



# NASA Systems Engineering and Safety Culture: Aerospace Project Design and Implementation Challenges

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## Goal

- Educate the MFPT community and partners on NASA Systems Engineering and safety processes

## Objective

- Communicate how NASA performs project design and implementation through real life examples



### Question to audience

- Why are we sitting here?

### Possible Answer

- Seeking greater success in project endeavors.

### Proposed solution

- Performing activities defined by Systems Engineering methods will greatly increase project success.
- Robust Safety Culture and processes in place



# Outline

Introduction

Goal and objective

SE history and definitions

SE benefits and key points

NASA SE processes

Design Reviews

Phases of the project

Goal Statements

Concept of Operations (ConOps)

Requirements Development

Verification and Validation

Design Solutions

Trade Studies

Work Breakdown/Product Breakdown Structure

Project Schedule and Cost

NASA Glenn Safety Culture and Common Practices

Risk Management - Analysis & Mitigation

Conclusions



# Definitions and Terms

## System:

- **NASA:** A set of interrelated components which interact with one another in an organized fashion toward a common purpose.
- **DOD:** An integrated composite of people, products, and processes that provide a capability to satisfy a stated need or objective.
- **INCOSE:** A construct or collection of different elements that together produce results not obtainable by the elements alone.



## SE history

1. [Systems Engineering can be traced back to Bell Telephone Laboratories in the 1940s](#)
2. 1950s and 60s DoD and NASA led the development and identification of new SE methods and modeling techniques
3. [International Council on Systems Engineering \(INCOSE\) 1995](#)
4. 2000s - The conception, design, development, production and operation of physical systems through Model Based Systems Engineering (MBSE)



# Systems Engineering Definition (NASA SP-6105)

***Systems engineering is a robust approach to the design, creation, and operation of systems.*** In simple terms, the approach consists of identification and quantification of system goals, creation of alternative system design concepts, performance of design trades, selection and implementation of the best design, verification that the design is properly built and integrated, and post-implementation assessment of how well the system meets (or met) the goals. An important aspect of this role is the creation of system models that facilitate assessment of the alternatives in various dimensions such as cost, performance, and risk.

***The objective of systems engineering is to see to it that the system is designed, built, and operated so that it accomplishes its purpose in the most cost-effective way possible, considering performance, cost, schedule, and risk.***



## Three Types of Systems Engineering:

1. Product Systems Engineering (PSE) is the focus on the design of physical systems consisting of hardware and software.
2. Enterprise Systems Engineering (ESE) pertains to the view of enterprises, that is, organizations or combinations of organizations, as systems.
3. Service Systems Engineering (SSE) has to do with the engineering of service systems.

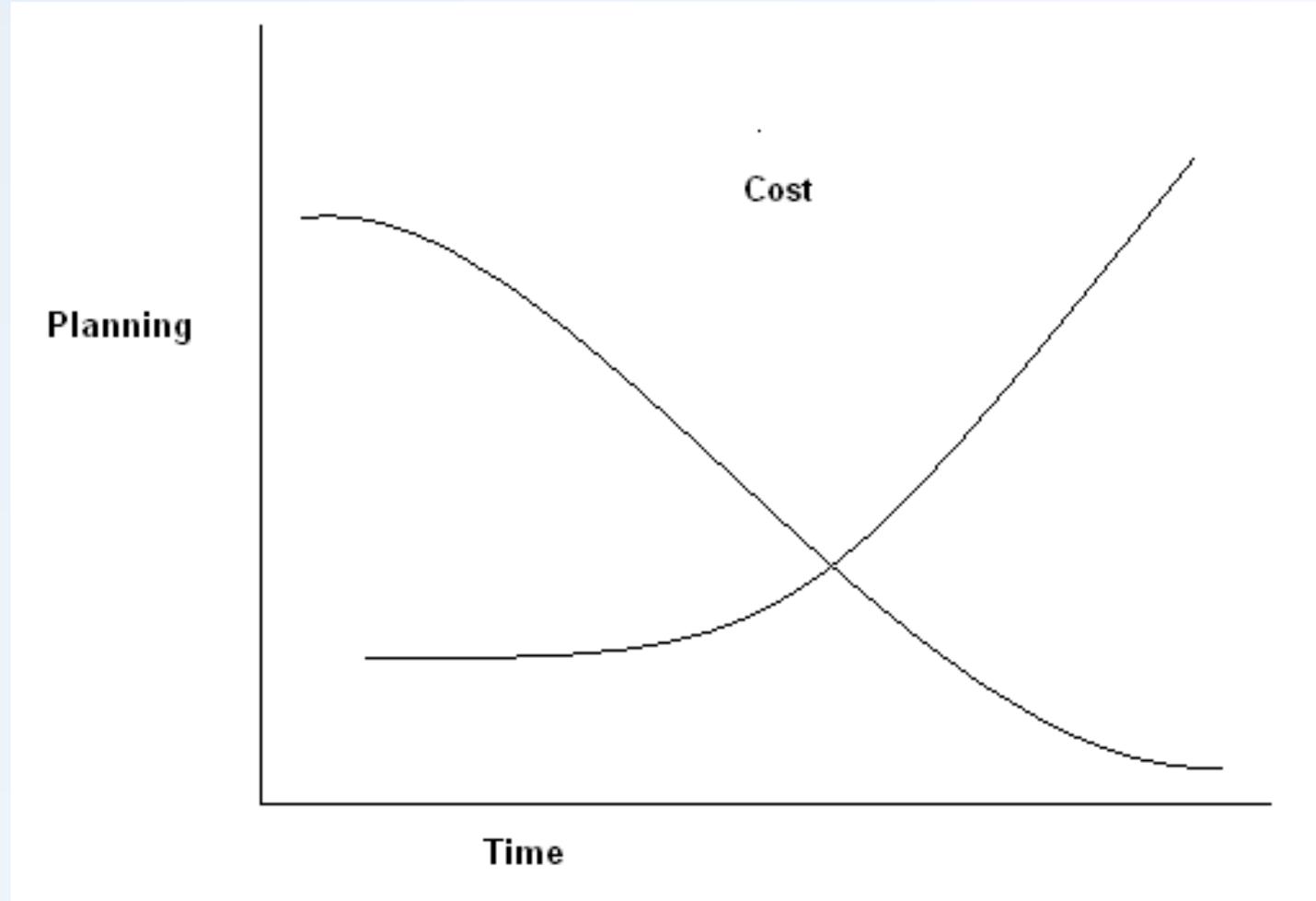


## Systems Engineering Competencies\*

<b>Competency Area:</b> <b>1.0 Concepts and Architecture</b>	<b>Competency Area:</b> <b>6.0 NASA Internal and External Environments</b>
1.1 Mission Needs Statement	6.1 Agency Structure, Mission, and Internal Goals
1.2 System Environments	6.2 NASA PM/SE Procedures and Guidelines
1.3 Trade Studies	6.3 External Relationships
1.4 System Architecture	
<b>Competency Area:</b> <b>2.0 System Design</b>	<b>Competency Area:</b> <b>7.0 Human Capital Management</b>
2.1 Stakeholder Expectation Definition & Management	7.1 Technical Staffing and Performance
2.2 Technical Requirements Definition	7.2 Team Dynamics and Management
2.3 Logical Decomposition	
2.4 Design Solution Definition	
<b>Competency Area:</b> <b>3.0 Production, Product Transition, Operations</b>	<b>Competency Area:</b> <b>8.0 Security, Safety and Mission Assurance</b>
3.1 Product Implementation	8.1 Security
3.2 Product Integration	8.2 Safety and Mission Assurance
3.3 Product Verification	
3.4 Product Validation	
3.5 Product Transition	
3.6 Operations	
<b>Competency Area:</b> <b>4.0 Technical Management</b>	<b>Competency Area:</b> <b>9.0 Professional and Leadership Development</b>
4.1 Technical Planning	9.1 Mentoring and Coaching
4.2 Requirements Management	9.2 Communication
4.3 Interface Management	9.3 Leadership
4.4 Technical Risk Management	
4.5 Configuration Management	
4.6 Technical Data Management	
4.7 Technical Assessment	
4.8 Technical Decision Analysis	
<b>Competency Area:</b> <b>5.0 Project Management and Control</b>	<b>Competency Area:</b> <b>10.0 Knowledge Management</b>
5.1 Acquisition Strategies and Procurement	10.1 Knowledge Capture and Transfer
5.2 Resource Management	
5.3 Contract Management	
5.4 Systems Engineering Management	

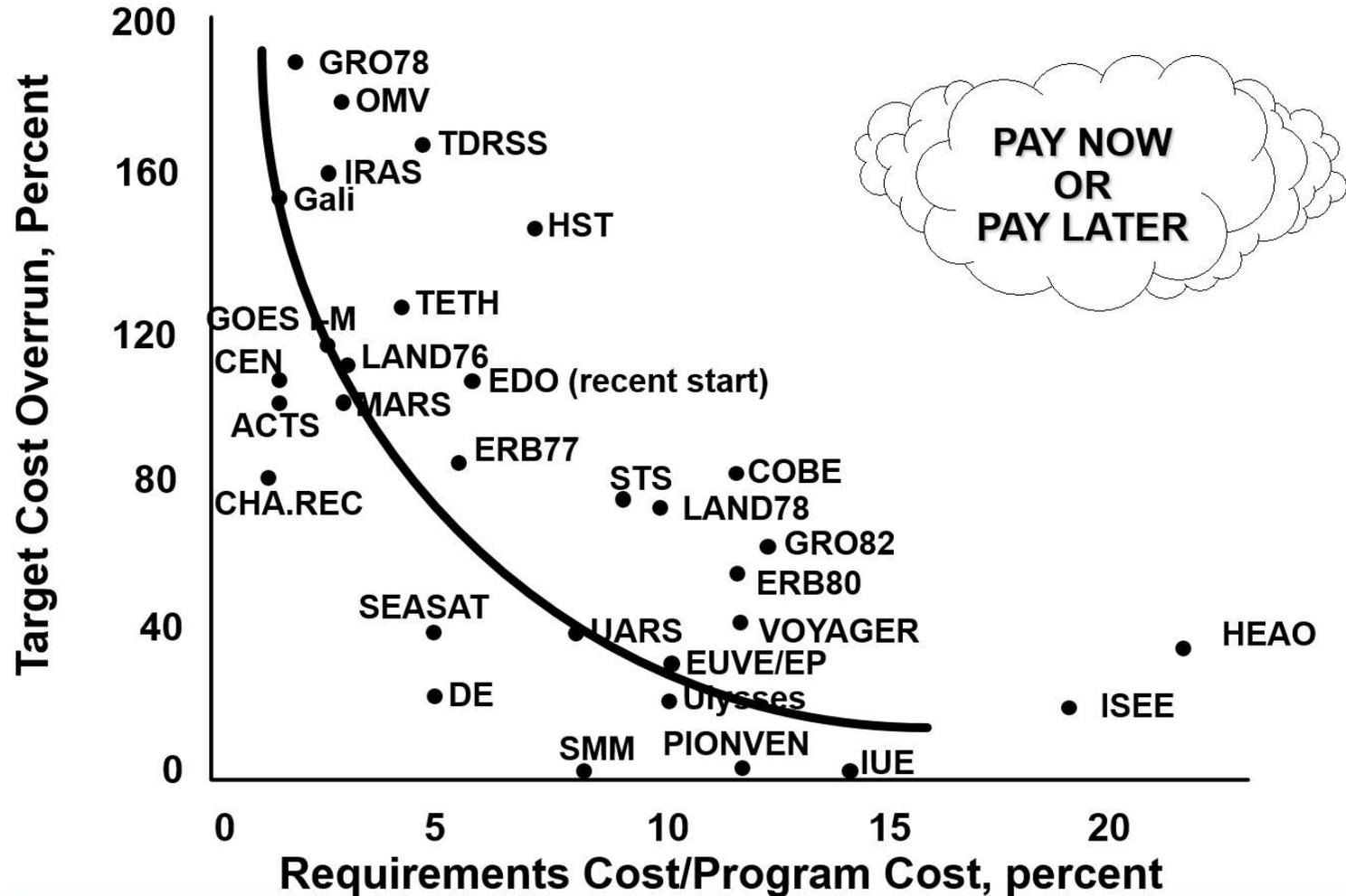


# Benefit of SE





# Effect of Requirements Definition Investment on Program Costs



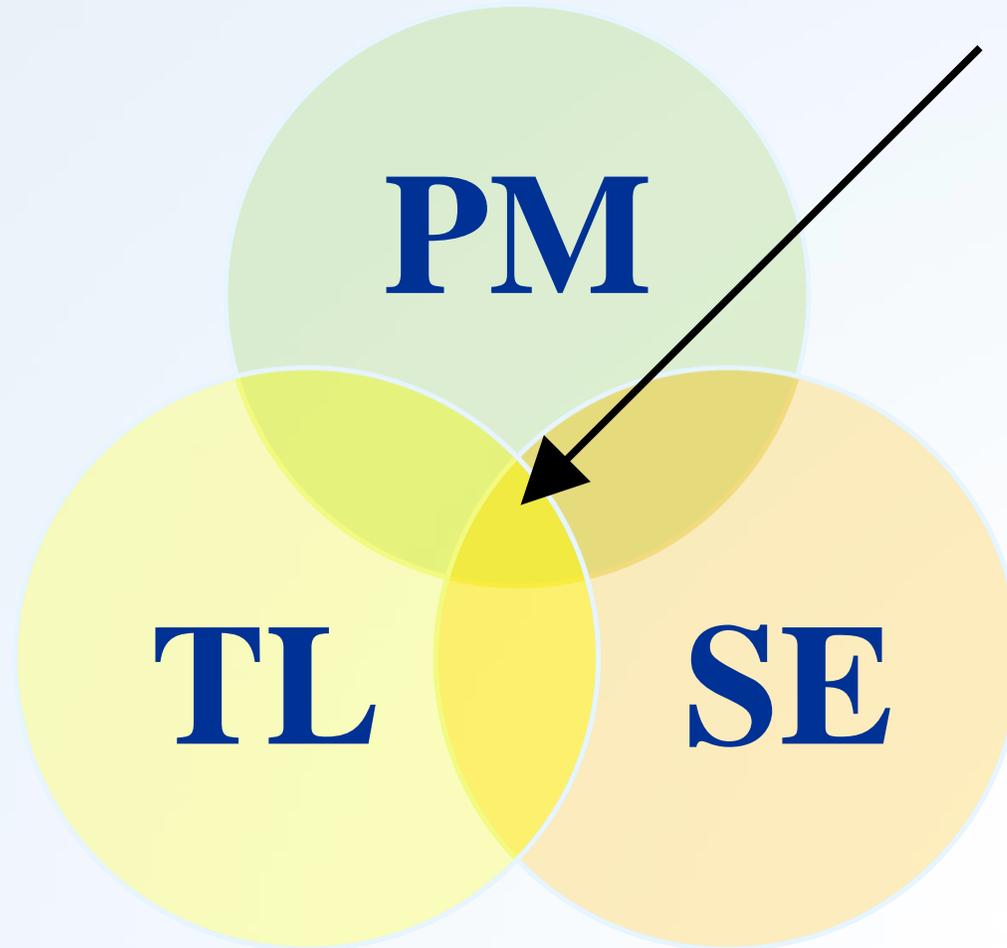


## Systems Engineering Leadership:

- Knowledge base
  - What do you know about the subject?
- Engineering judgment
  - Experience, successes
- Effective Communication
  - Written, verbal, diplomacy
- Systematic Processes
  - Company policy
  - Examples: CMMI, ISO, NPR 7123.1A



Interaction of PM, SE, and TL = WBS creation:





## MUST BALANCE

Risk (R)! Performance (P)! Cost (C)!

$$C * R = P$$

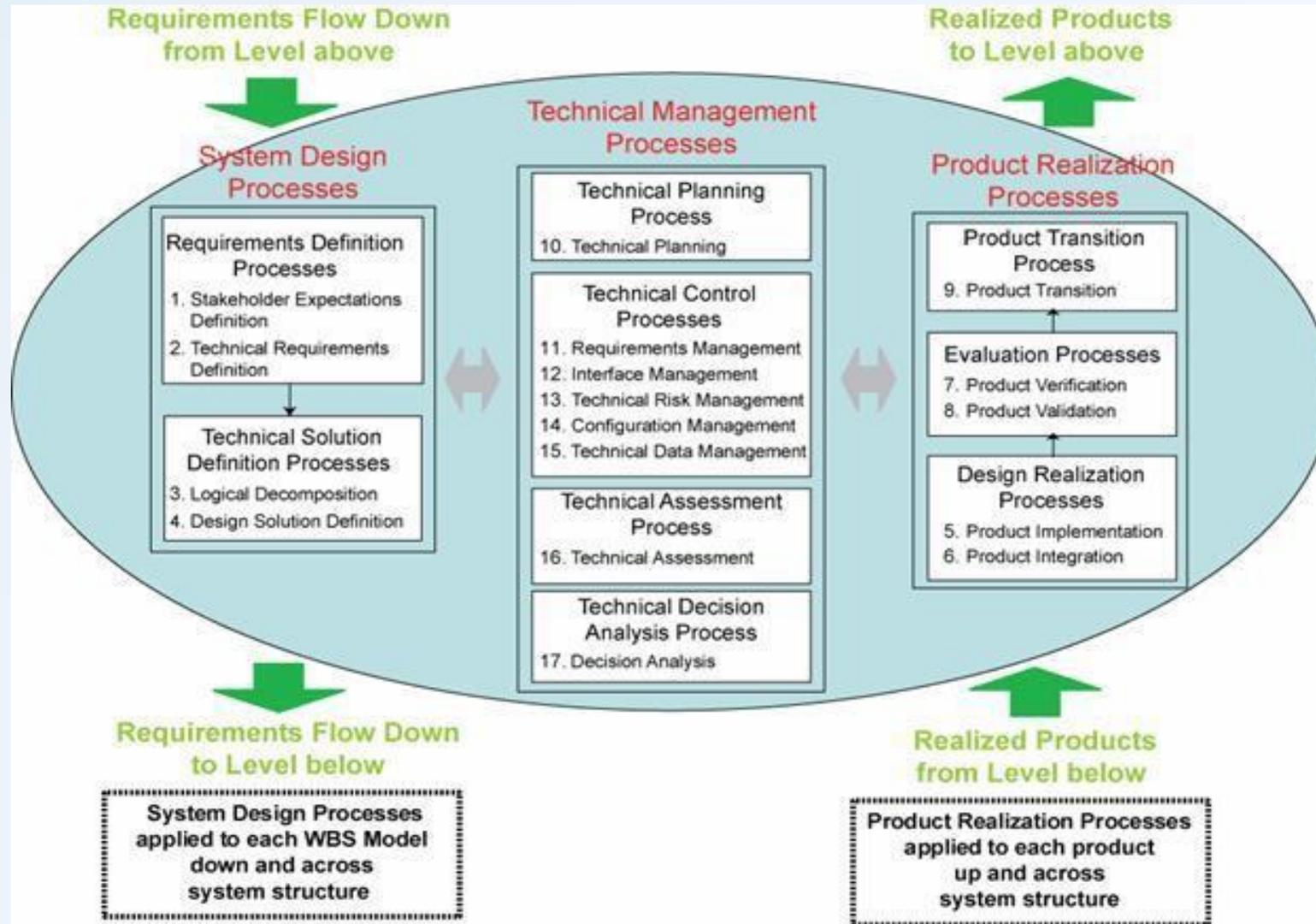
1. Reduce C at constant R = P drops
2. Reduce R with constant C = P drops
3. Reduce P at constant C = Risk drops
4. Reduce P at constant R = Cost drops
5. Reduce C at constant P = Risk increase
6. Reduce R at constant P = Cost increase
7. Etc.



# Design Engineering Dilemma

## Engineers want a solution NOW!

- General statements lead to detailed design on first step.
- Difficult to step back and look at BIG picture
- Up front requirements definition and systems engineering planning are PARAMOUNT before designs start getting built.
- Late design changes cost \$\$\$\$\$
- Communication is KEY.





**NASA/SP-2007-6105**  
**Rev1**

**NASA**  
**Systems Engineering**  
**Handbook**





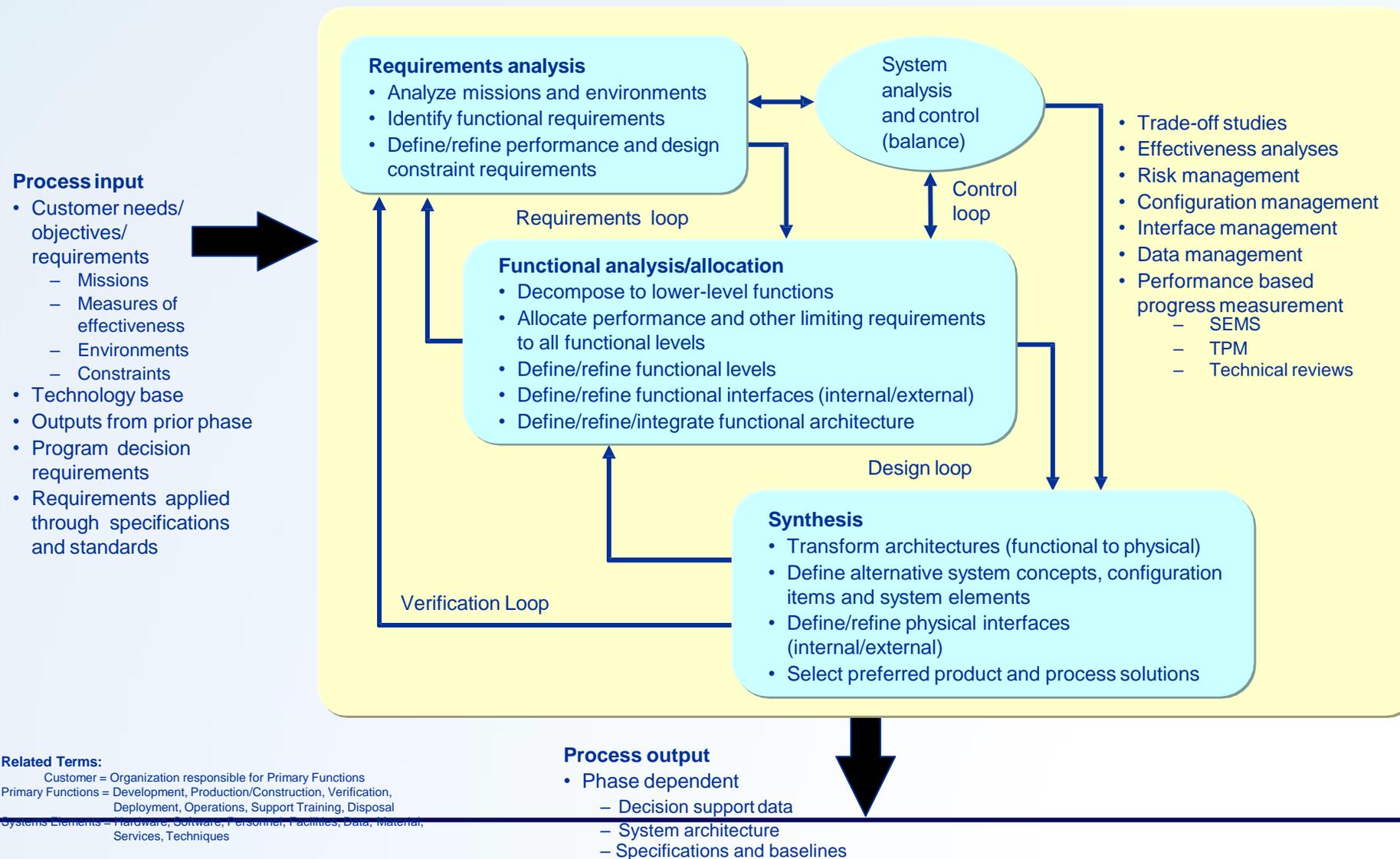
This handbook consists of six core chapters:

- (1) Systems engineering fundamentals discussion
- (2) the NASA program/project life cycles
- (3) systems engineering processes to get from a concept to a design
- (4) systems engineering processes to get from a design to a final product
- (5) crosscutting management processes in systems engineering
- (6) special topics relative to systems engineering



# The Systems Engineering Process

## Per INCOSE Systems Engineering Handbook





# NASA Program/Project Life Cycle

## **NASA Program/Project Life Cycle**

Program Formulation

Program Implementation

Project Pre-Phase A: Concept Studies

Project Phase A: Concept and Technology Development

Project Phase B: Preliminary Design and Technology Completion

Project Phase C: Final Design and Fabrication

Project Phase D: System Assembly, Integration and Test, Launch

Project Phase E: Operations and Sustainment

Project Phase F: Closeout

Funding: The Budget Cycle

Tailoring and Customization of NPR 7123.1 Requirements

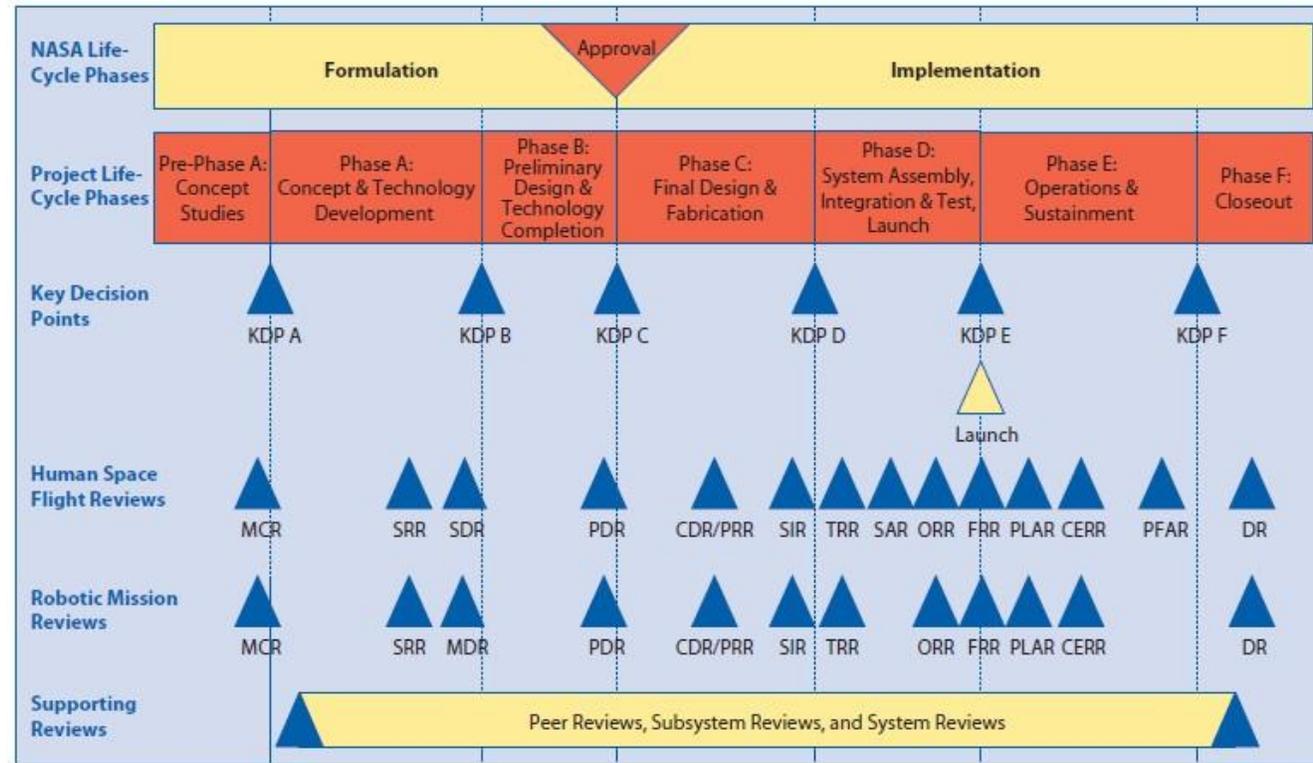


# NASA Formulation Phase

- Phase A
    - Mission Goals and Objectives
    - Concept Design Evaluation Criteria
    - Mission Concepts
    - Operations Concepts
    - Life-cycle Cost Estimates
    - Feasibility Assessment
  - Phase B (PDR)
    - Mission Need Statement
    - Function Mission Concept
    - Preliminary System Specification
    - Science and Technical Requirements
    - Trade & Analysis Results
    - Technology Development Plan
  - Phase C (CDR)
    - System Concept & Architecture
    - System Specification
    - Interface Requirements
    - Environmental Specification
    - Human System Standards
    - Concept/Design Evaluation Criteria
    - Development Test Plans
    - Engineering Units
    - Risk Analyses
    - Development Test Results
    - Technology Development
-



CDR	Critical Design Review	PLAR	Post-Launch Assessment Review
CERR	Critical Events Readiness Review	PRR	Production Readiness Review
DR	Decommissioning Review	P/SDR	Program/System Definition Review
FRR	Flight Readiness Review	P/SRR	Program/System Requirements Review
KDP	Key Decision Point	PSR	Program Status Review
MCR	Mission Concept Review	SAR	System Acceptance Review
MDR	Mission Definition Review	SDR	System Definition Review
ORR	Operational Readiness Review	SIR	System Integration Review
PDR	Preliminary Design Review	SRR	System Requirements Review
PFAR	Post-Flight Assessment Review	TRR	Test Readiness Review
PIR	Program Implementation Review		





# Leading up to Preliminary Design Review

- To determine the feasibility and desirability of a suggested new major system and establish an initial baseline compatible with strategic plans.
- Develop final mission concept, system-level requirements, and needed system structure technology developments.
- Mature requirements for all products in the developing product tree, develop ConOps, preliminary designs, and perform feasibility analysis of the verification and validation concepts to ensure the designs will likely be able to meet their requirements.



## Output of PDR

End products in the form of mockups, trade study results, specification and interface documents, and Prototypes.

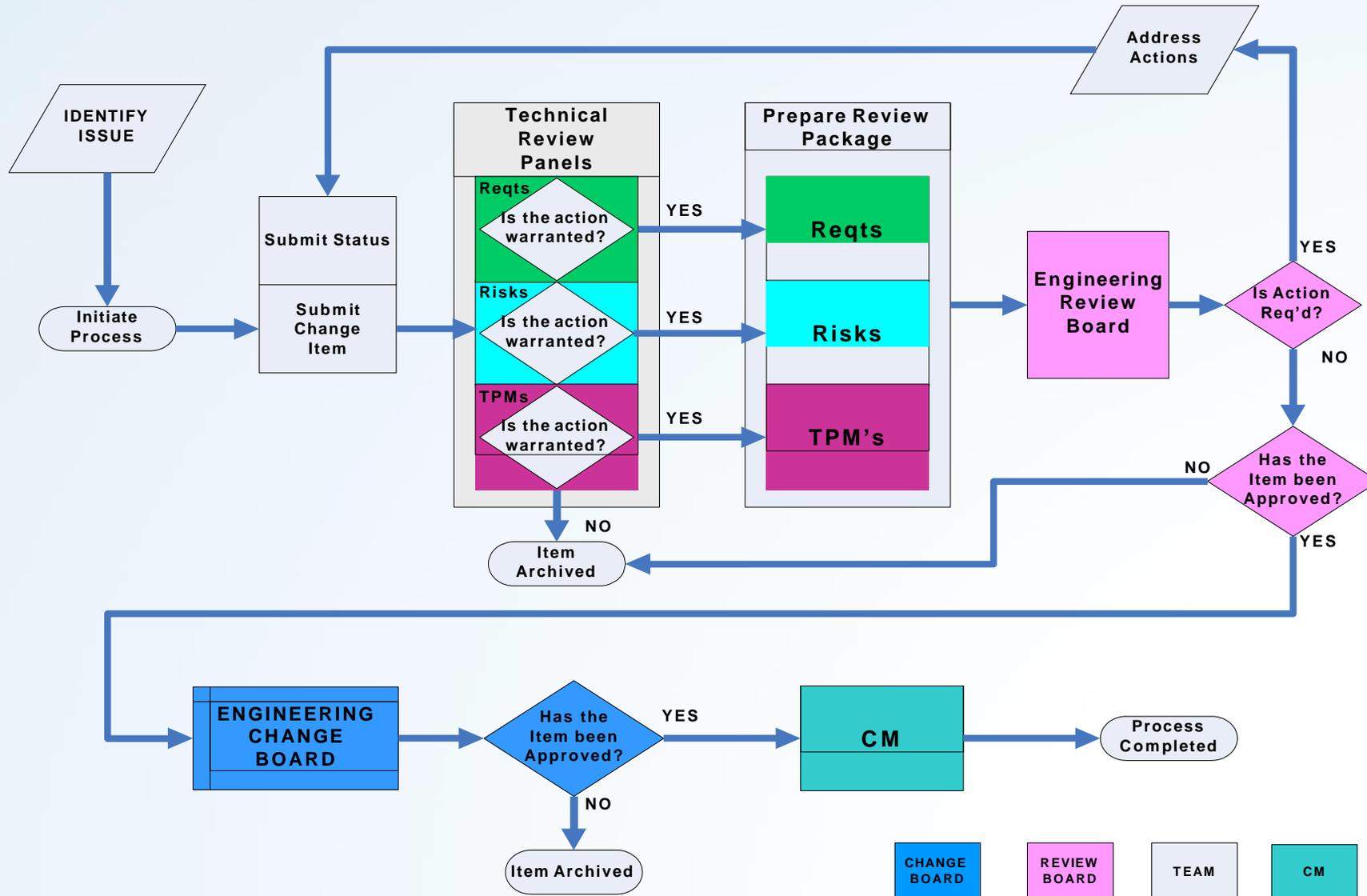


# How to get to PDR

- Main Goal and Objective
- Functional Mission and Concept of Operations
- Develop High Level Requirements
- Identify Key Driving Requirements
- Define Verification Methods
- Identify Design Solutions
- Perform Trade Studies (Identify Stakeholders)
- Develop a Work Break Down Structure (Product Based)
- Cost and Schedule
- Risk Management and Mitigation
- Technical Performance Measures
- Configuration Management



# Business Rhythm





# REVIEW CYCLE

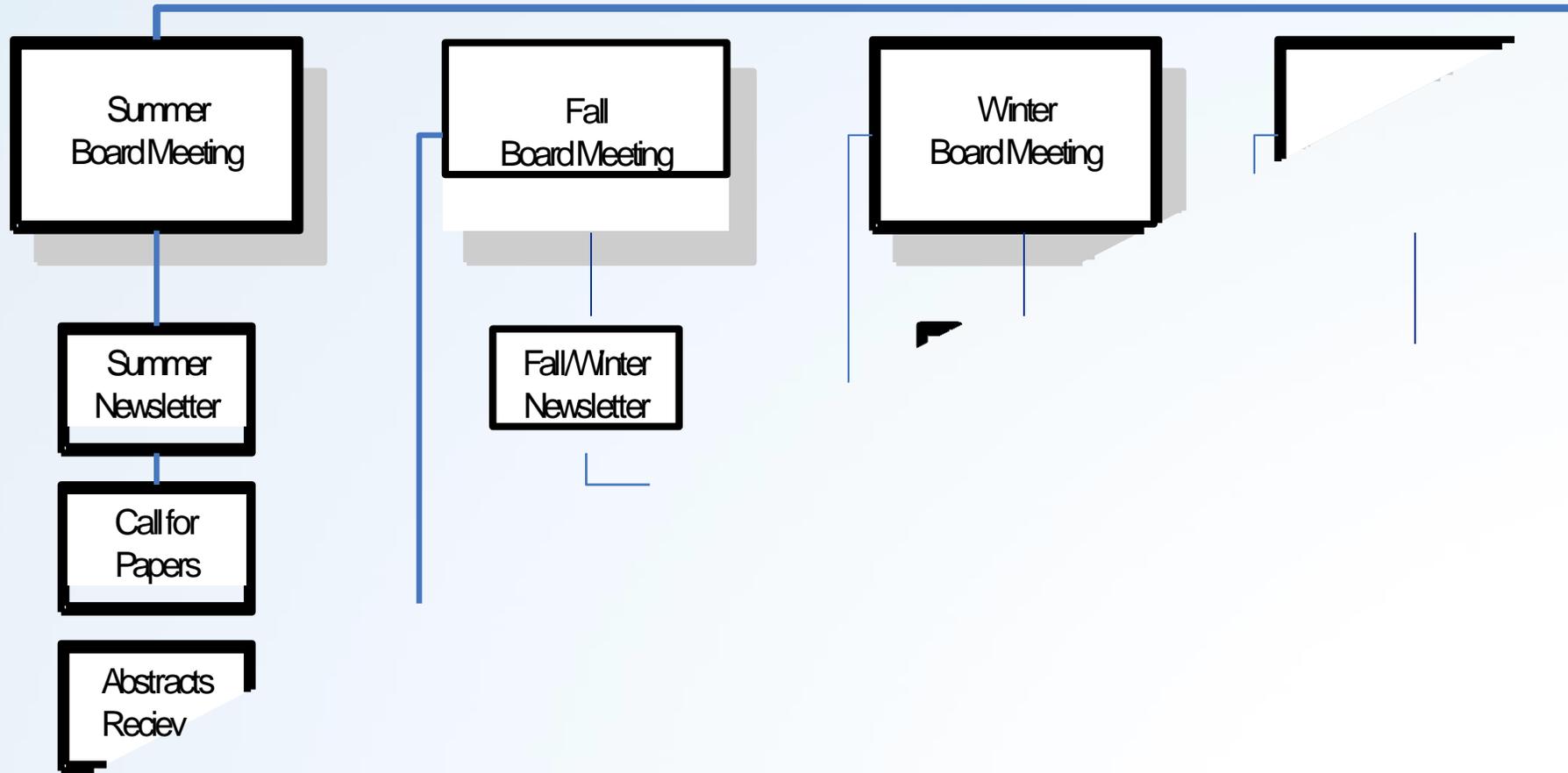




# Concept of Operations Examples



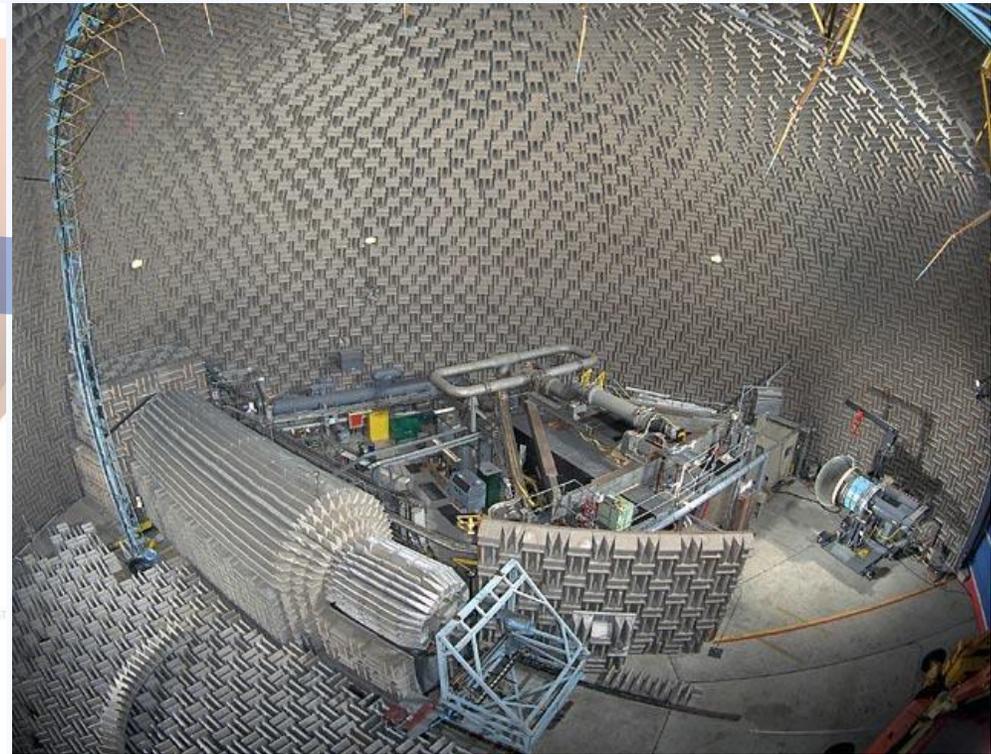
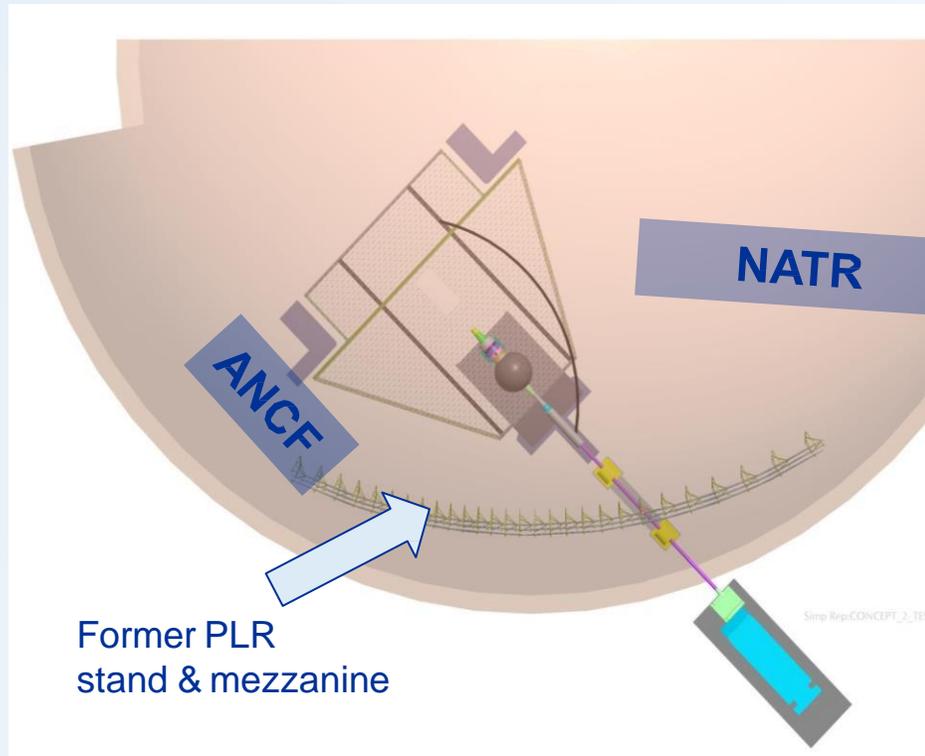
# MFPT Concept of Operations



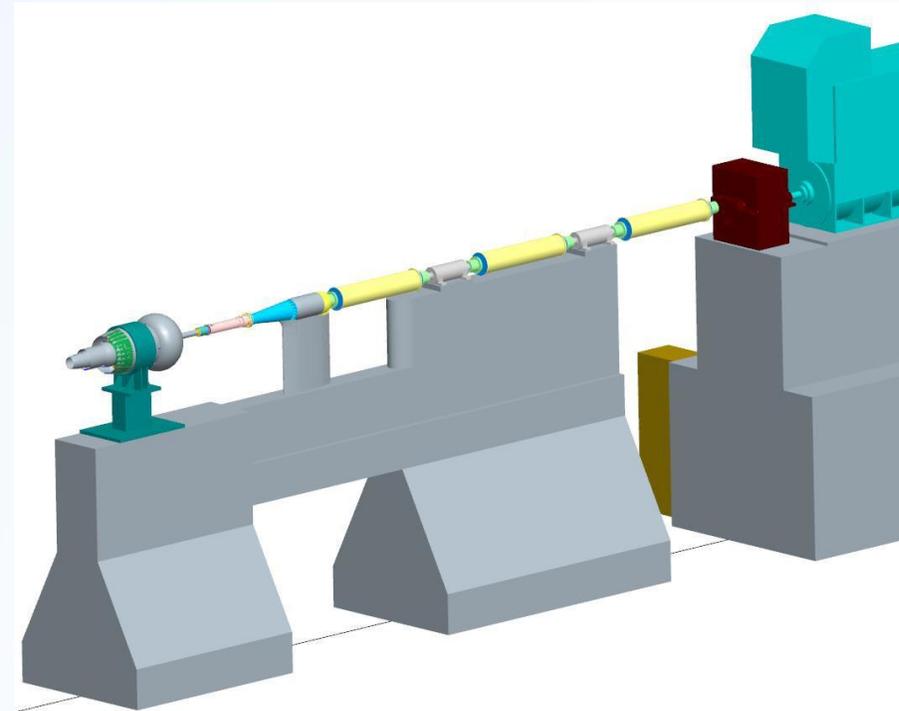


# ANCF II Location in AAPL

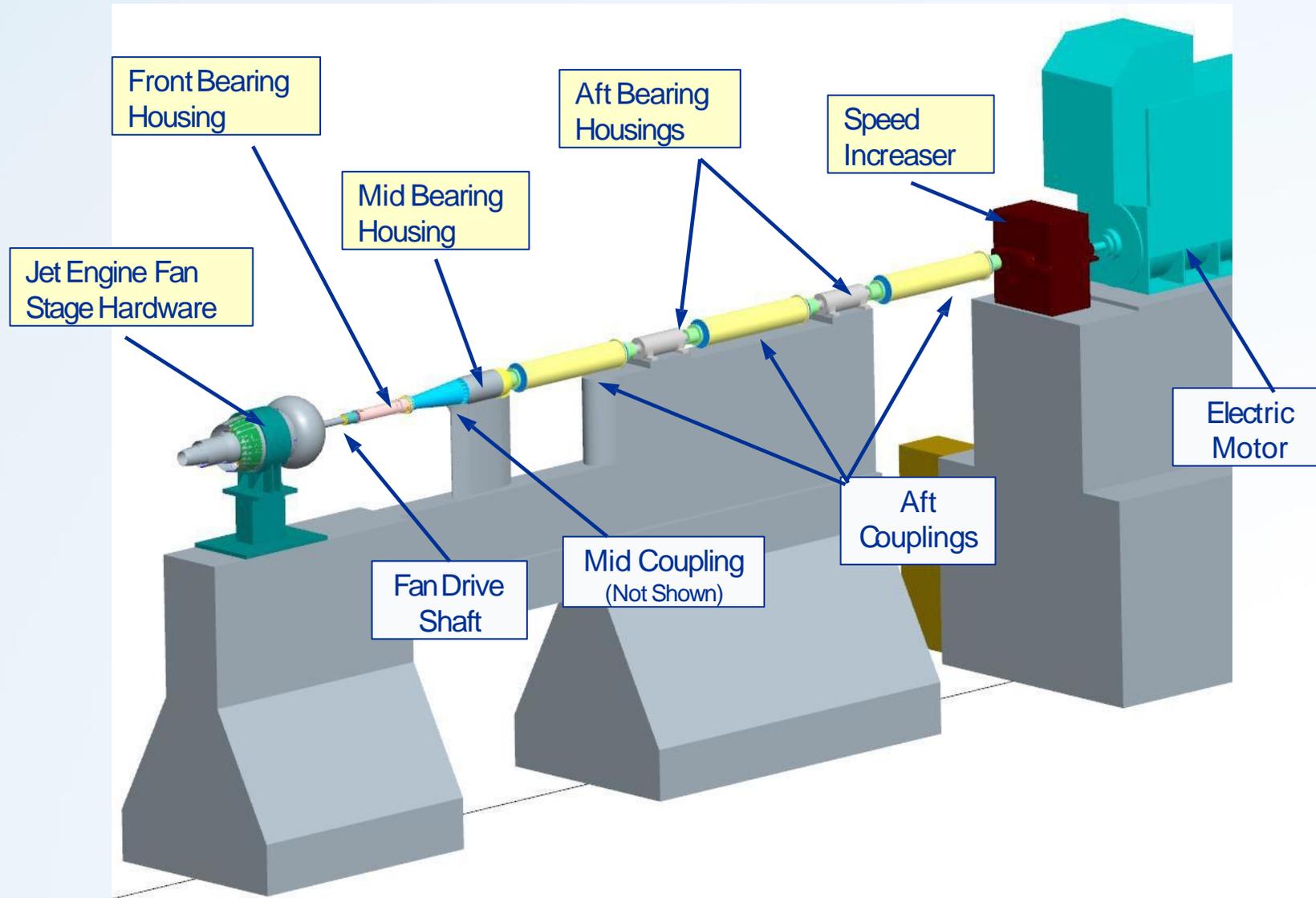
Proposed location of the new test rig with respect to current facility layout.



# Background Information

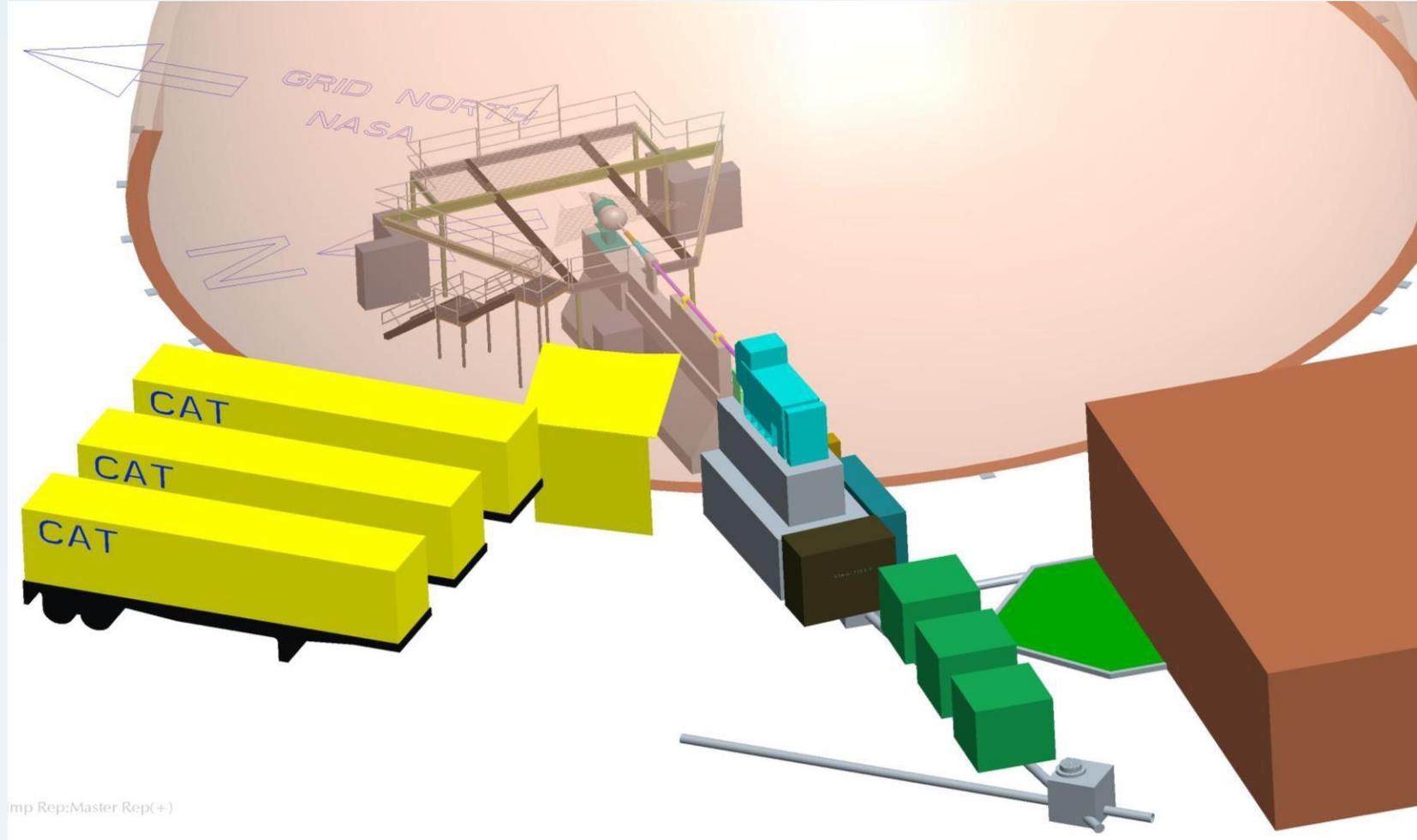


# Front Driven Fan- Test Rig Overview



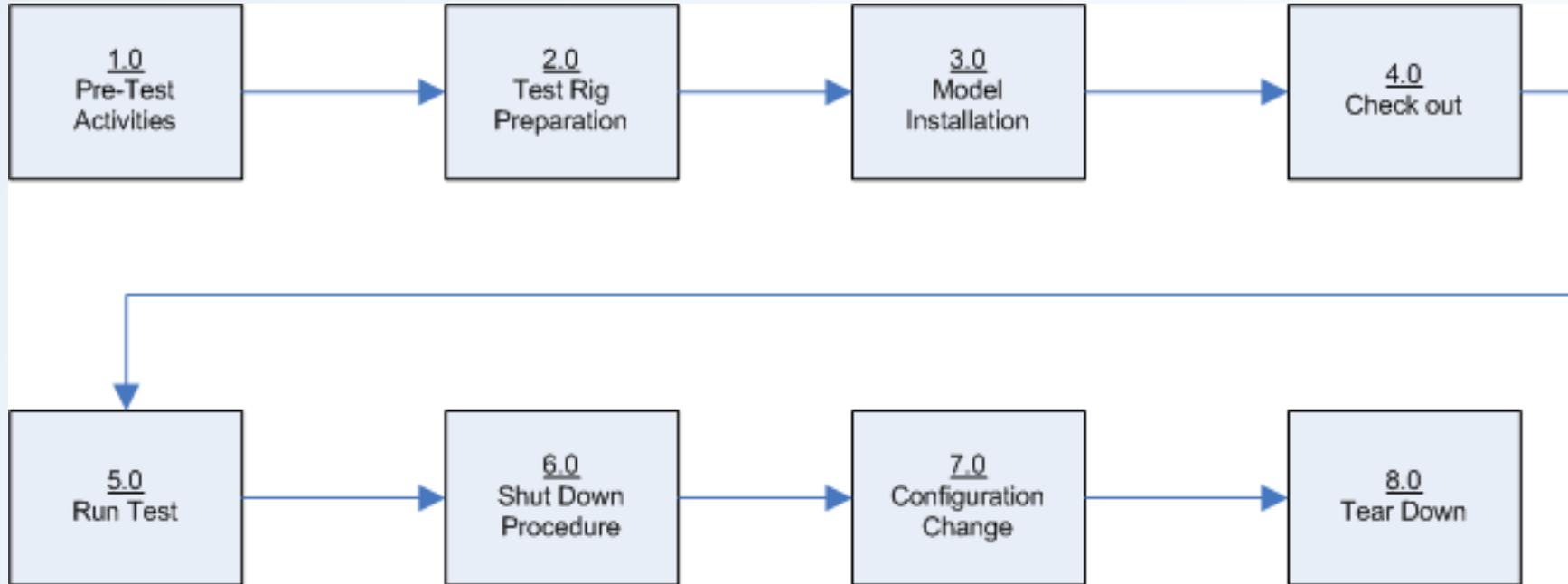


# Objective: Identify, prioritize and manage risks





# Concept of Operations



# ANCF II Functional Flow



# DGEN380 Turbofan Engine



2 spool, geared fan (3.32 ratio), unmixed, separate flow exhaust

Centrifugal compressor, LP/HP turbine (43,000/52,000 rpm),

Thrust 560 lbf, 7.6 BPR, 1.2 FPR, 5.3 OPR, 28.7 lb/s mass flow

14 inch diameter fan, 14 fan blades, (13,000 rpm)

$V_{tip} = 785$  fps subsonic tip speed



**Low component count/easy disassembly**

© Price-Induction: used with permission

# DGEN380 Complete System



Engine  
Stand  
ICD



Tool  
Kit



Control  
Monitor  
Bench



# Conceptual DART Major Components



*Pictures for illustration purposes only*

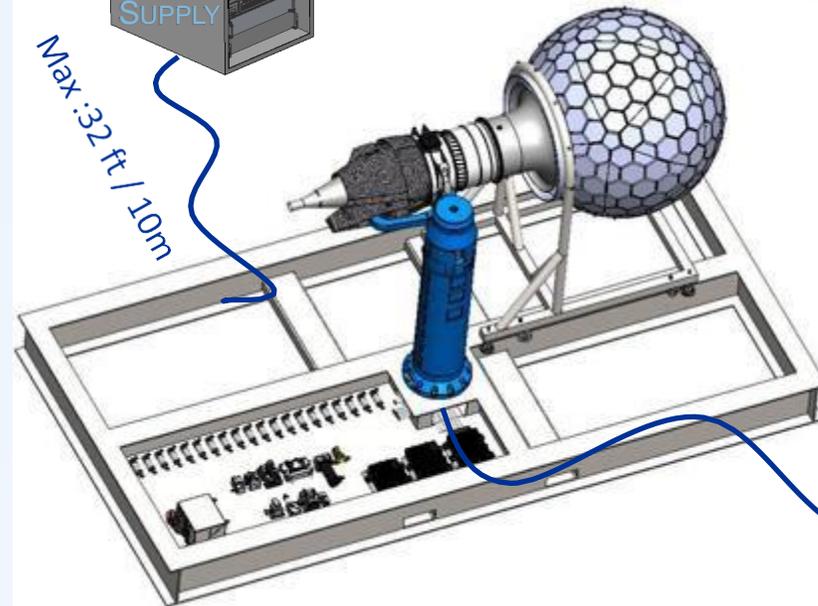
HARNESS (OPTICAL FIBER  
+ COMMAND SIGNALS)  
MAX DISTANCE :: 50M /  
164 FT

Fire Suppression



3-PHASE  
200V  
SUPPLY

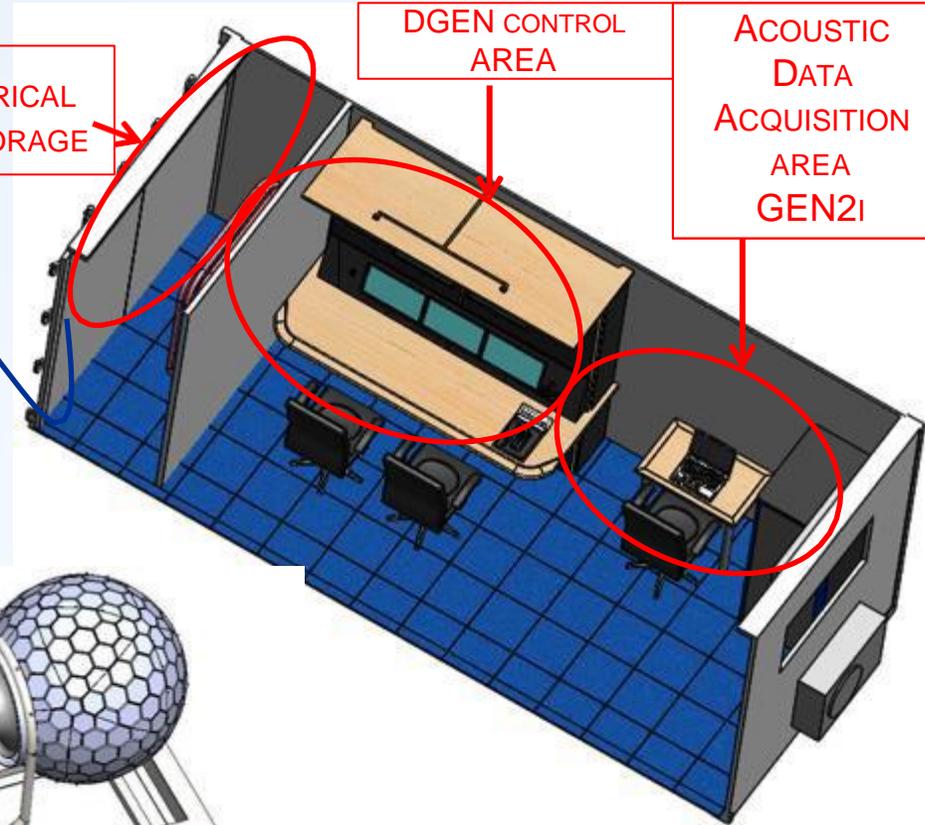
Max : 32 ft / 10m



ELECTRICAL  
BAY STORAGE

DGEN CONTROL  
AREA

ACOUSTIC  
DATA  
ACQUISITION  
AREA  
GEN2i

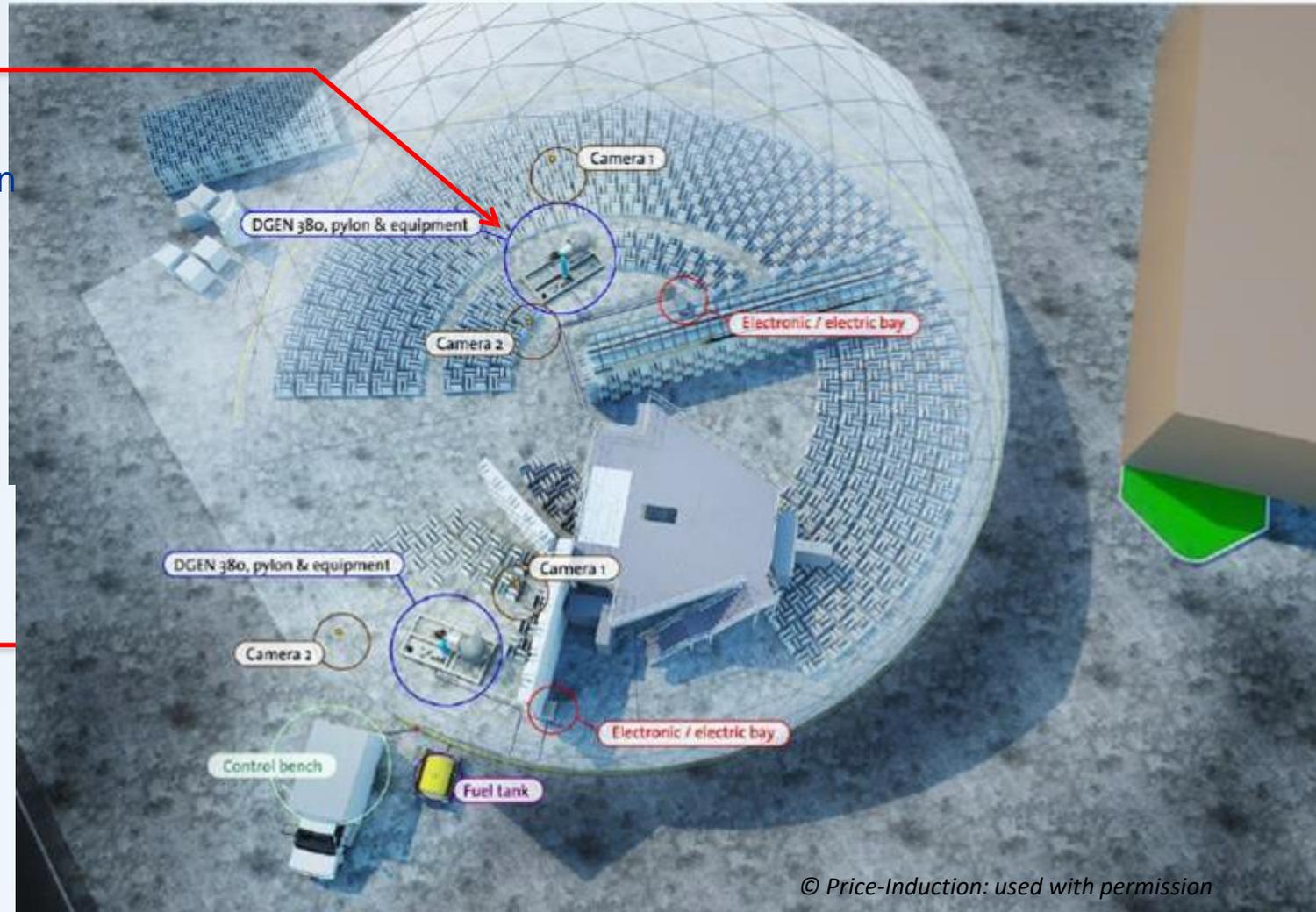




# DART in AAPL

Location #2  
Overhead array  
Jet Noise tests  
Airframe Integration

Location #1  
Check Outs  
In-close array  
Fan Noise tests  
Control tests  
SDTs





# System Design Processes

1 Stakeholder Expectations Definition

2 Technical Requirements Definition

3 Logical Decomposition

4 Design Solution Definition



# Stakeholder Expectations

- Understand User Requirements
- High Level Specifications
- Lessons Learned



# Understand User Requirements

- Need?
- User vision?
- Cost?
- Risk?
- Educate diplomatically



# Requirements Definition

- Tools for Discovery
  - Con Ops
  - Functional Analysis
  - Logical Decomposition



# High Level Specifications

- Functional Characteristics
- Thresholds/uncertainty
- Operational Goal
- Key Performance Parameters (KPPs)



# KPPs

- Most essential (speed, accuracy. . .)
- Need a threshold (minimum value)
- Operational Goal metrics
- Document in High Level Program Requirements



# Types of Requirements

- Functional – what does it do?
- Operational – how is it operated?
- Constraints/Ground Rules – restrictions on development, operation, support
- Performance – How does it perform?
- Process – Prevailing guidelines and procedures the system is designed in.



# Requirements vs. Specifications

- Requirement = states a problem
- Specification = is a solution
- Can be one in the same. For example:
  - Logistics
  - Materials Processes
  - Reliability
  - Availability
  - Interchangeability
  - Other –ilities
  - Interfaces
  - Workmanship (some kind of metric)
  - Physical Properties



# Deriving Requirements Lessons Learned

- Achievable
  - Verifiable (VCRM!!)
  - Crystal clear
  - Completeness
  - Appropriate level
  - Reflects need not solution  
(no design solution at high level)
-

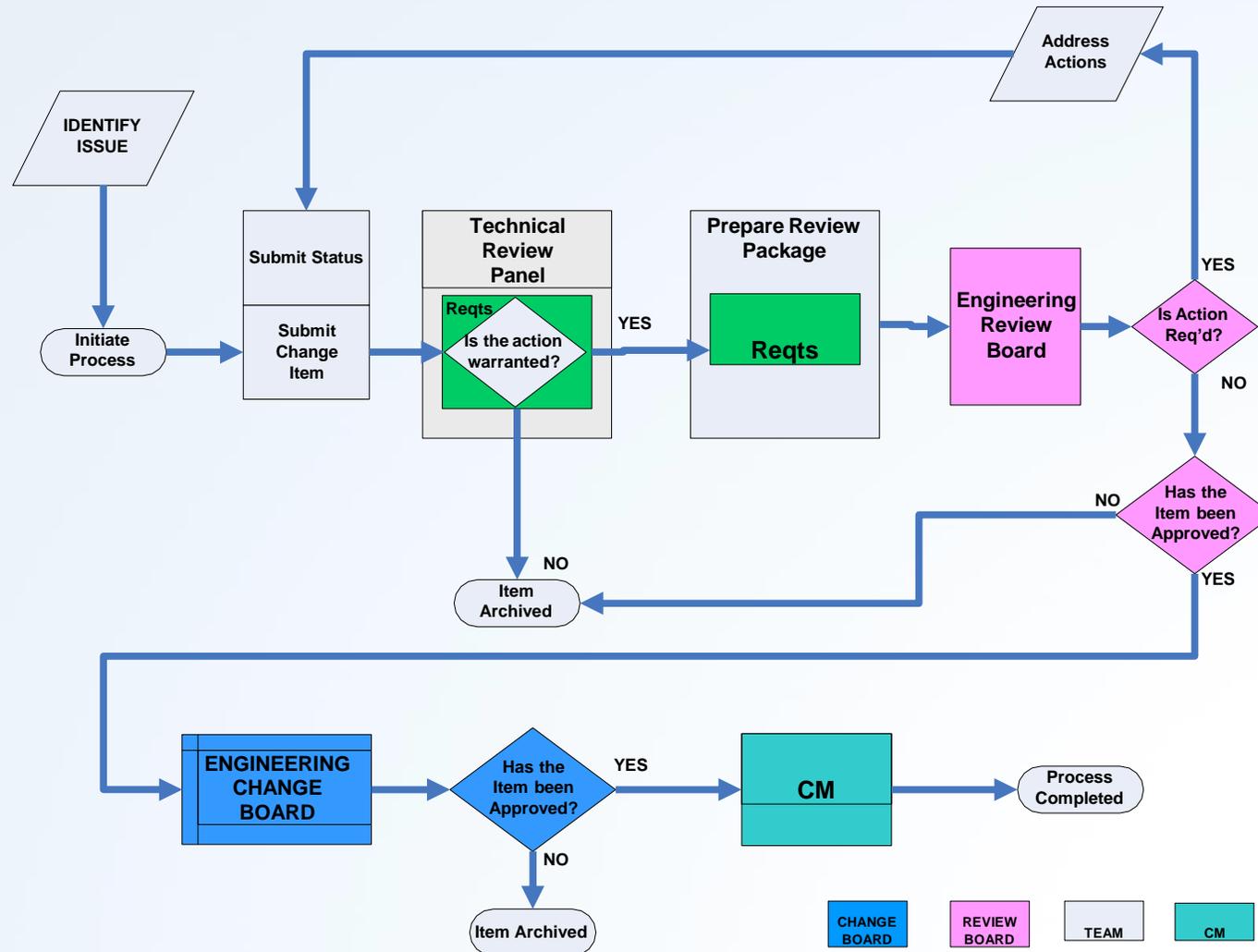


# Deriving Requirements Lessons Learned

- One “shall” per requirement
  - One requirement at a time.
  - Use simplest language possible
  - Plan to iterate
  - “Will” is statement of intent but not binding.
  - “must” shall not be used.
-



# Requirements Review Process





# Requirements Traceability

High Level Requirements	Design Solution	sub system detail
DR28 All critical dimensions shall be field verified prior to finalization of design.	DR28.1 AAPL historical field implementation methodology shall be used.	DR28.1.1 Actual Field implementation
Rationale: Quality	V27.2 Analysis: Report: AAPL DART Fuel Tank Implementation	DR10.1.1 NNC12BA01B, GESS-3 Task 483 DART/AAPL Facility Integration Fuel System Engineering Report
		DR5.2.1 NNC12BA01B, GESS-3 Task 484 DART/AAPL Facility Integration DART test stand Engineering Report
		DR27.2.1 Field Implementation following Report specifications in AAPL DART Fuel Tank Implementation



# Verification and Validation

The purpose of the V&V Plan is to identify the activities (right way) that will establish compliance with the requirements (verification) and to establish that the system will meet the customers' expectations (the right thing) (validation)

# Verification



- A Verification Matrix (VM) is generated to show the requirement traceability and closure methodology.



## Verification Definitions

- **Demonstration:** Showing the use of an end product achieves the individual specified requirement. It is generally a basic confirmation of performance capability, differentiated from testing by the lack of detailed data gathering. Demonstrations can involve the use of physical models or mock-ups; for example, a demonstration could be the actual operation of the end product by highly-qualified personnel who perform a one-time event that demonstrates a capability to operate at extreme limits of system performance, an operation not normally expected from a representative operation of the product.



## Verification Definitions

- **Inspection:** The visual examination of a realized end product or drawing. Inspection is generally used to verify physical design features or specific manufacturer identification. For example, if there is a requirement that the safety arming pin has a red flag with the words “Remove Before Flight” stenciled on the flag in black letters, a visual inspection of the arming pin flag can be used to determine if this requirement was met.



- Analysis: The use of mathematical modeling and analytical techniques to predict the suitability of a design to stakeholder expectations based on calculated data or data derived from lower system structure end product verifications. Analysis is generally used when a prototype; engineering model; or fabricated, assembled, and integrated product is not available. Analysis includes the use of modeling and simulation as analytical tools. A model is a mathematical representation of reality. A simulation is the manipulation of a model. Analysis can include verification by similarity of a heritage product.



## Verification Definitions

- **Test:** The use of an end product to obtain detailed data to verify performance, or provide sufficient information to verify performance through further analysis. Testing can be conducted on final end products, breadboards, brass boards or prototypes. Testing produces data at discrete points for each specified requirement under controlled conditions and is the most resource-intensive verification technique. As the saying goes, *“Test as you fly, and fly as you test.”* Testing can also be done in facilities that simulate flight conditions. Also done to verify and validate CFD and other flow simulation modeling software development.

## W-6B Schlieren System Project



## APPENDIX B: VERIFICATION CROSS REFERENCE

Table B1: Verification Cross Reference Matrix (VCRM)

Require. No.	Requirement Text	Verif. Method	Verification Text
SS14	The System shall be delivered with the necessary alignment tools provided and a procedural document for set up and alignment	I	Inspect deliverables list
SS15	The System shall have protective dust covers for any new mirrors that are specified	I	Inspect deliverables list
SS16	Existing mirror protective covers shall be tested for fit and can be modified to fit new structure if used in the new system.	D	Demonstrate capability at end use
SS17	The System shall include a light shutter on the output of the light source.	D	Demonstrate capability at end use
SS18	The System shall have remote operation capability.	I	Inspection of drawings



# Mandatory Requirements Information

Reqmt. I.D.	Parent	Requirement Text	Mission Applic a bility			VCRM	
			GTA	CEV	Altair	Method	Description
IET 3.1.1.1	Derived	All GSE, adapter and test fixtures which come in direct contact with the Constellation Program GTA and Qualification test articles shall be provided, operated and maintained by the customer.	X	X	X	I	A list of GSE, adapter and test fixtures will be provided prior to testing to delineate the hardware which the customer will be providing, operating and maintaining.
IET 3.2.1.2.2	CxP 70036 , 5.8.1	The MVF sinusoidal vibration system shall apply vibration in each of three orthogonal axes (each axis individually).	X	X		T	A test with a dummy test article will be performed to ensure proper operation.



## Model Based Systems Engineering (MBSE)

INCOSE defines MBSE as “Model-based systems engineering (MBSE) is the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases.” In practice, System Markup Language (SysML) based models have gained the most prevalence in MBSE application. These models are system relationship models and are useful for showing relationships among system functions, requirements, developers, and users. These models support 3 aspects of systems engineering:

System Functional Flows (i.e., System Architecture)

System Requirements Traceability

System and Organizational Process Flows



## **Model Based Systems Engineering (MBSE)**

There are several organizations that have been working to advance the SysML modeling capabilities and applications.

These include the INCOSE MBSE Initiative and the NASA MBSE Pathfinder.

The INCOSE MBSE Initiative is looking at a broad list of topics in the application of MBSE.



## Design Solutions and Trade Studies



# Trade Studies and the Decision Analysis Process

- Used to:
  - Evaluate technical issues and alternatives
  - Evaluate uncertainties in decision making support
- Used throughout:
  - System design
  - Technical management
  - Product realization



## Basic Principles

1. Define the Objective (requirements analysis)
2. Identify alternatives (concept exploration)
3. Compare the alternatives (definition)
4. Sensitivity analysis (validation)



# Decision Process

1. Define the Objective
2. Identify decision stakeholders
3. Identify alternatives
4. Identify analysis team
5. Define the decision factors/criteria
6. Select evaluation tools and methods
7. Compare the alternatives based on criteria
8. Perform Sensitivity analysis
9. Select the preferred alternative
10. Document the decision



## Define the Objective

- Include principal requirements
- Identify the mandatory ones that must be met. These are called the Key Driving Requirements (KDRs)
- I believe these are Vibration Sensitivity, Image Area Viewing, Robust design, and Ease of Setup



## Identify Stakeholders

- Important to identify correctly
- Buy in must be achieved by all stakeholders
- Without stakeholder input, key requirements might be omitted
- User, developer, funder, manufacturer, expert



## Identify Alternatives

- Rigorous effort to identify several candidates
- Predecessor as baseline
- Competing technologies
- Anticipated technological advances
- Innovative concepts



## Identify Team

- Relevant stakeholders
- Experts in the technology
- Expert users of tools/methodology
- Systems engineering leader
- Outside subject matter experts



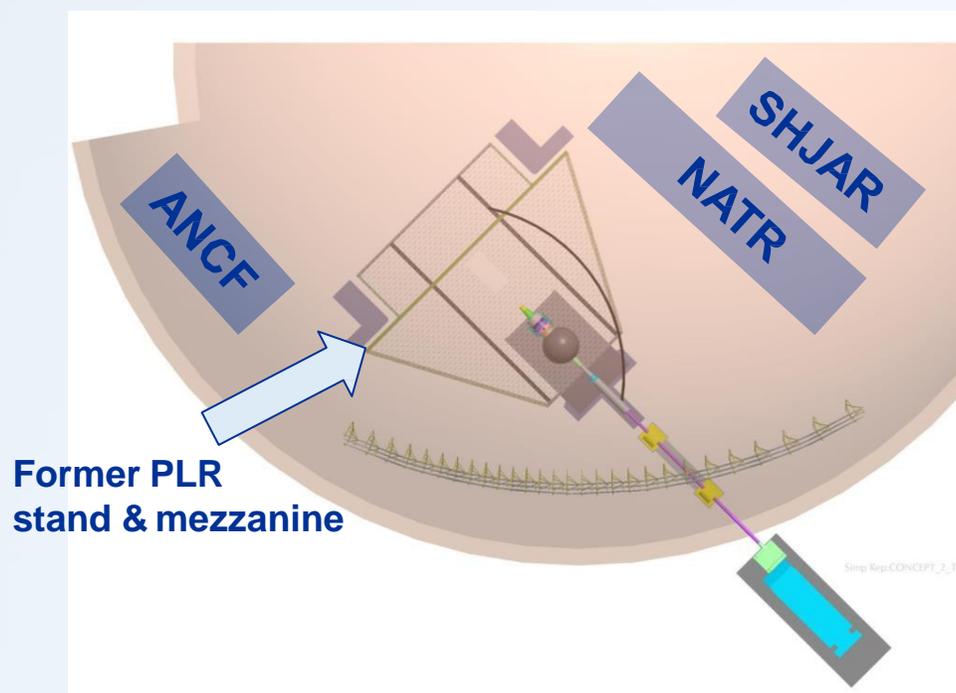
## Define Criteria

1. Types/Figures of Merit (FOMs)
  - Technology limitations (size, wt, power, etc)
  - Environmental impact
  - Safety
  - Risks
  - Life Cycle costs
  - Schedule impact
  - -ilities
2. Acceptable range and scale
3. Rank by importance



# DART Location in AAPL

- This plan view shows the proposed location of the new test rig with respect to current facility layout
- DART test rig would use current thrust stand area in the AAPL with the mezzanine used as a work platform for research hardware access



- Chosen to provide best far-field acoustic arena
- Location allows for addition of extensive sound barrier between motor & acoustic arena
- Minimizes interference with existing rigs
- Will still be able to maintain ANCF I and share campaign crew



# Concept Speed/Power Ranges Considered

ID	Speed/Power	Description
Low	5,000rpm/500hp	Low end facility power upgrade/ Belt/pulley transmission
Mid (1)	6,000rpm/1,000hp	Low end facility power upgrade/ Gearbox coupling – right angle
Mid (2)	10,000rpm/3,000hp	High end facility power upgrade/ Gearbox coupling – right angle / long shaft
T55	16,000rpm/3500hp	Commercial turboshaft / long shaft
High	21,000rpm/7,000hp	Hot air turbine



# Concept Comparison (revised)

	T55 Turboshaft Drive	Electric motor w/ gearbox (Mid1 power)	Electric motor w/ gearbox (Mid2 power)	4 stage hot air turbine
<b>Speed(rpm) / Power(hp)</b>	16,000 / 3500	6000 / 1000	10,000 / 3000 or 15,000 / 4000	21,000 / 7000
<b>Research Capability</b>	All but highest PR takeoff (not reversible)	All PR approach ADP cutback (reversible)	All but highest PR takeoff (reversible)	All +margin (not reversible)
<b>Technical Design Challenges</b>	HI	MID	HI	LOW
<b>Component Noise / Acoustic Environment</b>	HI / MID	MID / MID	HI / MID	LOW / HI
<b>Test Schedule Flexibility</b>	HI	HI	HI	MID
<b>Maintenance / Support</b>	HI	LOW	MID	HI
<b>Project Schedule</b>	24 months	20 months	24 months	28 months
<b>Cost(\$K)</b>				
- Design	1500	1250	1500	1250
- Manufacturing	1250	1250	1250	1000
- Facility	400	100	100	500
- Procurement	850	400	900	1500
<b>- Total</b>	<b>\$4000K</b>	<b>\$3000K</b>	<b>\$3750K</b>	<b>\$4250K</b>



Requirements	Weight	T55 Turboshaft Drive	Score	Weighted Score	Electric Motor w/ Gearbox	Score	Weighted Score
<b>Speed(rpm) / Power(hp)</b> -ability to provide the full power at speed	4	16,000 / 3000- power limitations at certain speed ranges	2	8	10,000 / 3000 or 15,000 / 4000	3	12
<b>Research Capability</b> -satisfies range of speed/power for fan operation, AND rotation directions	5	Limited speed control and unidirectional	1	5	Precise speed control and bidirectional	3	15
<b>Technical Design Challenges</b> - power source only; ease of integration of auxiliary systems	3	Multiple support systems-noise, emissions, cooling and containment. High level of effort	1	3	Commercial hardware with integrated support systems. Standard level of effort	2	6
<b>Component Noise / Acoustic Environment</b> -impact on acoustic test environment and outside environment	4	Very loud +130dB difficult to treat for outside and could allow noise into dome	1	4	Low noise design for motor is 85dB, but gearbox noise may be more	2	8
<b>Test Schedule Flexibility</b> -ease of test scheduling and making changes	3	Minimal logistics issues	3	9	Uncertainty with logistics of generators	2	6
<b>Maintenance / Support</b> -regular and rebuild maintenance and manpower for operation	3	High operation support required, regular and scheduled[return to vendor] maintenance	1	3	Low maintenance and manpower for operation	3	9
<b>Project Schedule</b> - design, procure, fab, install and checkout	2	More support systems required and increased checkout time of operations	1	2	Off shelf design with basic checkouts	2	4
<b>Cost</b> - design, procure, fab, install and checkout	5		2	10		2	10
<b>TOTAL SCORE</b>				<b>44</b>			<b>70</b>



## Work Breakdown Structure / Product Breakdown Structure

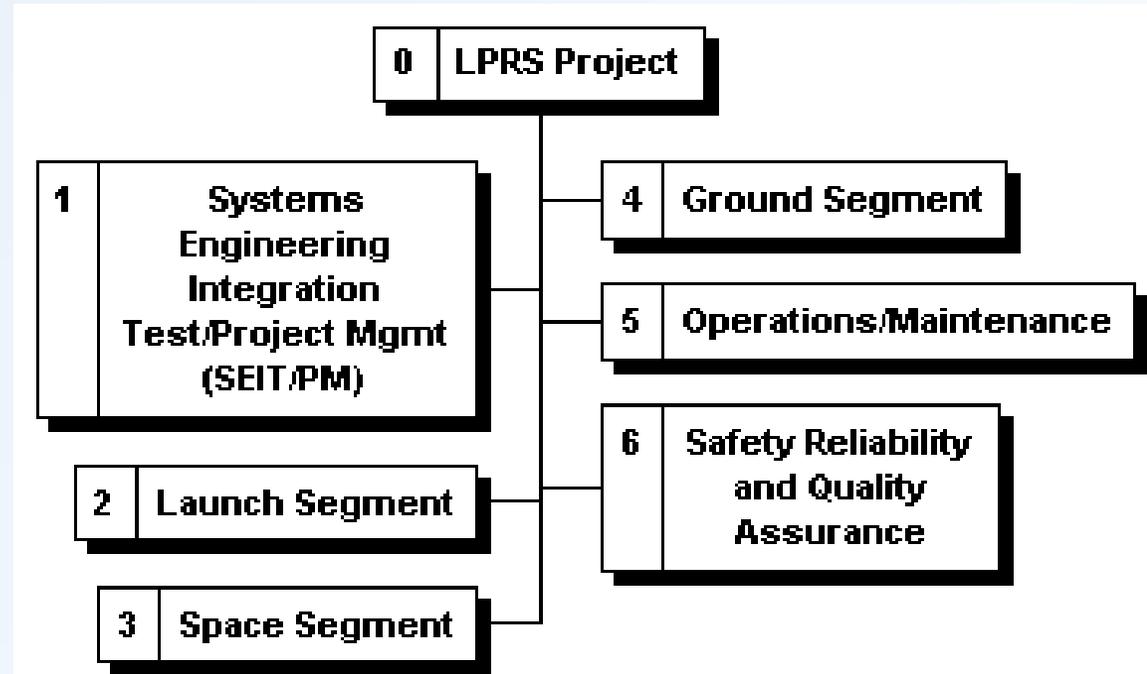


# Work Breakdown Structure (WBS)

---

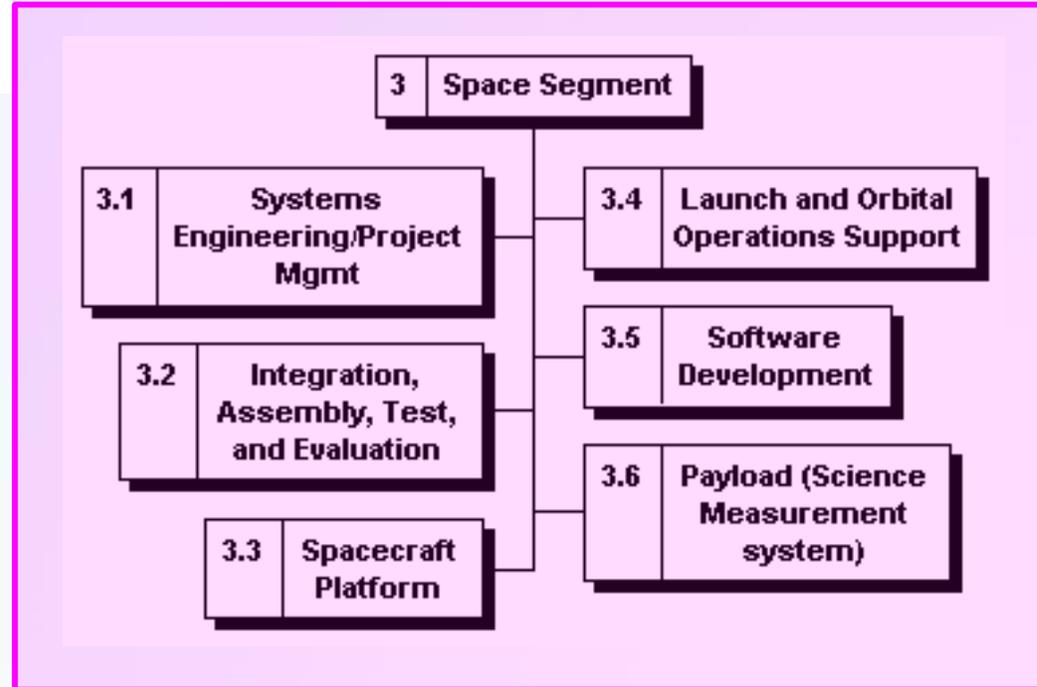
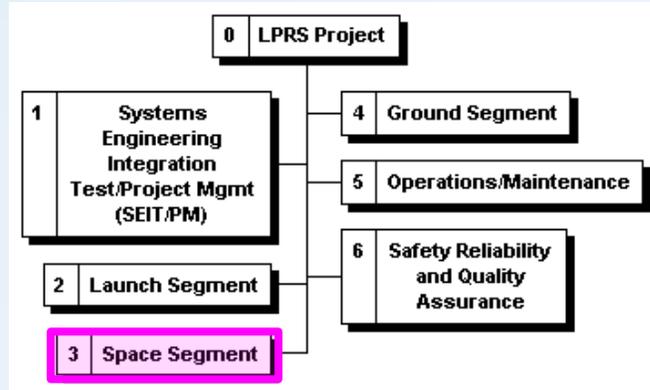


# Work Breakdown Structure (WBS)



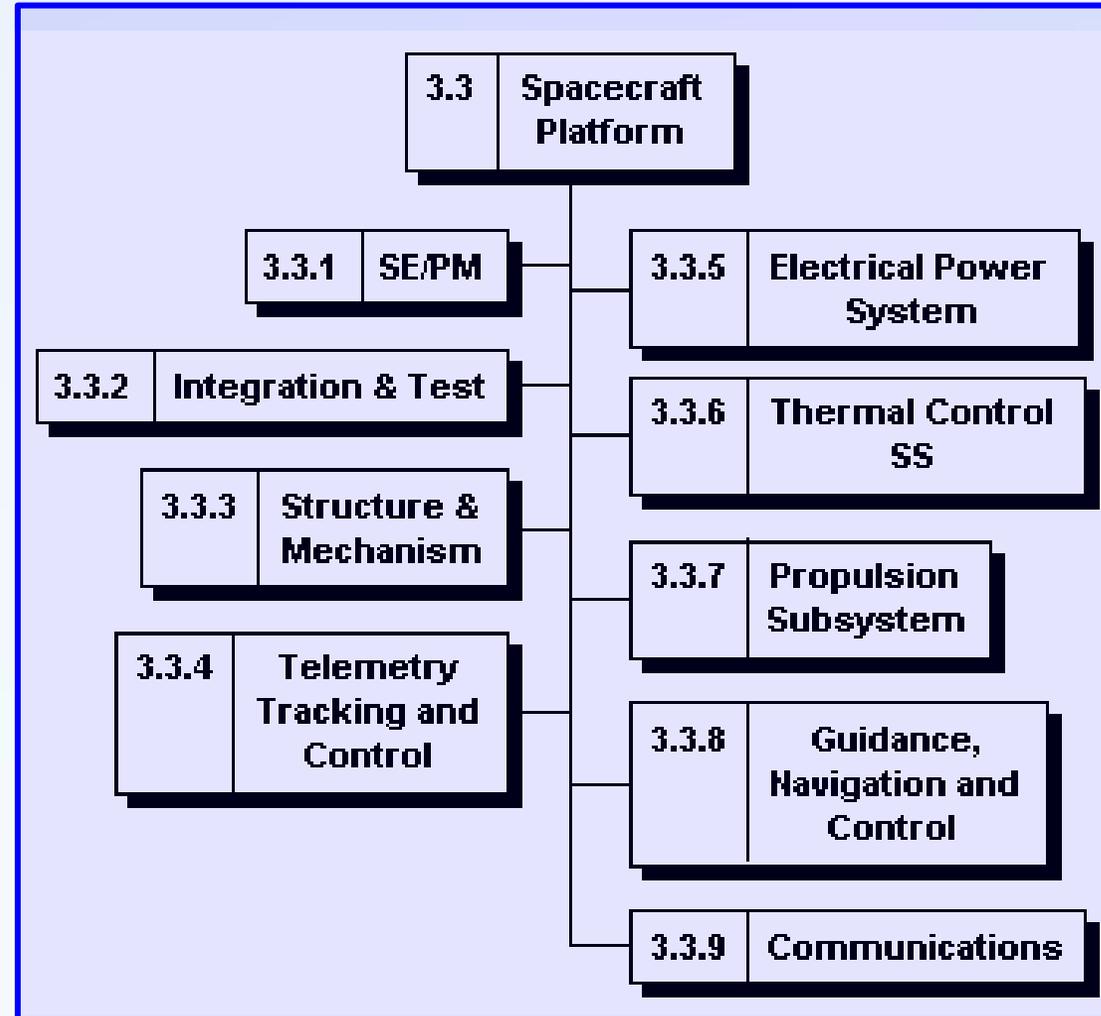
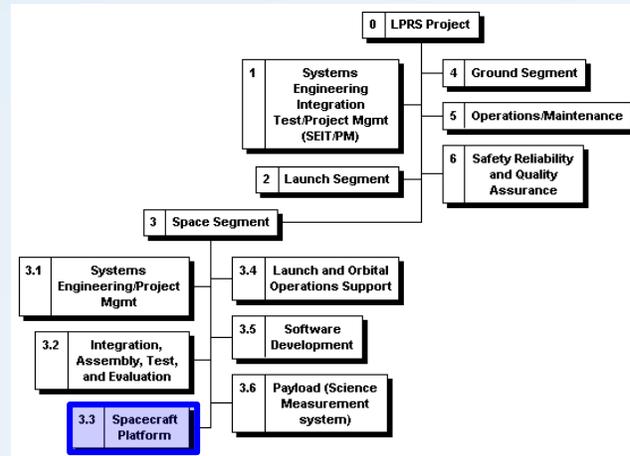


# WBS



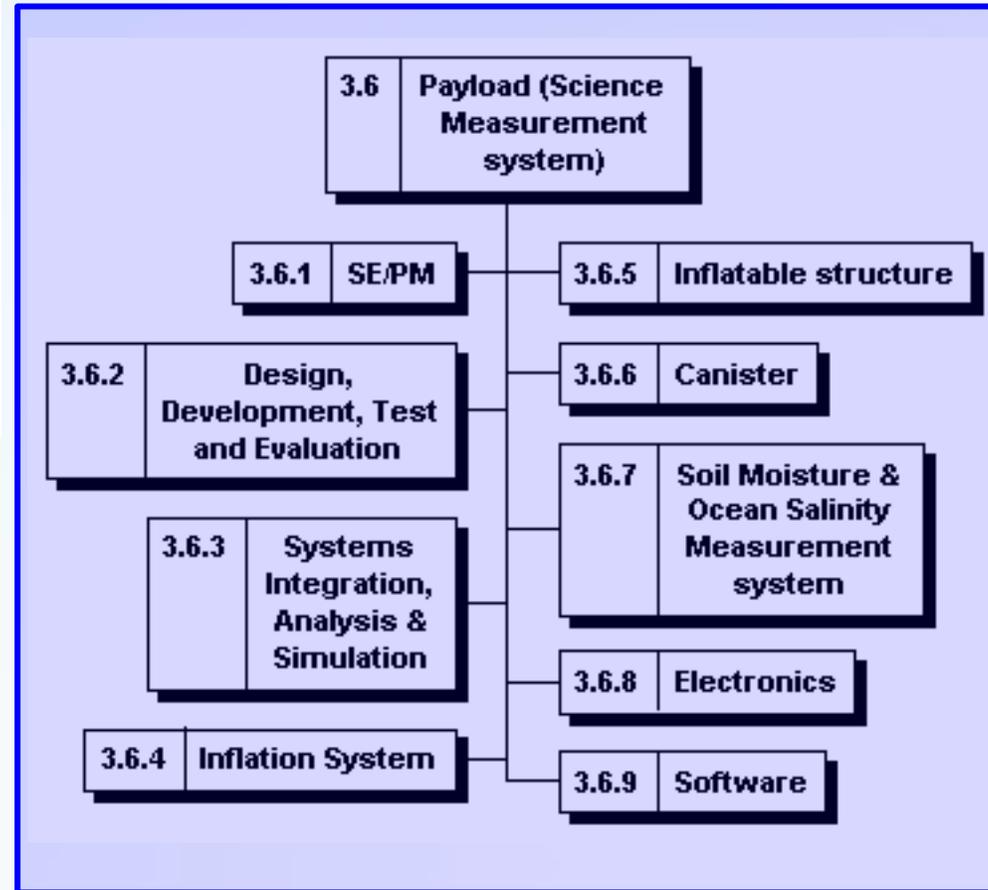
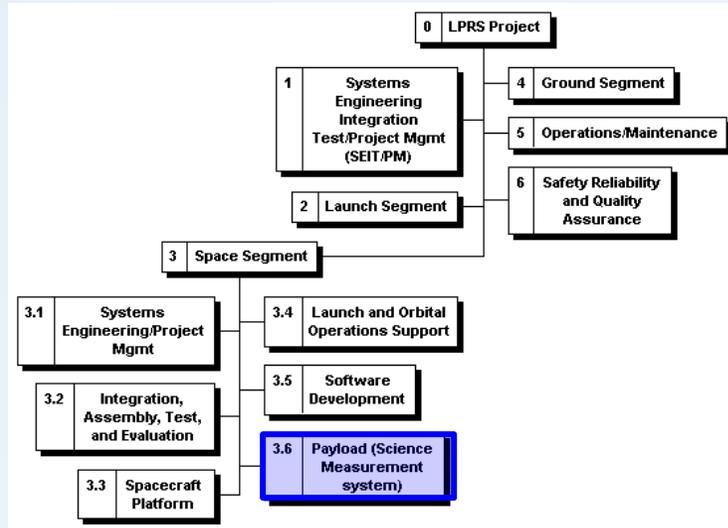


# WBS



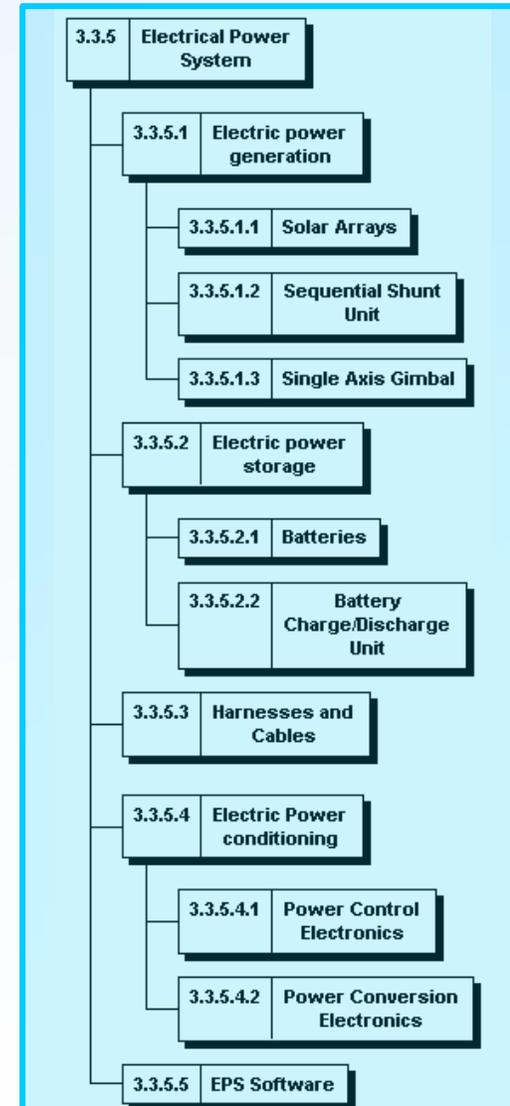
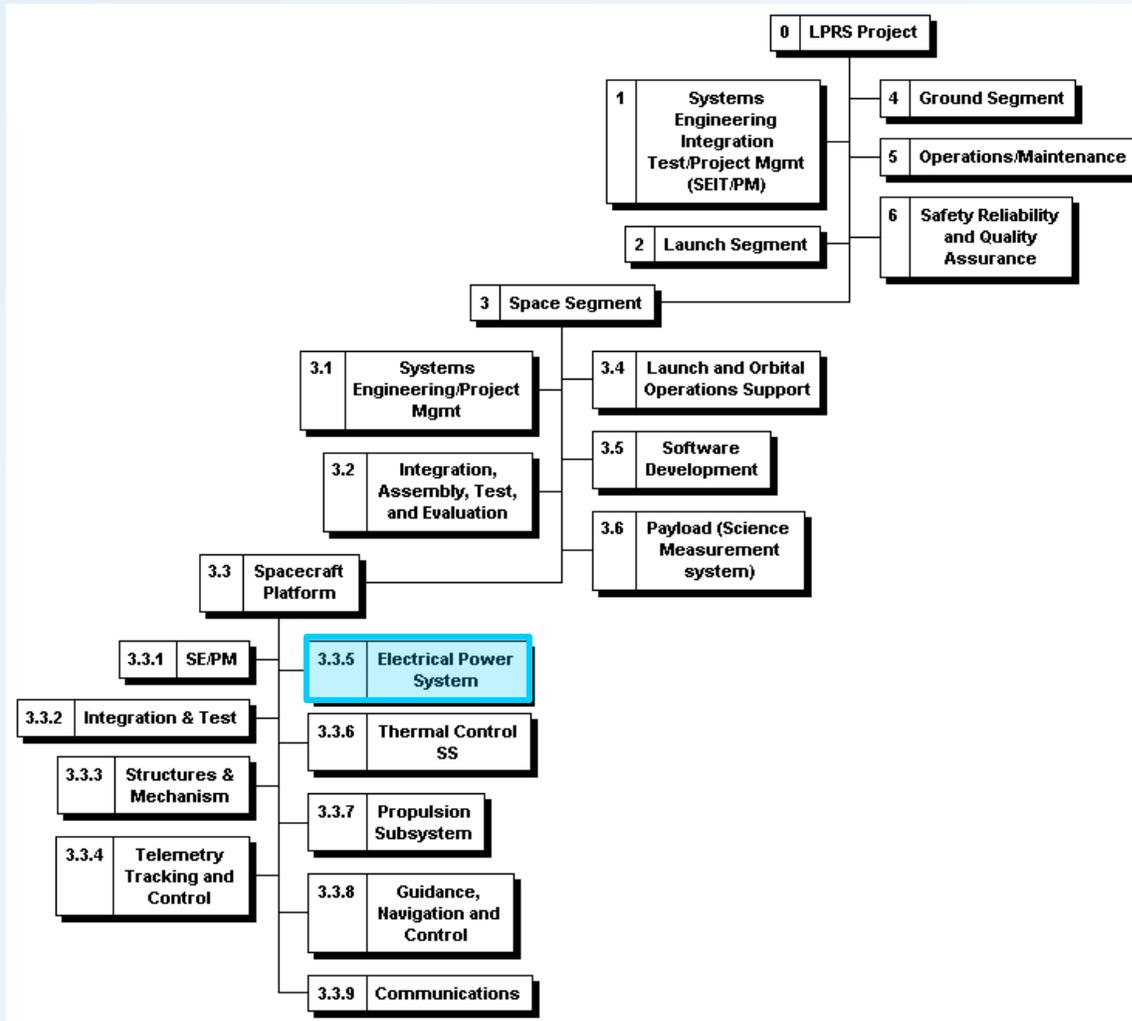


# WBS



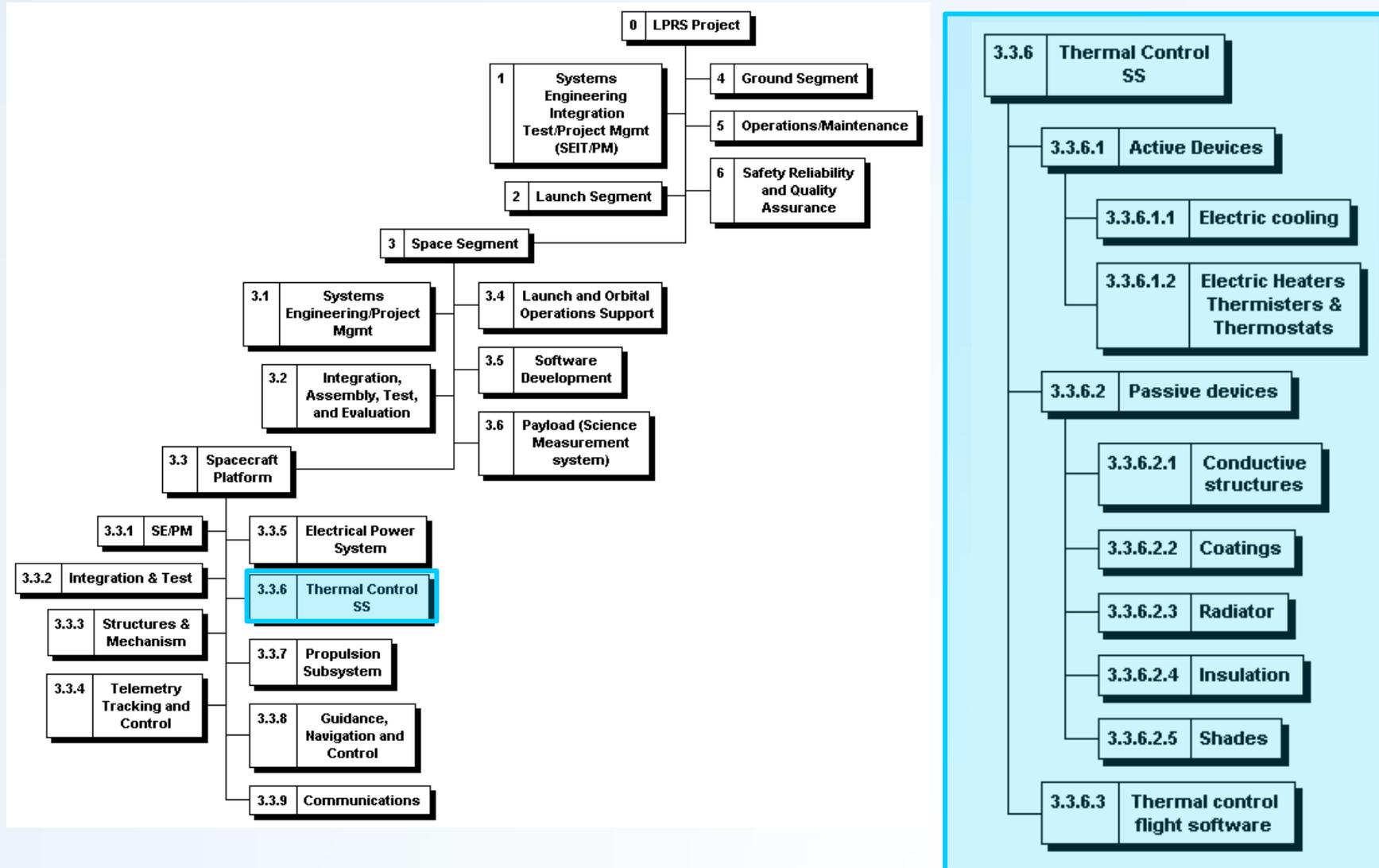


# WBS



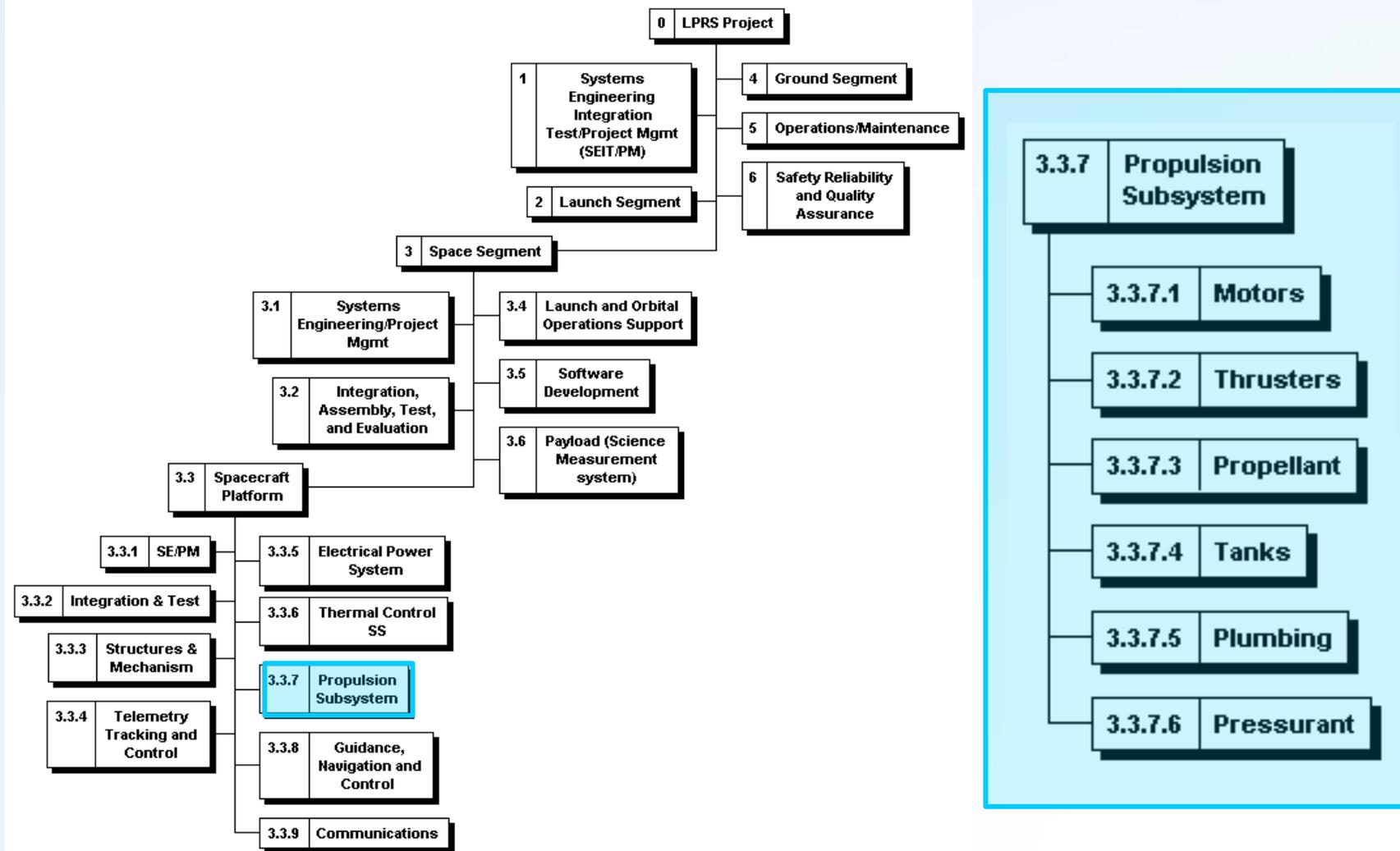


# WBS





# WBS





# WBS Dictionary

This document establishes the Light Passive Radiometer Sensor (LPRS) Satellite project work breakdown structure (WBS). This WBS is defined, developed, and maintained throughout the system life cycle. It will evolve over the life cycle of the project. It is a product oriented family tree composed of hardware, software, services, data, and facilities. It displays and defines the products to be developed and/or produced. It relates the elements of work to be accomplished to each other and to the endproduct.

ID	Title	Description	Resources	Deliverables	Components	Dependencies
3.3	Spacecraft platform	This element refers to the principle operating space vehicle which serves as a housing or platform for carrying a payload in space. This element consists of the work required to design, develop, produce, and test through certification and acceptance a Spacecraft platform meeting all LPRS Spacecraft-level and interface requirements. This element includes SE and PM efforts to develop the spacecraft platform. The Spacecraft platform subsystems have been separated as follows: Structures and Mechanisms; Telemetry, Tracking & Control ( TT&C); Electrical Power Subsystem; Thermal Control; Propulsion; Guidance, Navigation, and Control (GN&C; and Communications (which includes Command and Data Handling),	Spacecraft platform PM	Deliver fully Functional Satellite according to the cost, schedule, specifications, and performance requirements.	3.3.1, 3.3.2, 3.3.3, 3.3.4, 3.3.5, 3.3.6, 3.3.7, 3.3.8, 3.3.9	In this space please list the dependencies on other parts of the project that will influence the schedule and completion of the work described in this element. As we move forward in the planning cycle these dependencies will be worked into the overall schedule.



# Schedule and Cost



# AAPL/DART Schedule

1Q, FY17			2Q, FY17			3Q, FY17			4Q, FY17		
O	N	D	J	F	M	A	M	J	J	A	S
DART CDR						DART Install *			DART 2 <sup>nd</sup> Phase **		

\* DGEN Package from PRICE 4/1/2017  
Training and test far field 4/1-4/30

\*\* Move to center of Dome  
And complete testing



# Schedule Phasing

## Completed December 2016:

- CDR

## GO-Forward:

- Post CDR Tasks
- Facility Systems Implementation
- DART Installation, Training, Checkout and Testing



# Labor Cost

## CDR Costs (finish tasks)

- (I) GESS3:  
Total = \$41K
- (I) Civil Servant  
Engineer - 80 hours

## Install, training and Checkout

5 week effort 3/20 through 4/21/2017

WYE Engineers (4)	800 HR
WYE Techs (7)	1400 HR
FTE Support (1)	200 HR

## DART First Entry Baseline Testing

1 week far field data and external phased array

WYE Engineers (4)	160 HR
WYE Techs (7)	280 HR
FTE Support (1)	40 HR

## DART Second Entry Testing Costs

4 week effort to move and test MDOF Liner

WYE Engineers (4)	640 HR
WYE Techs (7)	1120 HR
FTE Support (1)	160 HR

## Totals

GESS3	\$41K
WYE Engineers (4)	1600 HR
WYE Techs (7)	2800 HR
FTE Support (1)	480 HR



# Procurement COST

Task	Procurement Cost (\$K)
Wedge Wall	30
Support Platform	10
Fuel Supply	10
Fan Containment (safety)	15
Instrumentation	10
Engine Support System Facility	
Integration (mobile control unit, Subsystems, PSO)	15
Maintenance Contract (3 yr)	25/75
	<b>115/165</b>

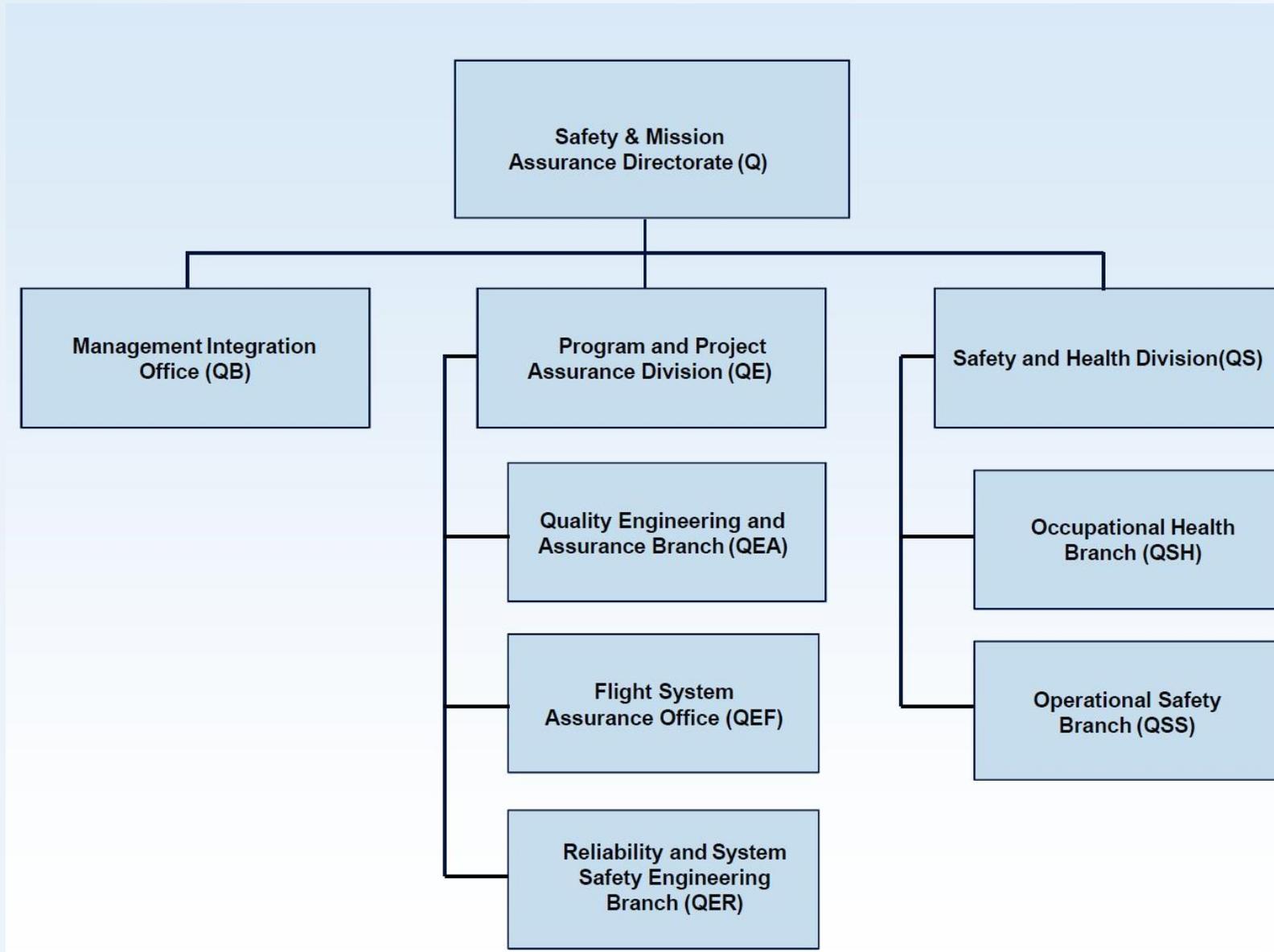


## NASA Glenn Safety Culture and Common Practices



## **Safety and Mission Assurance Directorate (Q)**

The Safety and Mission Assurance Directorate (SMAD) ensures a safe, healthful, and protective environment for the Glenn Research Center's community and enables the mission success of our programs and projects.





## Failure Prevention at Glenn Research Center

A multi-pronged strategy is used at GRC to ensure a safe and successful research and testing culture is maintained. With the many potential pressure, high energy, chemicals/materials and laser application systems in use at the lab, it is essential that this culture of safety and reliability is implemented across all aspects of research and testing to prevent failure, personnel injury and loss of life. Using expertise from employees at the lab, the following offices, committees, and identified authorities:

Pressure Systems Office

Safety Office

    Safety Committee

    Laser Safety Committee

    Environmental Safety

    Authority Having Jurisdiction (Fire and Explosives Safety)

Risk Management

Quality Control

Etc.



# Glenn Safety Manual



## GLENN RESEARCH CENTER, SAFETY MANUAL TABLE OF CONTENTS

**NOTE:** The revisions to these Chapters will be maintained and approved by the Safety and Health Division (SHeD). The expiration dates are listed in the columns next to each chapter. If you are referencing paper copies, please verify that it is the most current version before use. Users of this manual should be cognizant of other documents such as the Environmental Programs Manual and Occupational Health Programs Manual.

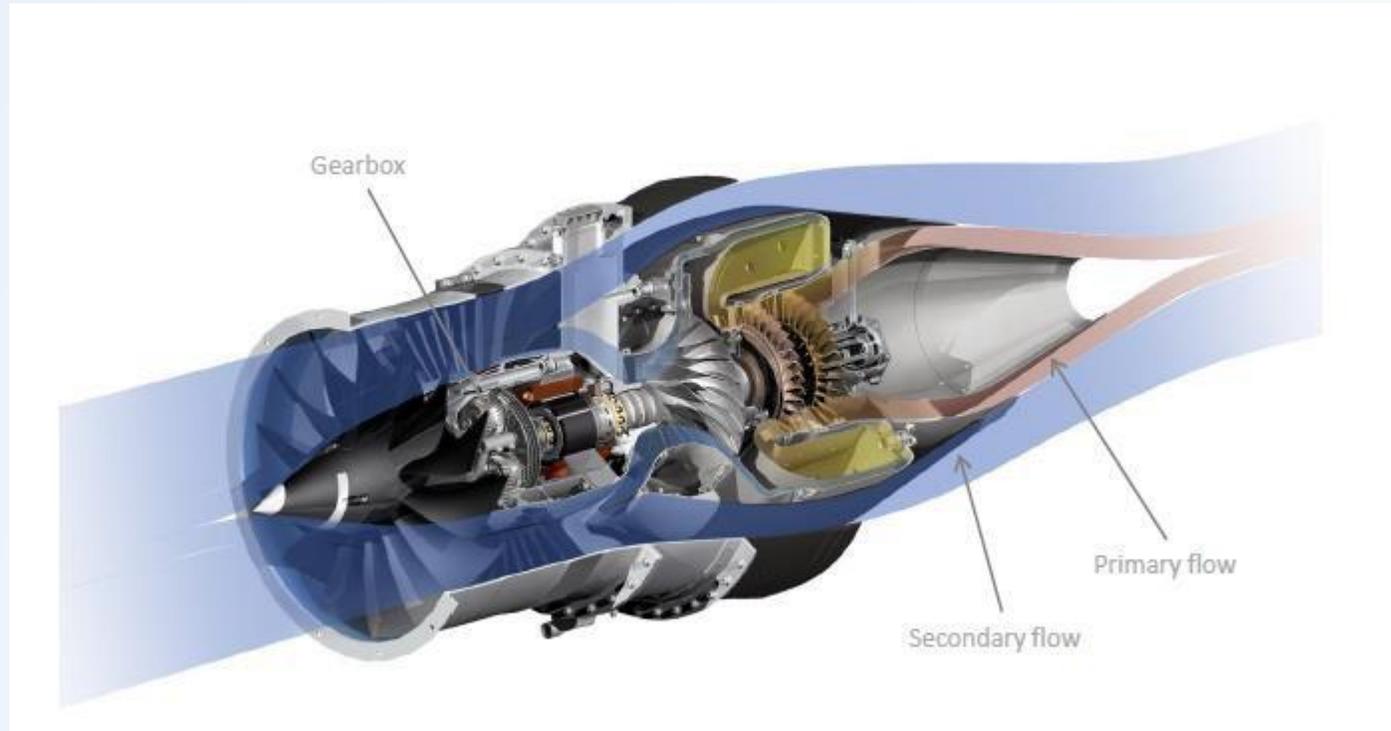
Chapter	Title	Expiration Date
Chapter 1	Safety Permit Process	9/2024
Chapter 2	Safety, Health, and Environmental Training and Certification	3/2024
Chapter 3	Facility System Safety	8/2022
Chapter 4	Formerly Student Safety and Health – see Chapter 2	n/a
Chapter 5	Oxygen	11/2024
Chapter 6	Hydrogen	11/2024
Chapter 7	Pressure Systems Safety	11/2024
Chapter 8	Electrical Systems Safety	6/2026
Chapter 9	Lockout/Tagout	1/2025
Chapter 10	Hazardous Operations	10/2024
Chapter 11	Process Safety Management	8/2024
Chapter 12	Aviation Safety	12/2023
Chapter 13	n/a	n/a
Chapter 14	Shop Safety	12/2022
Chapter 15	Personal Protective Equipment and Job Hazard Analysis	6/2026
Chapter 16	Regulatory Permit Requirements	9/2024
Chapter 17	Construction Safety and Health	12/2023
Chapter 18	Explosives, Propellants, & Pyrotechnics	6/2026
Chapter 19	Vehicle & Pedestrian Safety	3/2026



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# Risk Management





# Aero-Acoustic Propulsion Laboratory (AAPL)

AAPL is a 65 ft high by 130 ft in diameter, providing an anechoic testing environment for engine component research and development.

To provide a reflection free acoustic environment, 17,000 custom-designed 2-ft thick fiberglass wedges are mounted on the dome's interior walls and floor areas adjacent to the test rigs.





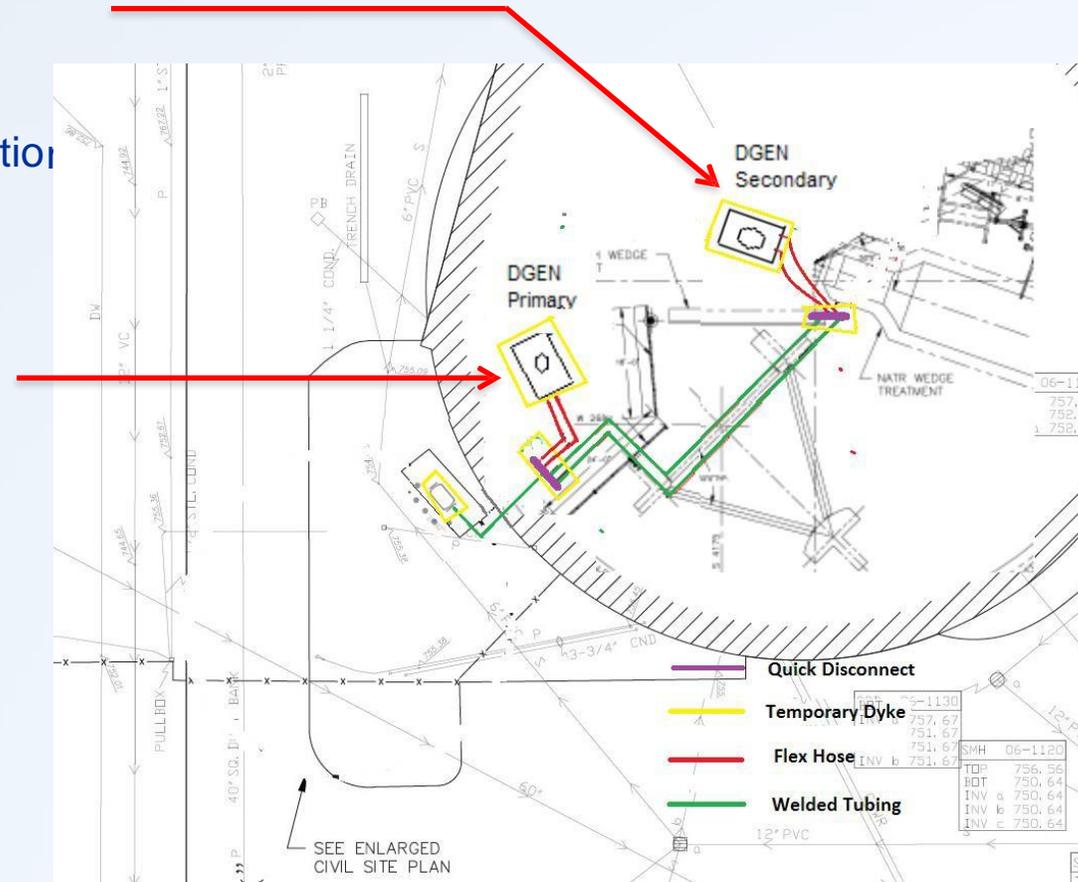
# DART in AAPL

## Location #2

Overhead array  
Jet Noise tests  
Airframe Integration

## Location #1

Check Outs  
In-close array  
Fan Noise tests  
Control tests  
SDTs





# Risk Management

## Top PDR Identified Risks

1. Life Cycle Fatigue failure
2. Fire in the engine
3. Overheating of electronics
4. Fuel System leak
5. Over-speed hardware failure
6. Data compromised by blast shield
7. Single engine/controls/parts supplier
8. Hardware damage during relocation
9. Heavy Maintenance technical support
10. Damage of Critical or long lead item



# Risk Management

## Top PDR Identified Risks

1. Life Cycle Fatigue failure (analysis complete)
2. Fire in the engine (accepted by project)
3. Overheating of electronics (monitor temperature)
4. Fuel System leak (Dikes, procedure, welded, visual)
5. Over-speed hardware failure (multiple speed control, shield)
6. Data compromised by blast shield (not in use during research)
7. Single engine/controls/parts supplier (live with it)
8. Hardware damage during relocation (inspection)
9. Heavy Maintenance technical support (maintenance contract)
10. Damage of Critical or long lead item (limited to engine components)



# Risk Management

## Newly Identified Risks

### 11. Redesigned Engine does not pass testing

- Unmodified engine has been tested and met vendor historical standards
- Redesigned/modified engine will be tested 22-March-2017

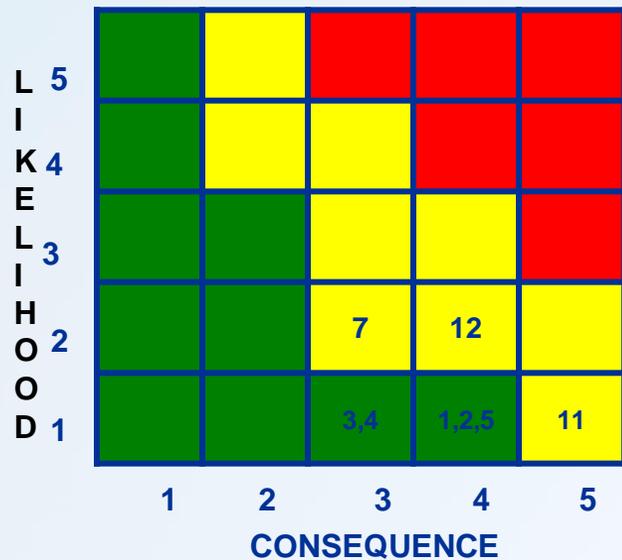
### 12. Labor force not sufficient to complete the tasks

- Will communicate need to project and management regularly



# DART Top Risk List

May 12, 2016



Legend	
↓	Decreasing (Improving)
↑	Increasing (Worsening)
⊕	Unchanged
\$	Cost Threat (Level 1, 2, 3)

Rank	Trend	Title	Owning Team	L I K E	Consequence			
					S A F E	P E R F	S C H	C O S T
	⊕			3	0	0	3	0
<b>CANDIDATE RISKS</b>								
1	↓	1- High Cycle Fatigue	Des.	2	4	3	4	4
3	↓	2- Fire in engine	Des.	1	3	3	4	4
4	↓	3- Overheating of electronics	Des.	1	3	1	1	3
5	↓	4-Fuel system leak	Res.	1	3	0	1	1
2	↓	5-Rotating hardware failure containment	Des.	1	4	0	3	3
3	⊕	7- supplier	Des.	2	0	3	3	3
1	⊕	11 – modified engine doesn't pass test	Des.	1	0	5	5	5
2	⊕	12 = labor force not available	Prog.	2	0	0	4	3
<b>ASSOCIATED RISKS</b>								
	⊕							
	⊕							
	⊕							



# Hazards Analysis



# Determine Risk Assessment Code

TABLE B.1—HAZARD CATEGORIES

Category	Personal Illness/Injury	Equipment Loss (\$K)	Downtime	Data Integrity	Environmental Effect
I Catastrophic	Death	>\$1000	>4 months	Data never recoverable or primary program objectives lost	Long-term (>5 years) environmental damage or requiring >\$1M to correct and/or in penalties
II Critical	Severe injury or occupational illness	\$1000 to \$250	4 months to 2 weeks	Repeat test program	Medium-term (1-5 years) environmental damage or requiring \$250K-\$1M to correct and/or in penalties
III Marginal	Minor injury or occupational illness	\$250 to \$25	2 weeks to 1 day	Repeat test period	Short-term (<1 year) environmental damage or requiring \$25K-\$250K to correct and/or in penalties
IV Negligible	No injury or illness	\$25 to \$1	<1 day	Repeat data point or data requires minor manipulation or computer rerun	Minor environmental damage, readily repaired and/or requiring \$1K-\$25K to correct and/or in penalties

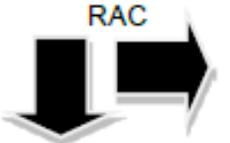
TABLE B.2—PROBABILITY LEVELS

Level	Descriptive Word	Qualitative Definition	Quantitative Definition
A	Frequent	Likely to occur repeatedly in system/component life cycle	$X > 10^{-1}$
B	Probable	Likely to occur several times in system/component life cycle	$10^{-1} \geq X > 10^{-2}$
C	Occasional	Likely to occur at some time in system/component life cycle	$10^{-2} \geq X > 10^{-3}$
D	Remote	Not likely to occur in system/component life cycle, but is possible	$10^{-3} \geq X > 10^{-6}$
E	Improbable	So unlikely that it can be assumed occurrence may not be experienced	$10^{-6} \geq X$
F	Impossible	Occurrence is physically impossible	



## Determine Risk Assessment Code

TABLE B.3—RISK ASSESSMENT CODE (RAC) MATRIX

 RAC	A Frequent	B Probable	C Occasional	D Remote	E Improbable
1 Catastrophic	1A	1B	1C	1D	1E
2 Critical	2A	2B	2C	2D	2E
3 Marginal	3A	3B	3C	3D	3E
4 Negligible	4A	4B	4C	4D	4E

RAC = (1) = (1A, 1B, 1C, 2A, 2B, or 3A): Unacceptable Risk; a safety permit cannot be issued without further hazard mitigation.

RAC = (2) = (1D, 2C, 2D, 3B or 3C): Undesirable Risk; the director of Safety and Mission Assurance Directorate must review and approve.

RAC = (3) = (1E, 2E, 3D, 3E, 4A, 4B): Acceptable Risk; this RAC is suitable for area safety committees to review and safety chairs to approve.

RAC = (4) = (4C, 4D or 4E): Acceptable Risk; this RAC is suitable for Area safety committees to review and safety chairs to approve.



**TABLE 6.1 IDENTIFICATION AND CONTROL OF HAZARDS – Engine/Rotating Machinery**

HAZARD	POSSIBLE EFFECT	HAZARD CONTROL	SEV	PROB	RAC
Engine Ingestion -Foreign object damage	Equipment damage and/or personnel injury	1. Check-sheet item and personnel training 2. ICD is in place to reduce the likelihood of any FOD	III	D	3
Engine Over-temp -Core stall -Hot engine start -Engine controls failure	Equipment damage and/or personnel injury	1. Thermocouple ITT sensor to annunciator	III	D	3
Rotor Over-speed -Controls malfunction	Equipment damage and/or personnel injury	1. RPM alarms on rotor	III	D	3



**TABLE 6.2 IDENTIFICATION AND CONTROL OF HAZARDS – Engine/Rotating Machinery Cont.**

HAZARD	POSSIBLE EFFECT	HAZARD CONTROL		SEV	PROB	RAC
High Engine Vibrations -Engine rotating components deterioration (DOD)	Equipment damage and/or personnel injury	1. Vibration high-level sensors alarm FADEC and to annunciator		II	E	3
Turbine Disk Failure -Material flaw -Material over-temp -Over-speed due to shaft failure -Turbine disk/blade penetration of test cell	Equipment damage and/or personnel injury	1. Engine has been fully tested prior to shipment to GRC	Property	II	D	2
		2. Engine health monitoring instrumentation including inter-stage turbine temperature T/C's 3. Low pressure turbine fails prior to high pressure turbine, forcing immediate stop 4. Florescent Penetrant Inspection 5. Assuming tri-burst mode failure at abort rpm, per Price Induction and Engineering calculations turbine fragments will not penetrate the proposed engine turbine housing; speed sensors with 2-levels of meter relay RPM alarms used to prevent over-speed. Turbine disk failure checked by SME. Fatigue analysis to be performed by SME.	Personnel	II	E	3
Fire -Fuel, engine oil -Surface contact of components with hot engine components	Equipment damage and/or personnel injury	1. Video camera coverage of test cell and engine 2. Engine T/C's 3. E-Stop cuts off facility fuel supply to engine pump 4. Fire extinguishers located in area for personnel evacuation 5. All combustibles removed from area 6. Facility acoustic wedges are fiberglass and will not burn		II	E	3



**TABLE 7 IDENTIFICATION AND CONTROL OF HAZARDS - Electrical/Instrumentation System**

HAZARD	POSSIBLE EFFECT	HAZARD CONTROL	SEV	PROB	RAC
Engine Over-speed	Equipment damage and/or personnel injury	1. Two levels of meter relay RPM alarms on each rotor, with hi-hi auto shutdown	II	E	3
Engine Over-temp	Equipment damage and/or personnel injury	1. Thermocouple ITT sensor alarm to annunciator, with hi-hi auto shutdown	III	E	3
Loss of Customer Control of Engine -FADEC failure	Equipment damage and/or personnel injury	1. Control fails last position, engine unable to accel. or decel. 2. Facility ES input mushroom switch shuts off fuel pump	III	E	3



**TABLE 8 IDENTIFICATION AND CONTROL OF HAZARDS - AAPL Fuel System**

HAZARD	POSSIBLE EFFECT	HAZARD CONTROL	SEV	PROB	RAC
Tank Rupture	Equipment damage and/or personnel injury	<ol style="list-style-type: none"> <li>1. Commercially purchased double walled fuel tank</li> <li>2. Tank will be located away from traffic, bollards will be in place</li> <li>3. Galvanized steel plate will be in place between tank and dome wall for additional protection from critical engine failure</li> </ol>	II	E	3
Fire – outside dome (fuel tank location)	Equipment damage and/or personnel injury	<ol style="list-style-type: none"> <li>1. Fuel tank will be located outside of dome</li> <li>2. Area around fuel tank fill point will be considered Class 1, Div. 1 per NEC standards; electronic components will be located outside of this area</li> <li>3. Fuel tank will be grounded</li> </ol>	II	E	3
Fire – inside dome (engine area)	Equipment damage and/or personnel injury	<ol style="list-style-type: none"> <li>1. All fuel fittings will be visually inspected for leaks before and after each run per check sheets</li> <li>2. Fuel system will be pressurized and leak checked prior to first engine operation</li> <li>3. Electrical area around engine will be Class 1, Div. 2 per NEC standards</li> </ol>	II	E	3

**TABLE 9 IDENTIFICATION AND CONTROL OF HAZARDS – Mobile Control Unit**

HAZARD	POSSIBLE EFFECT	HAZARD CONTROL	SEV	PROB	RAC
Arc Flash	Equipment damage and/or personnel injury	<ol style="list-style-type: none"> <li>1. Electrical to follow NEC and NFPA guidelines</li> <li>2. No-load interlocks employed to ensure that system is not connected when risk of arc-flash present</li> <li>3. Electrical enclosures properly secured and labeled as per NFPA 70E.</li> </ol>	II	E	3
Ground Fault, Short Circuit, or Brown Out.	Equipment damage and/or personnel injury	<ol style="list-style-type: none"> <li>1. All accessory outlets confirmed UL listed Ground Fault Interrupter Type.</li> <li>2. Overall electrical system GFCI and short circuit protection to NEC standard.</li> <li>3. Overall electrical system Surge Suppression.</li> <li>4. Electrical safety system with Emergency shutoffs, and monitoring.</li> <li>5. Uninterruptable Power Supply system to ensure against uncontrolled power loss</li> </ol>	III	E	3
Fire – inside truck (rear cabin area)	Equipment damage and/or personnel injury	<ol style="list-style-type: none"> <li>1. Ground fault, short circuit, and overload protection to control risk of electrical fire.</li> <li>2. Electrical fire rated fire extinguisher provided in rear cabin.</li> <li>3. Proper equipment temperature monitoring to reduce risk of fire due to failure.</li> <li>4. Support systems such as lighting and climate control, etc. rated for road use and installation as per UL listing and DOT requirements.</li> </ol>	II	E	3



**TABLE 9 IDENTIFICATION AND CONTROL OF HAZARDS – Mobile Control Unit (Continued)**

HAZARD	POSSIBLE EFFECT	HAZARD CONTROL	SEV	PROB	RAC
Adverse Environmental conditions	Equipment damage and/or personnel injury	1. Internal climate control system and monitoring to control ambient temperature and humidity.	III	E	3
Excessive Noise	personnel injury	1. Safe positioning of truck away from noise sources. 2. Hearing protection available. 3. Noise survey will be performed and warning signs posted.	III	E	3

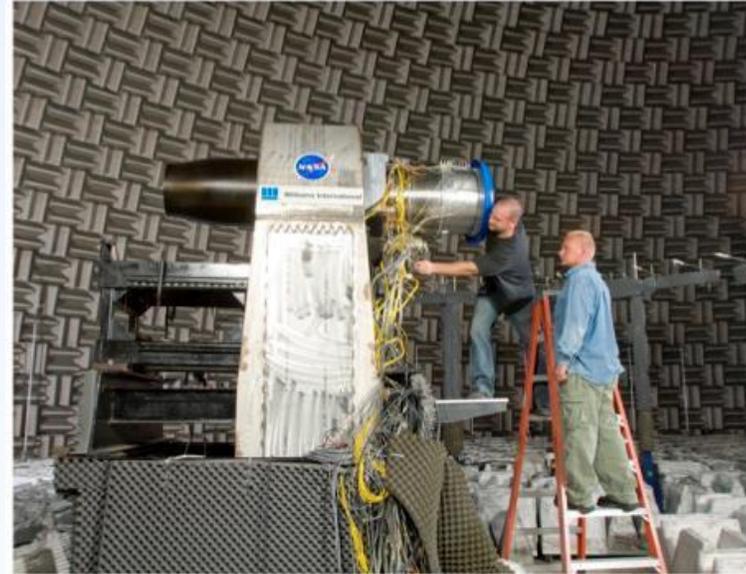


# Blast Shield

The DGEN engine is not designed to contain LPT and HPT 1/3rd disk fragment and intermediate fragments.

So the DGEN will contain:

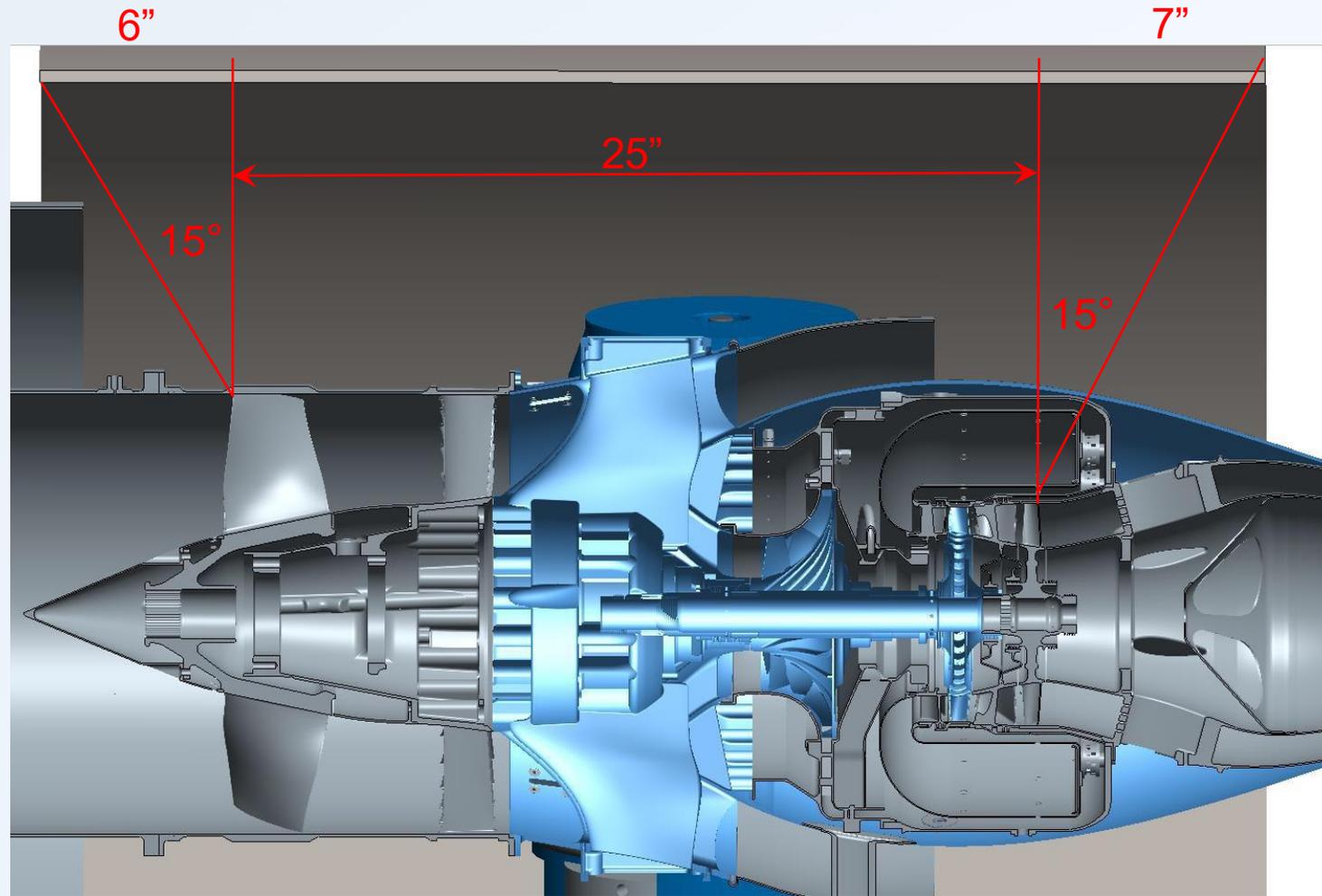
- any fan failure;
- any HPC failure;
- any HPT or LPT blade off.





# Containment Shield

15° Scatter Zones



Fan

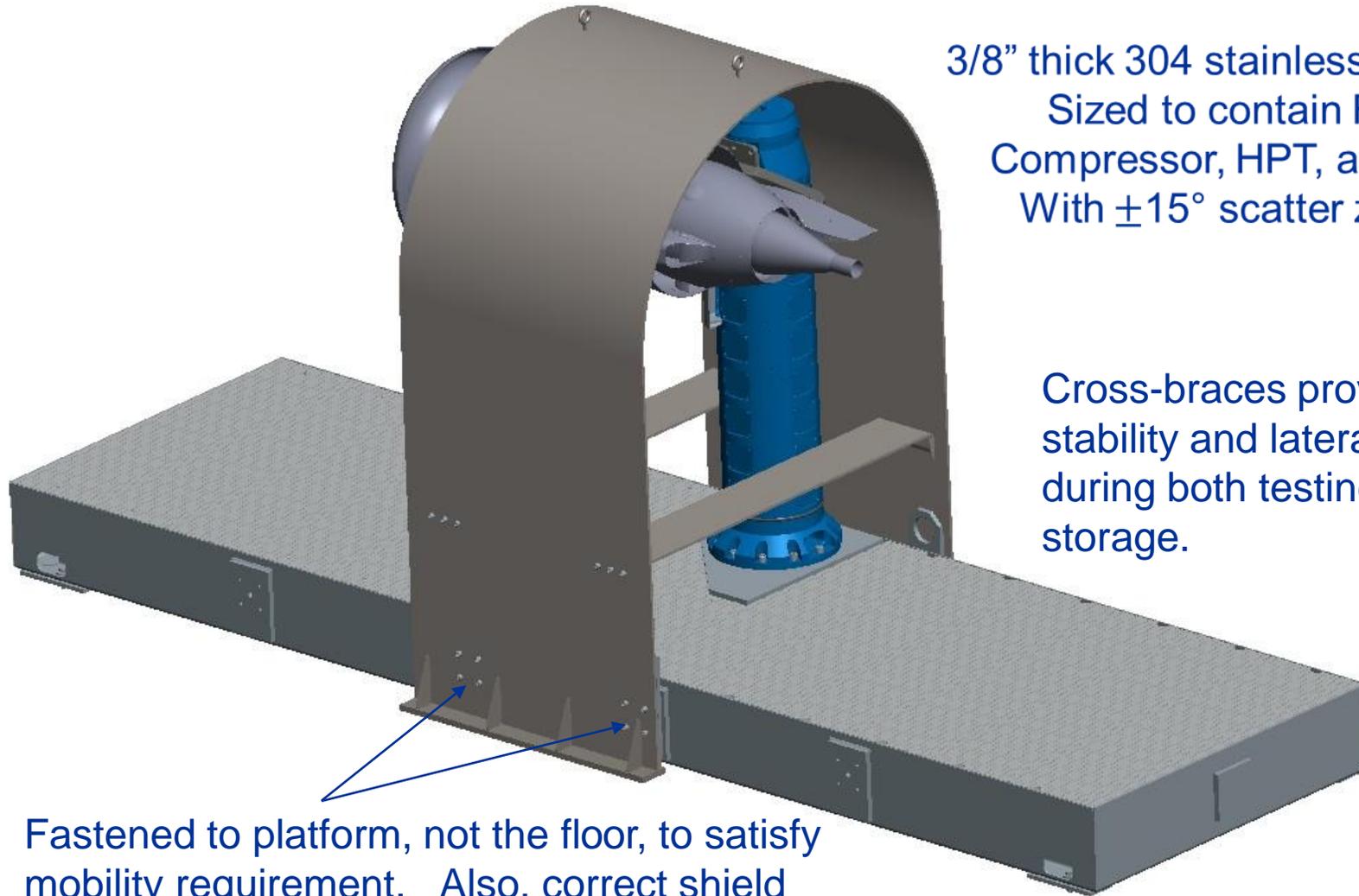
Comp

HPT

LPT



# External Containment Shield



3/8" thick 304 stainless steel,  
Sized to contain Fan,  
Compressor, HPT, and LPT  
With  $\pm 15^\circ$  scatter zones

Cross-braces provide  
stability and lateral stiffness  
during both testing and  
storage.

Fastened to platform, not the floor, to satisfy  
mobility requirement. Also, correct shield  
position is guaranteed regardless of siting.



## Margins of Safety for Shield Mounting Fasteners During a Tri-hub Failure of HPT

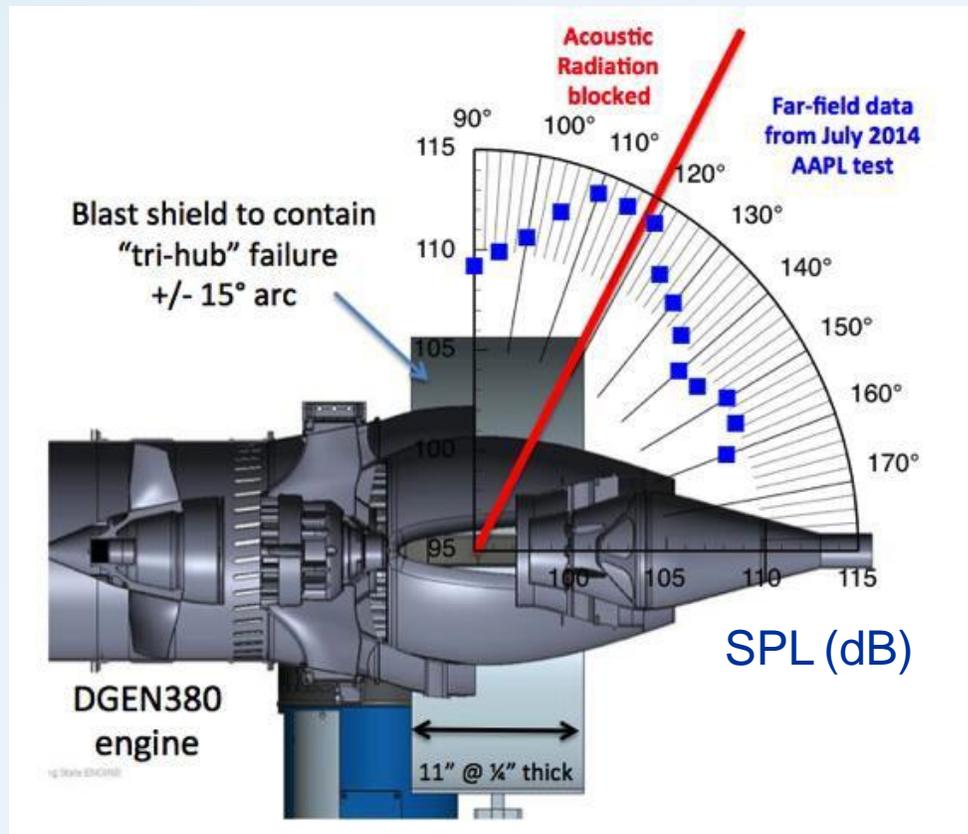
Case	Tri-hub burst Description	Analysis Type	Stiffness (lbf/in)	Impact Force (lbf)	Fastener Load Type	Fastener <sup>1</sup> Load	Maximum <sup>2</sup> Fastener Margin
#1	Single horizontal	Hand-calc	1816	24,107	Tension & Shear	1507	.42
#2	Single vertical	Hand-calc	6373	45,159	Shear	2822	4.1
#3	Single horizontal	Elastic FEA	885	16,829	Tension & Shear	1052	.42
#4	Symmetric horizontal	Elastic FEA	4273	36,978	Tension & Shear	4622	.15
#5	Single horizontal	Plastic FEA	n/a	13,300	Tension & Shear	831	.42
#6	Single vertical	Plastic FEA	n/a	41,000	Shear	2563	4.6

1: Fasteners: M12 @ 15,676 lbf preload (70% of proof strength)

2: Varied load vector from pure tension to pure shear.



# Containment Shield



Shield design as shown, precludes acquisition of far field acoustic data.

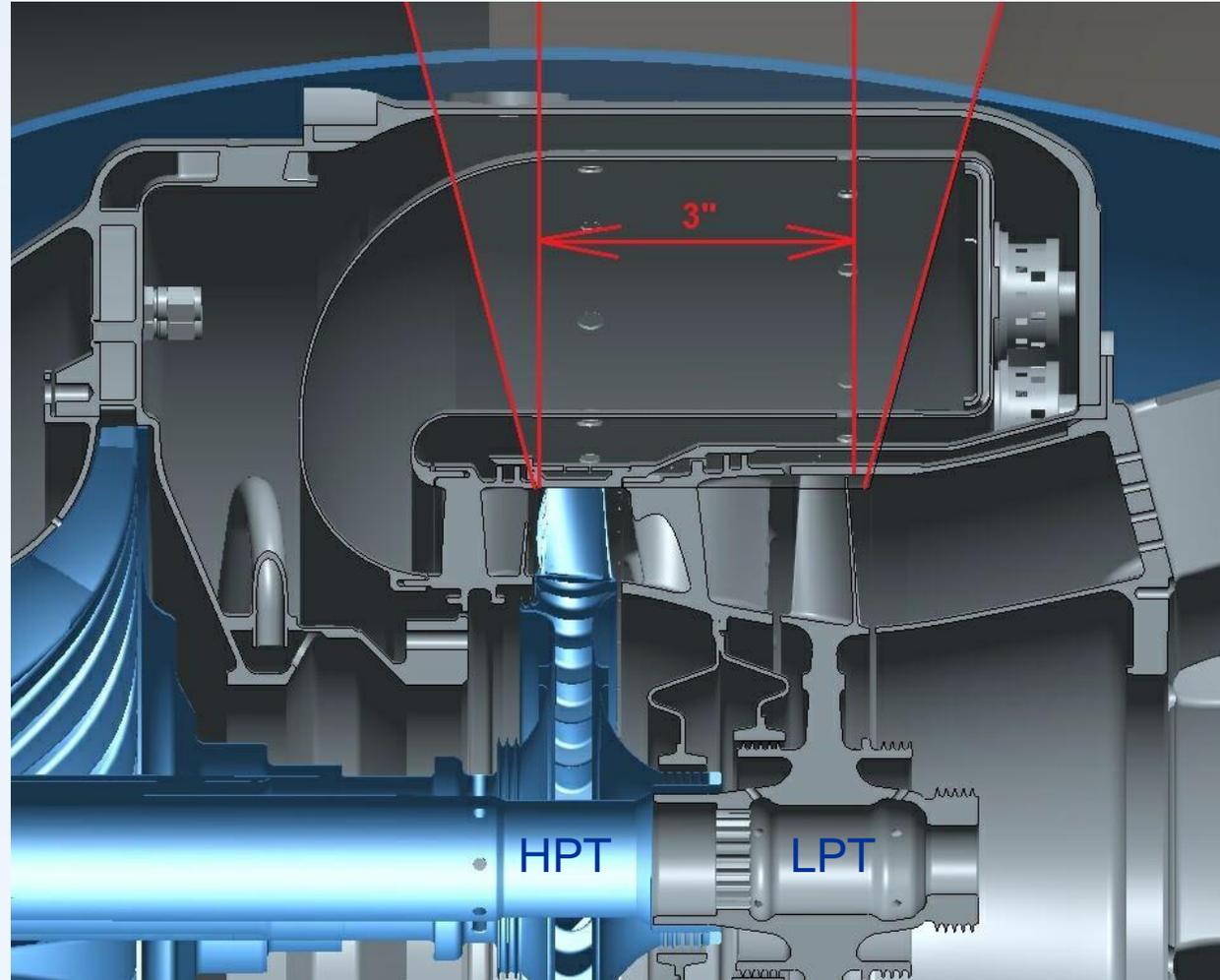
External containment will be used for check outs and any significant engine modifications.

It was determined that the HPT / LPT still needs to be shielded so the design team proposed a design for internal containment.



# Containment Shield

15° Scatter Zones





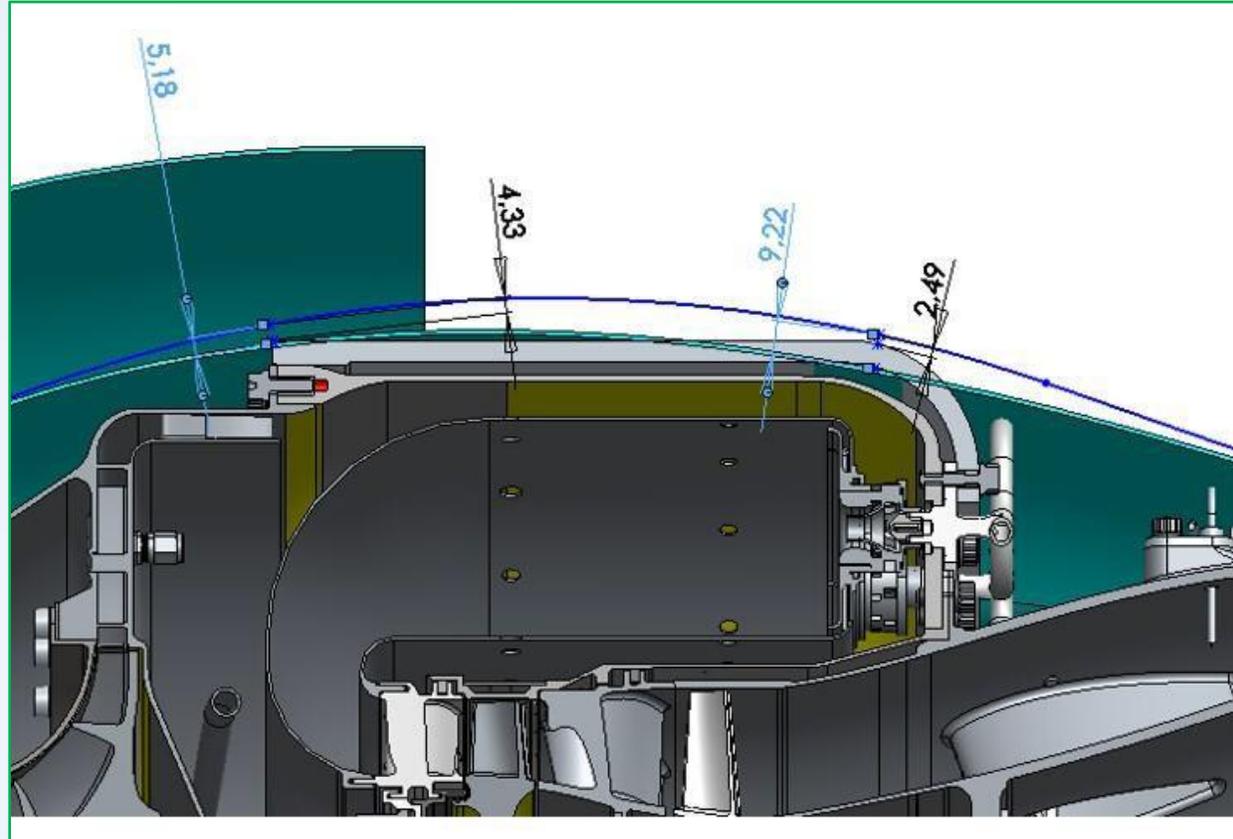
# Internal Containment

## LPT & HPT

- Permanent external containment shield not suitable for clean acoustic environment.
  - Solution : Vendor was able to modify internal engine spool to satisfy requirement of containing tri-hub failure. Vendor, with NASA oversight designed, fabricated, and assembled a thicker shield inside the turbofan engine.
  - Shield surrounds LPT & HPT
  - Will not contaminate acoustic data
  - Due to thickness change in spool, there was some effect on fan flow path. Vendor performed study and determined impact was not significant to engine performance. As part of final engine delivery package, re-baselined engine performance prior to delivery.

# Containment Shield

## Proposed Internal Shield

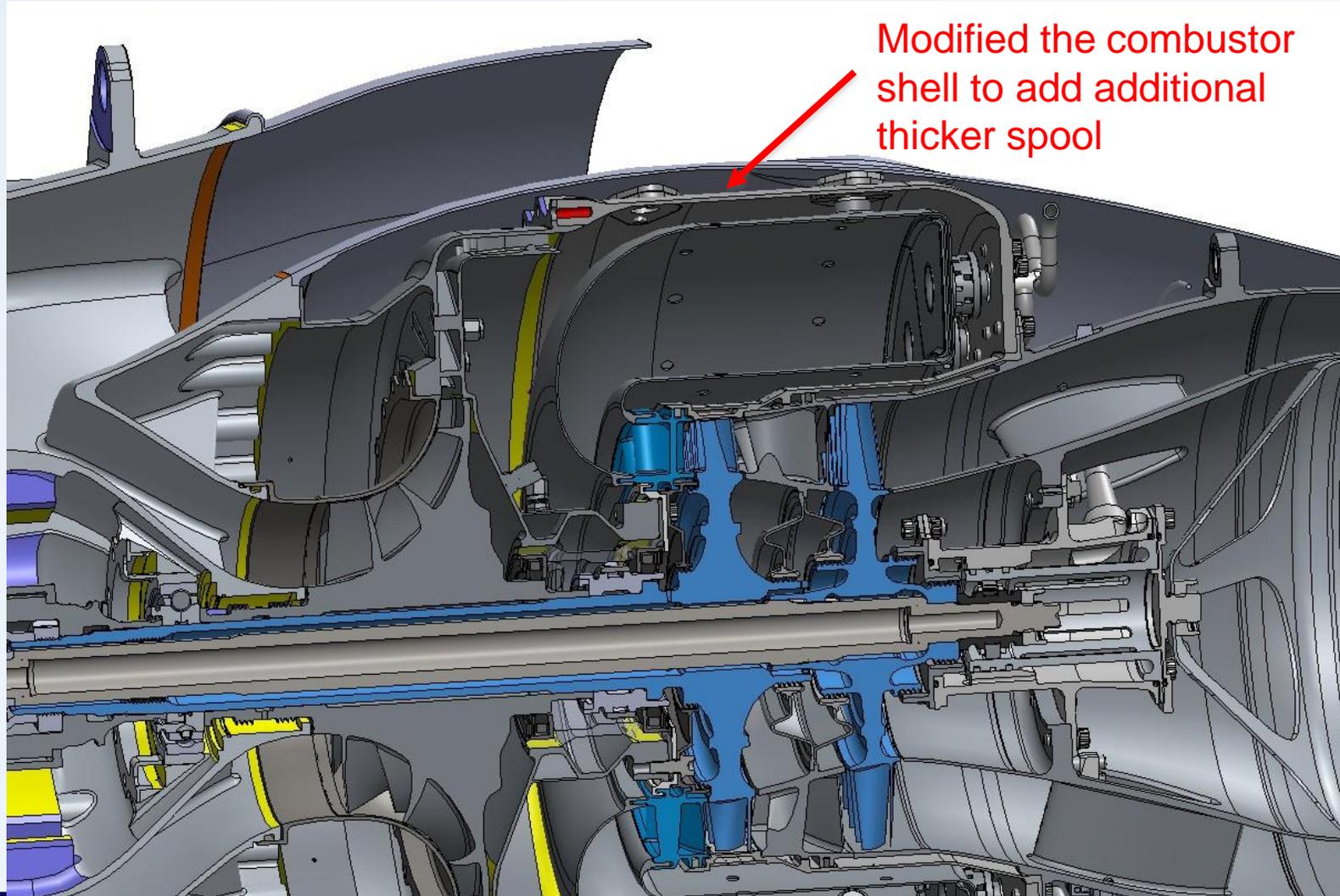


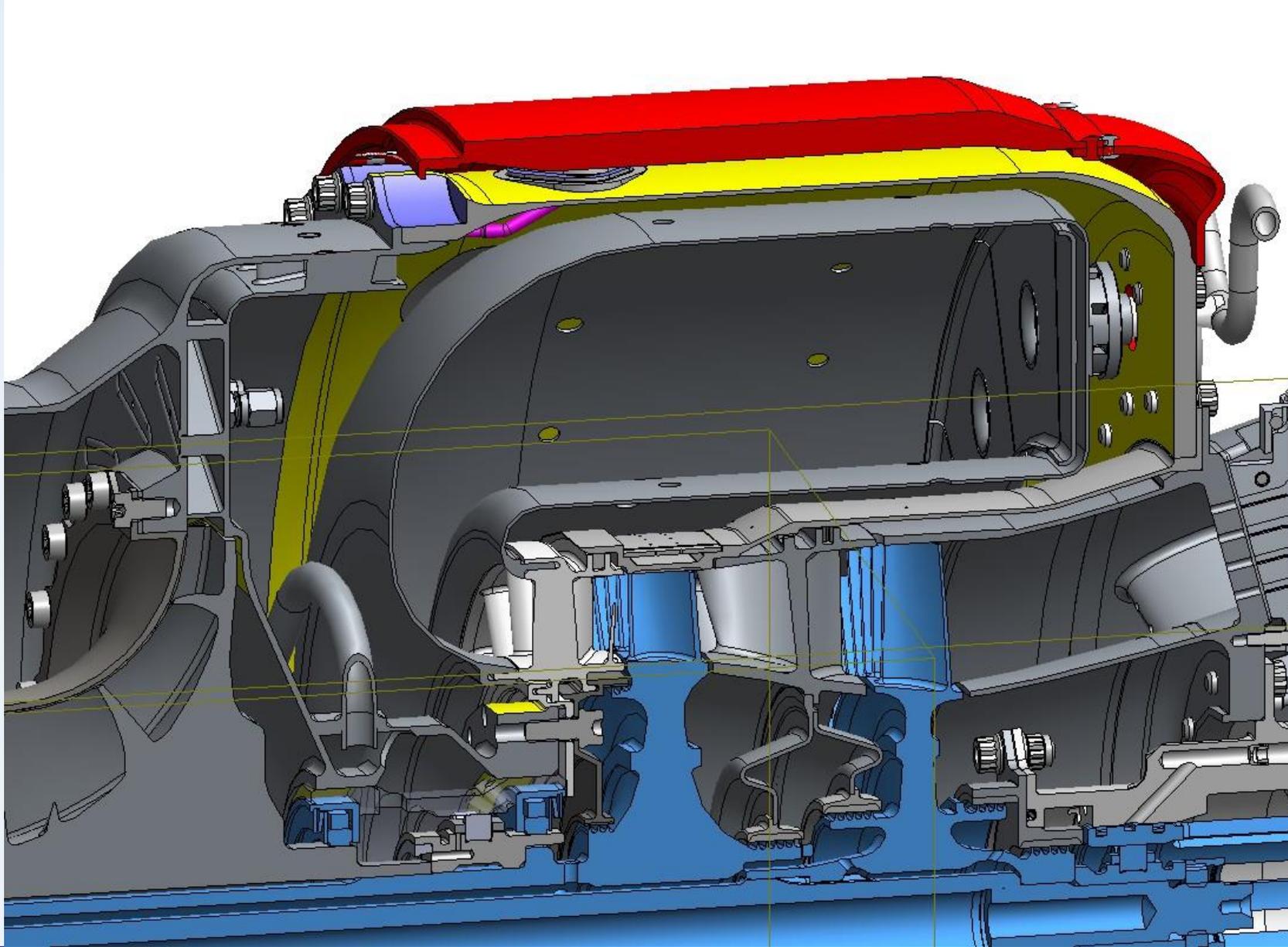
Effect to carbon composite bifurcated core fairing shown in blue line



# Internal Containment

## LPT & HPT







# Research Requirements

**SUBJECT:** Research Requirements Document for DART Baseline Testing

**BACKGROUND:** The AATT project /ANR subproject requires baseline acoustic and performance measurements on the DART test rig. This activity supports a level II project milestone.

**TIME FRAME:** Immediately succeeding the installation and operator training of the DART test rig. This is expected to be accomplished before 1-May-2017.

**CONFIGURATIONS:** standard configuration in ANCF location.

- (1) Operational/Research control from TRUCK
- (2) Operational overview in Control Room

**SYSTEMS REQUIRED:**

- (1) 10-foot acoustic array system (acquired in TRUCK)
- (2) Array-48 data system (Gary Podboy – setup in control room)

# Test Plan



**OPERATIONAL:** A data sweep will be defined as:  
After initial start-up (procedure to be define by Price Induction) data will be acquired over a range of RPM from ground idle (47%) to flight cruise (95.6%), with at least 30 or 60 sec steady state point at every intermediate 10% RPM (50%,60%,70%,80%,90%); followed by a return to ground idle low repeat point, then a direct return to flight-cruise to acquire a high repeat point. The manufacturer defines this as 1.5 cycles. Prior experience indicates a data sweep will take 30-45 minutes. For setting gains, and checking data procedures, the farfield array should be connected and in place for all sweeps. All configurations w/o external blast shield

## DAY 1

- Array48 Data position 1 (aft) (60 sec)

- Array48 Data position 2 (fwd)

## DAY 2

- Far-field Acoustic Data (30 sec)

## DAY 3

- Demo (project / center) on 28-April



# Operations

- **Electrical Checksheets**
- **Mechanical Checksheets**
- **User Manual**



# Mechanical Checksheets

## DART MECHANICAL OPERATIONAL PROCEDURES

Filename: DART\_MECH\_CHK\_2017  
Revised: 23 March 2017

Date: \_\_\_\_\_ Operator: \_\_\_\_\_

Configuration: \_\_\_\_\_

Acoustic Test: \_\_\_\_\_ Sideline Array: \_\_\_\_\_ Farfield Array: \_\_\_\_\_ Phased Array: \_\_\_\_\_

Run Time: Start: \_\_\_\_\_ Finish: \_\_\_\_\_

Data Points: \_\_\_\_\_

Fuel Level: Start: \_\_\_\_\_ Finish: \_\_\_\_\_



# Mobile Turbo Engine Control

The DART MCU was previously used as a mobile testbed for proving aeronautical communications and locator systems.

Modified to meet requirements for DART application



# DART TRUCK Power Checksheets



## Power Up Procedure

1. Ensure Key is not in ignition, engage parking brake, and install steering wheel lock.
2. Ensure Dome DART disconnect is in the on position
3. Remove lock out device from exterior dome interlock (red switch), keep lock out device.
4. Plug in DART truck 100amp power cable (Blue connectors) to blue power socket on passenger side of dart truck. Turn gray locking ring to lock in place.
5. Use lock out device on truck side to lock cable in place through hole in gray collar.
6. Plug in DART truck 100amp power cable to interlock disconnect on exterior of dome. Turn gray locking ring to lock plug in place.
7. Turn exterior dome DART interlock disconnect to ON (red switch up). Disconnect will not turn on without cord plugged in and locked.
8. Check rear of truck power transfer switch, ensure Main power light in on. Turn switches so that main power is engaged.
9. Turn on front and rear florescent lights.
10. Turn on all monitors, press power buttons to power up all computers.
11. Ensure thermostat is set to correct mode for season, turn on air conditioners to match thermostat setting. Thermostat should be set to 70 degrees.
12. Give steering lock, plug lock, and ignition keys to test conductor.



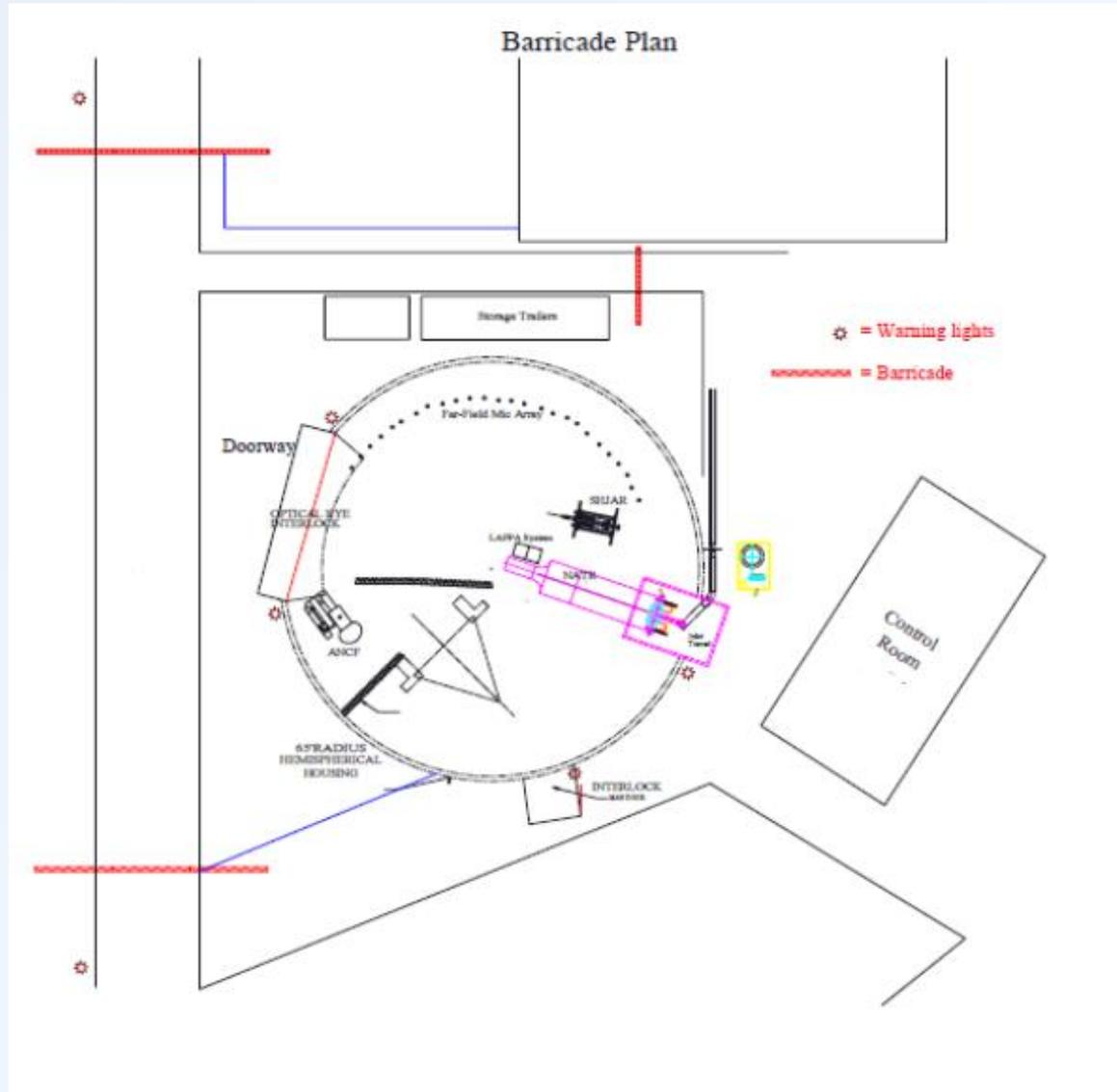
# DART TRUCK Power Checksheets

## Power Down Procedure

1. Retrieve lock out keys from test conductor
2. Ensure all computers and monitors are shut down and off
3. In DART MCU on rear transfer switch panel, turn TS1 to AUX power setting.
4. Turn exterior dome interlock disconnect switch to OFF (red switch down).
5. Turn dome plug locking ring to unlock plug, then remove plug.
6. Remove truck plug lock out device
7. Turn truck plug locking ring to unlock plug, then remove plug.
8. Return and lock the lock out device to the dome exterior interlock disconnect.
9. Coil up 100 amp cord and place in labeled storage bin.
10. If MCU unit is to be moved ensure auxiliary cord is not plugged in (gray plug, rear passenger side).
11. Check all exterior outlets for any attached cords, remove any plugged in cords
12. Check all instrumentation connectors, remove any plugged in cables
13. Unlock steering lock and store behind driver seat.



# Barricade Plan





# Mechanical Checksheets

## AAPL/DOME SET-UP

\_\_\_\_ Review Emergency Procedures

\_\_\_\_ AAPL mechanical and electrical checksheets must be completed prior to qualified operator starting fuel system or engine itself

\_\_\_\_ Close and lock K-road gates, close bldg 90 access road gate

\_\_\_\_ Turn on warning lights by dome entrances (3)

\_\_\_\_ Determine if researchers want dome vent fan on or off, then set accordingly

\_\_\_\_ Position portable video camera to observe engine

\_\_\_\_ Verify external microphone is in place (should be within 30 ft of engine)



## **FUEL SYSTEM MAIN COMPONENTS**

**500 Gallon Double Wall Fuel Tank**  
1) double wall satisfies requirement for secondary containment  
2) vented to ambient  
3) safety relief devices  
4) inner shell leak detection

**Low Pressure Gear Pump**  
rated 2gpm with .5hp 110/220 volt single phase explosion Proof motor

**Pressure differential and other electrical devices within area explosion proof**

**Flexible Hose connection from outside isolation valve to fuel interface at base of pylon**  
1) Aviation Fueling Hose w/ MxM NPT Ends (3/4" x 50')  
2) High-performance aviation fueling hose; hydrostatic tested to 600 PSI and inspected for electrical continuity



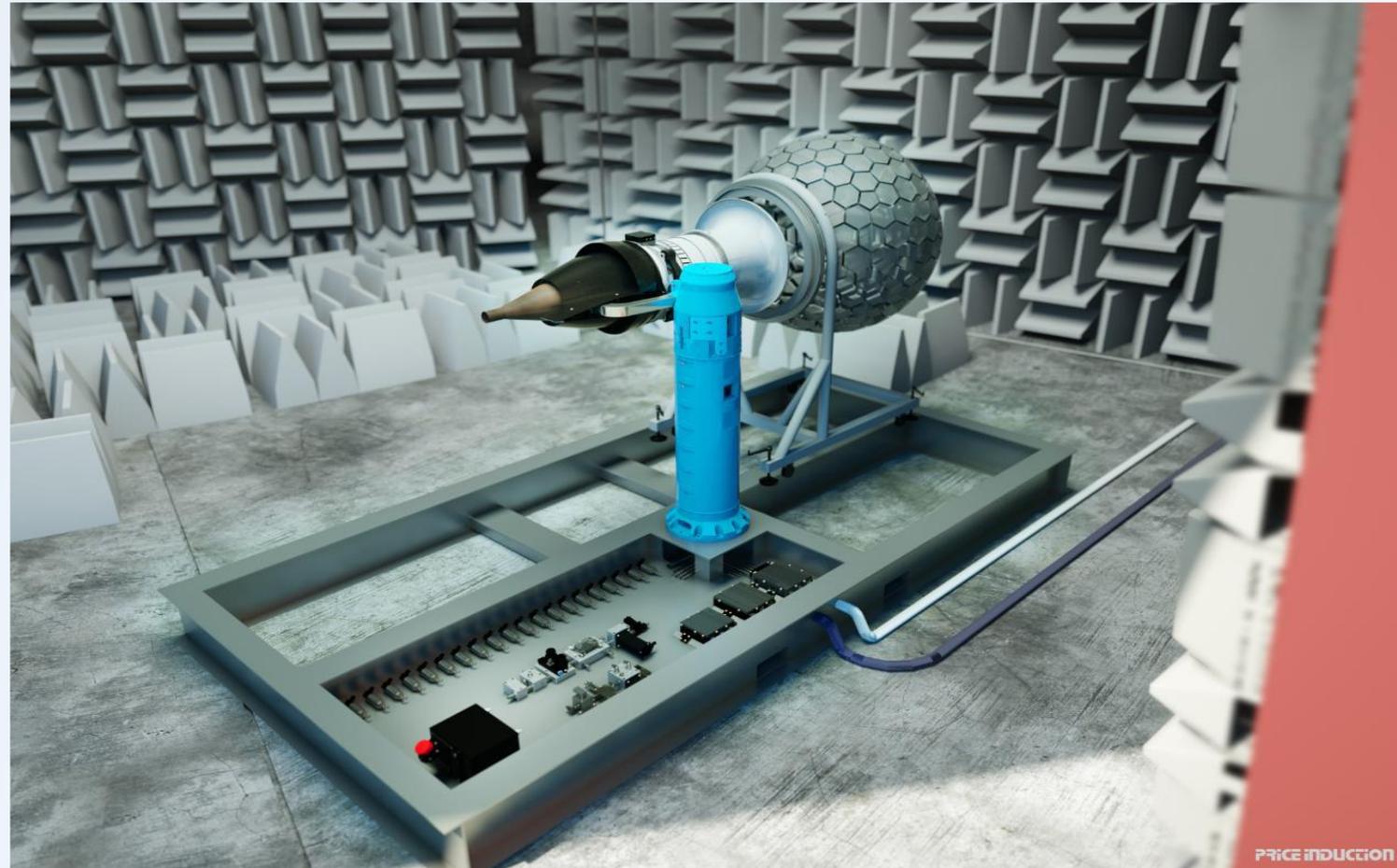
# Mechanical Checksheets

## Fuel System

- \_\_\_\_\_ Verify area around tank and piping free of drips, puddles, or staining
- \_\_\_\_\_ Verify area around tank free of wedges
- \_\_\_\_\_ Verify fuel pump is primed
- \_\_\_\_\_ Inspect all system components for any sign of leakage (fuel lines, fuel panel, fuel tank, all fittings, etc.)
- \_\_\_\_\_ Place drain covers over the three drains outside the dome
- \_\_\_\_\_ Verify ground cable is connected to tank and in good condition
- \_\_\_\_\_ Verify fuel system pressure is at 23 psi



# Engine Stand





# Mechanical Checksheets

## Engine/Stand/ICD

\_\_\_\_ Inspect inside/around engine/ICD and test area (clear of debris, tools, other objects)

\_\_\_\_ Roll ICD rack into place and secure (leveling feet)

\_\_\_\_ Verify configuration is correct, have researcher or OPS Engineer confirm

\_\_\_\_ If performing Idle leak checks or troubleshooting, observe the restricted areas around inlet and exhaust of engine

\_\_\_\_ Verify dome door opened fully

\_\_\_\_ If personnel **are** permitted in dome during test, notify them that engine will be running and instruct them to notify operator when entering and leaving the dome

\_\_\_\_ If personnel **are not** permitted in dome during test, clear personnel from dome and place 'no admittance' sign/stanchion on landing outside personnel door

\_\_\_\_ Verify any in-dome researchers/technicians have radio and PPE

\_\_\_\_ Erect barrier and warning sign outside of dome personnel access door (OPS engineer)



# Mechanical Checksheets

## CONTROL ROOM SET UP

\_\_\_\_ Verify external microphone audio is activated

\_\_\_\_ Adjust camera views as needed

\_\_\_\_ Verify video is recording

\_\_\_\_ Verify dome intercom switch is “on”

\_\_\_\_ Check dome area is cleared of personnel and announce via intercom that engine is about to start running

\_\_\_\_ Turn off dome intercom switch

\_\_\_\_ Confirm electrical checksheets are completed



# Mechanical Checksheets

## SHUTDOWN

### Fuel System Shutdown

- \_\_\_\_\_ Record ending fuel level on front page of checksheets
- \_\_\_\_\_ Verify area around tank and piping free of drips, puddles or staining
- \_\_\_\_\_ Inspect all system components for any sign of leakage (fuel lines, fuel panel, fuel tank, all fittings, etc.)



# Emergency Procedures

- **Engine Fire**
- **Truck Fire**
- **Fuel system Fire**
- **Fuel Leak**
- **Facility Emergency**



## Subsystem Checkouts/IST

- **Electrical**
- **Mechanical**



## Safety Permit and PSO

### **Conditions before safety permit can be approved:**

- 1.No open PSO items. Fuel system needs PSO approval. PSO documents need to be uploaded to safety permit.
- 2.No open issues with Environmental. Environmental checklist needs to be uploaded to safety permit.
- 3.Written Emergency Response Procedure is needed. Upload to safety permit.

### **Other actions to be performed:**

- 1.Noise survey will be conducted during testing.
- 2.Weight of engine cart needs to be stenciled on cart.



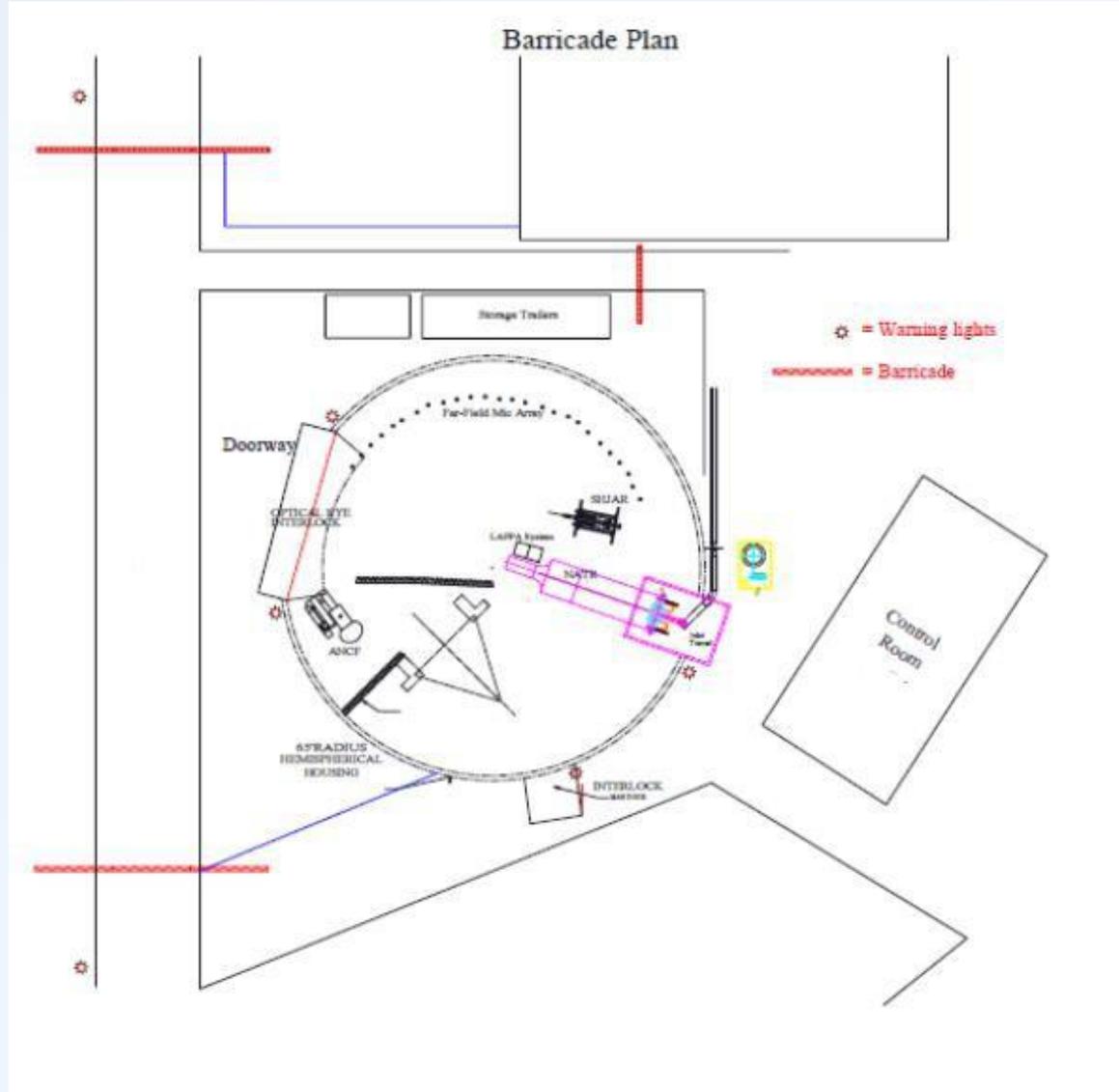
# Safety Permit and PSO

## Conditions for conducting activity:

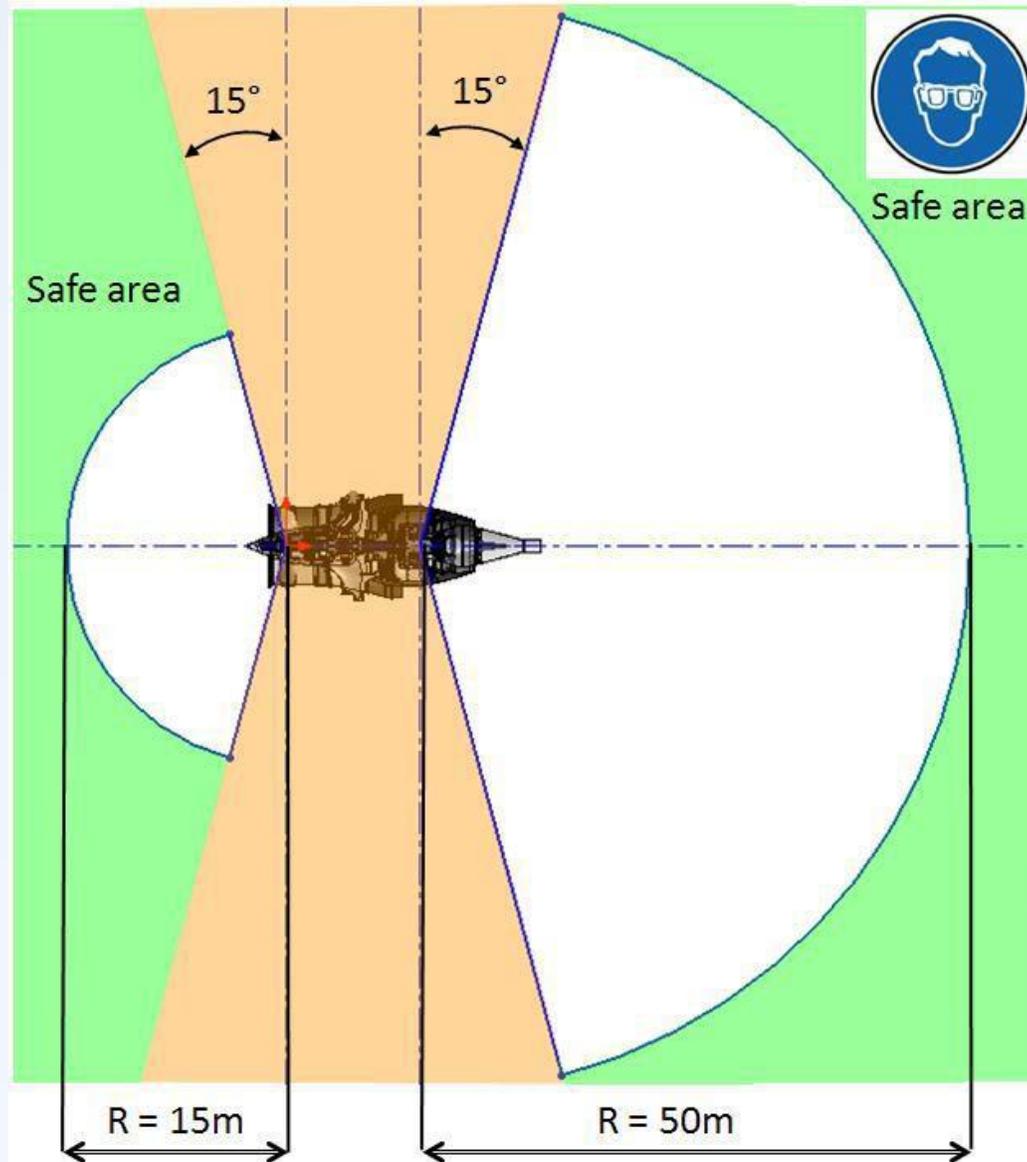
1. Alarms & shutdowns will be checked out prior to testing.
2. Facility and engine inspections will be conducted prior to testing.
3. Limited personnel access during engine electric cranking (9000 RPM)
4. No one is allowed in the Dome when engine is running on fuel.
5. Sewer drains will be covered when testing.
6. Permit only covers the primary location of engine as shown in hazards analysis.
7. The “two person buddy” system will be used.
8. A fire detector will be installed and operable in the truck when testing.
9. The qualified operators listed will also be qualified to operate the Price Induction system.
10. Barricades will be used when test is in progress.
11. Verify Radio communications with AAPL Control Room



# Barricade Plan



# Engine Safe Zones





# Operators

- personnel will be responsible for training AAPL personnel as qualified operators of the engine system. They will perform their own set of set up and shutdown checksheets
- Vendor will provide engine operational checksheets. Checksheets will also be used for barricading and general dome operational constraints.
- AAPL personnel will perform inspection checksheets pertaining to general Dome operating procedures as well as general engine safety conditions
- All engine operations will be controlled from the TRUCK.
- As necessary, an additional crew member may be staffed in the control room to provide additional oversight using Dome facility cameras. Radio communications will be maintained throughout test run. E-Stop available.



# Electrical / Instrumentation Systems

- Controls
  - Full Authority Digital Engine Control (FADEC)
    - Responsible for all of the automatic shutdowns & alarms
- Data Acquisition
  - Acoustic data will be collected using appropriate system
  - Price auxiliary data collection system is used for engine performance data
- Video Monitoring
  - Facility video surveillance system (fixed & portable)
    - Operators will have video monitors in test area



# Conclusions

1. Using NASA Systems Engineering processes ensures project success
2. NASA Glenn Safety culture and Safety Manual processes ensure project success.
3. New or modified flight hardware and test rigs are developed and tested successfully increasing the national aerospace development capabilities.



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