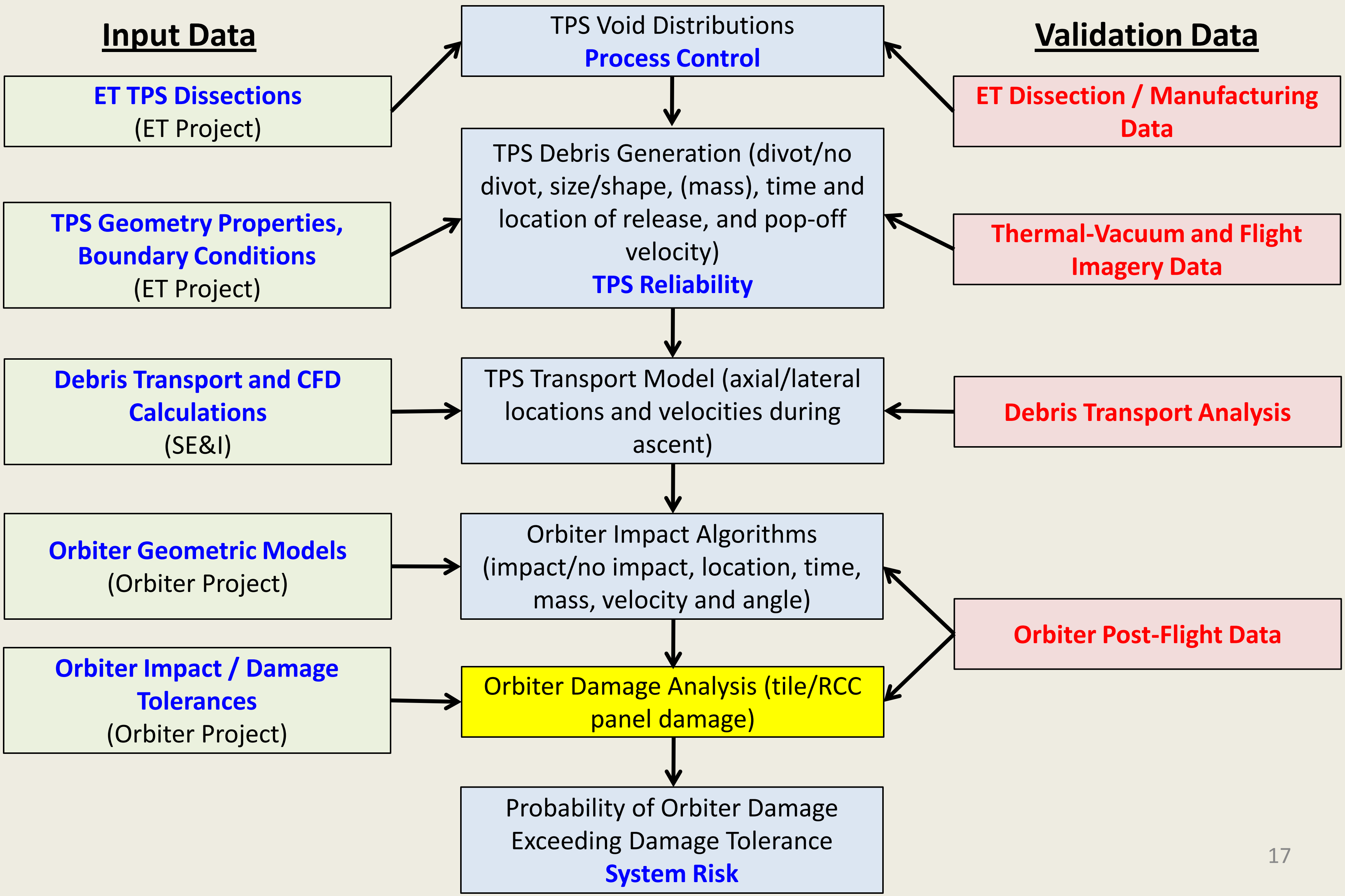
- The ET TPS is a foam-type material applied to the ET to maintain cryogenic propellant quality, minimize ice and frost formation, and protect the structure from ascent, plume, and re-entry heating.
- The TPS during re-entry is needed because after ET/Orbiter separation, premature structural overheating due to loss of TPS could result in a premature ET breakup with debris landing outside the predicted footprint.



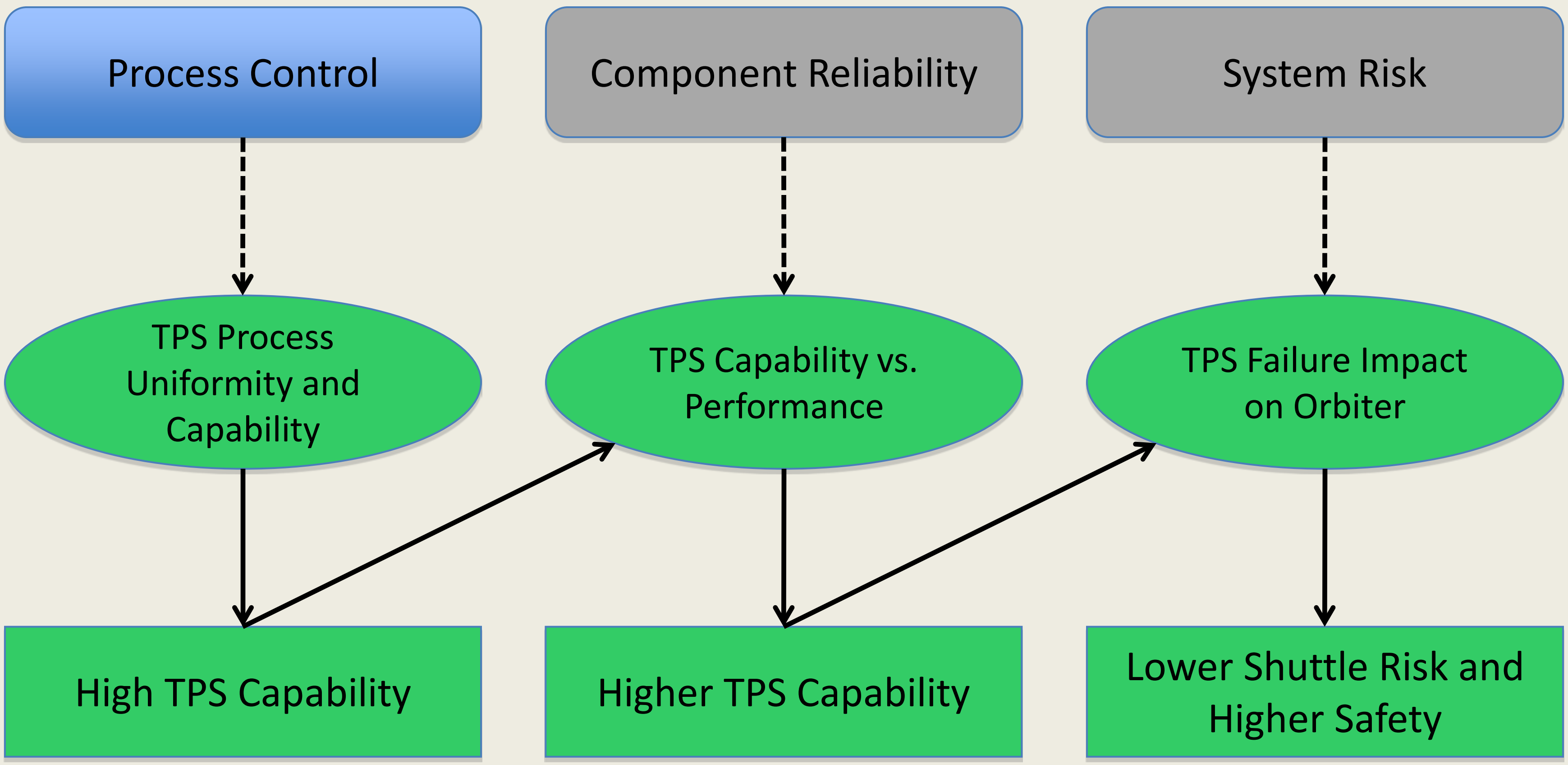
# Reliability of TPS

- The reliability of the TPS is broadly defined as its strength versus the stress put on it in flight.
- High TPS reliability means less debris released and fewer hits to the orbiter, reducing system risk.
- Process control, process uniformity, high process capability are critical factors in achieving high TPS reliability.
- Good process uniformity and high process capability yield fewer process defects, smaller defect sizes, and good material properties that meets the engineering specification—the critical ingredients of high reliability.

# Impact of Process Reliability



# Impact of Process Reliability



# The Message

- The clear message from the Columbia accident and the ET TPS foam experience is that inadequate manufacturing and quality control can have a severe negative impact on component reliability and system safety

- It is critical to understand the relationship between process control, component reliability, and system safety upfront in the design process.

# Concluding Remarks

- Quantitative Reliability Engineering analysis involves more than just reliability predictions and reliability demonstration that are performed against a given program or project requirements.

- Quantitative Reliability Engineering analysis can play a key role in supporting a broad range of applications. It is critical in addressing design and manufacturing deficiencies.

- High Reliability means design it right and build it right