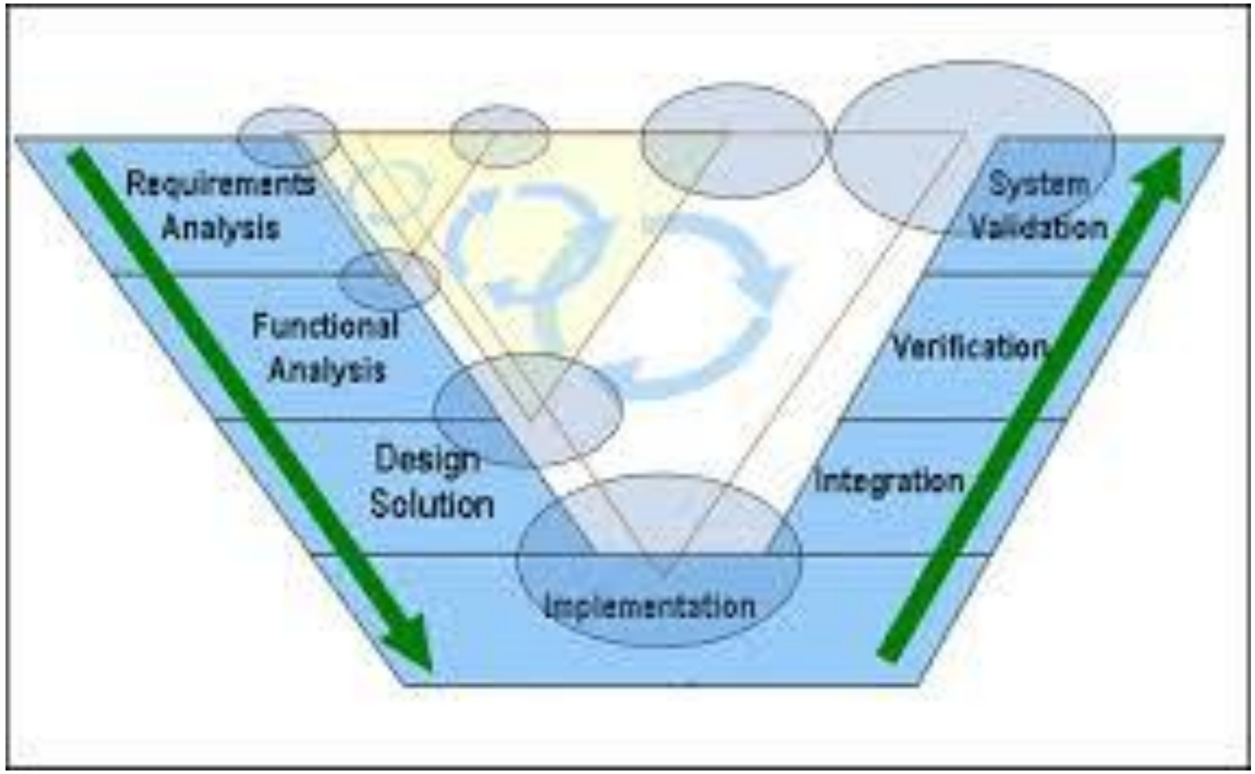
Systems Engineering for Rockets - Hypersonics



Dr. Chuck Easttom, M.Ed, MSDS, MBA, MSSE, Ph.D.[2], D.Sc.

TS-126 launched on November 14, 2008. When the shuttle reached orbit, two automatic functions failed:

• S-band/Ku-band handover

Shuttle to ground communications that rely on radio frequencies use S-band frequencies (1,700-2,300MHz) during launch, then automatically switch to the more powerful Ku-band (15,250-17,250MHz) in orbit. This handover failed.

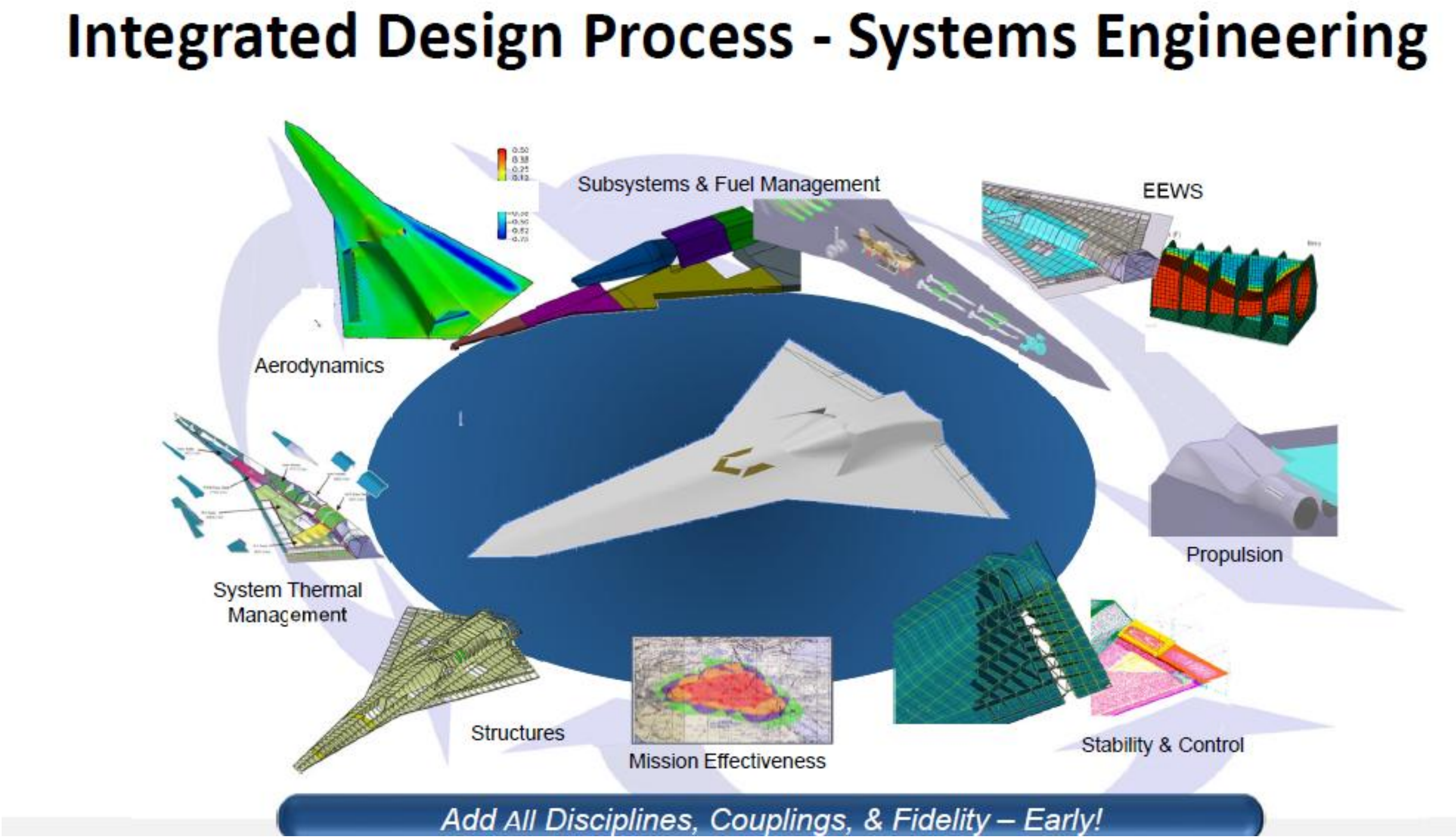
• Payload Signal Processor (PSP) port shift

The shuttle communicates with its payload through the PSP, which can be configured via RF link or hardwired umbilical. On STS-126, payload communications were configured for RF link during launch but failed to switch to umbilical when the shuttle reached orbit

Case Study 10

Dr. Chuck Easttom, M.Ed, MSDS, MBA, MSSE, Ph.D.[2], D.Sc.

Integrated Design Process - Systems Engineering



Systems Engineering

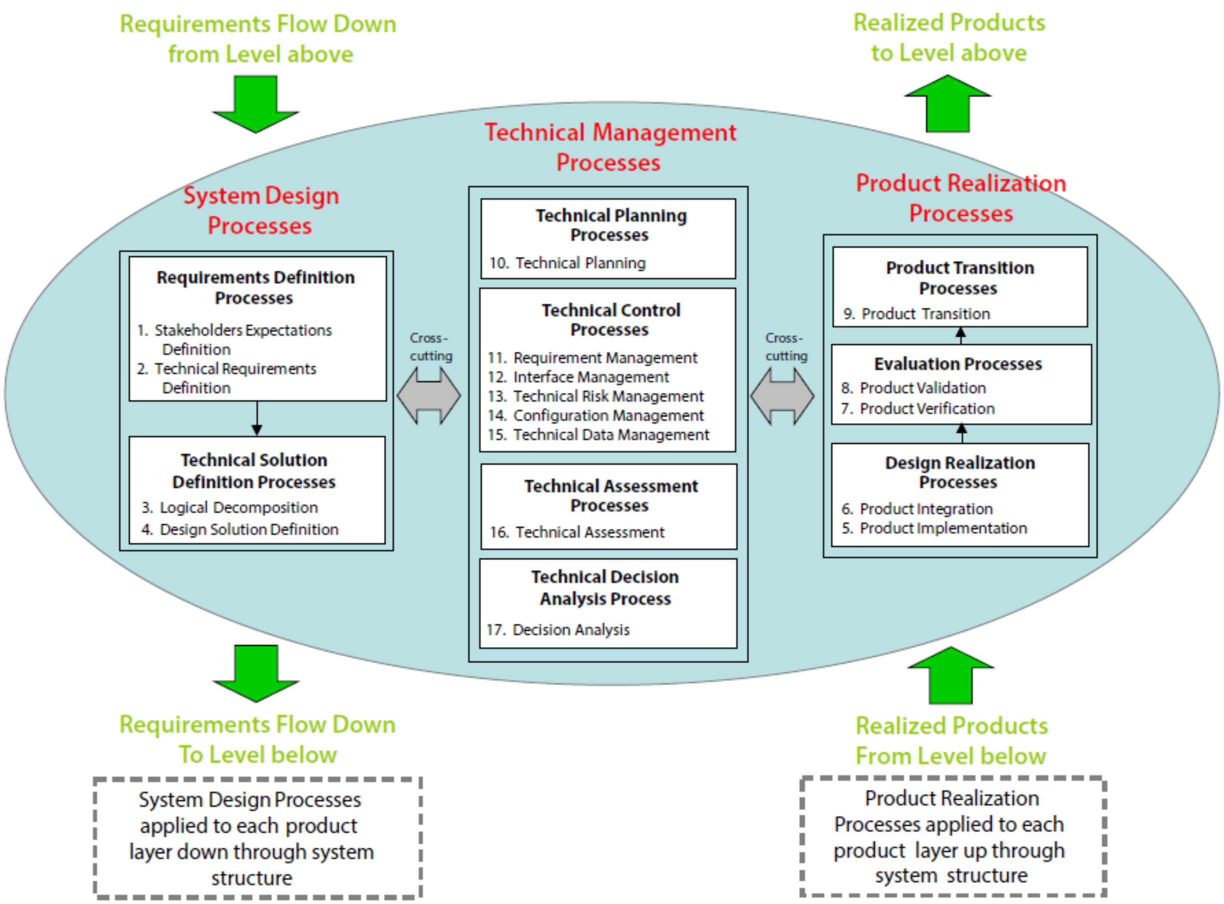
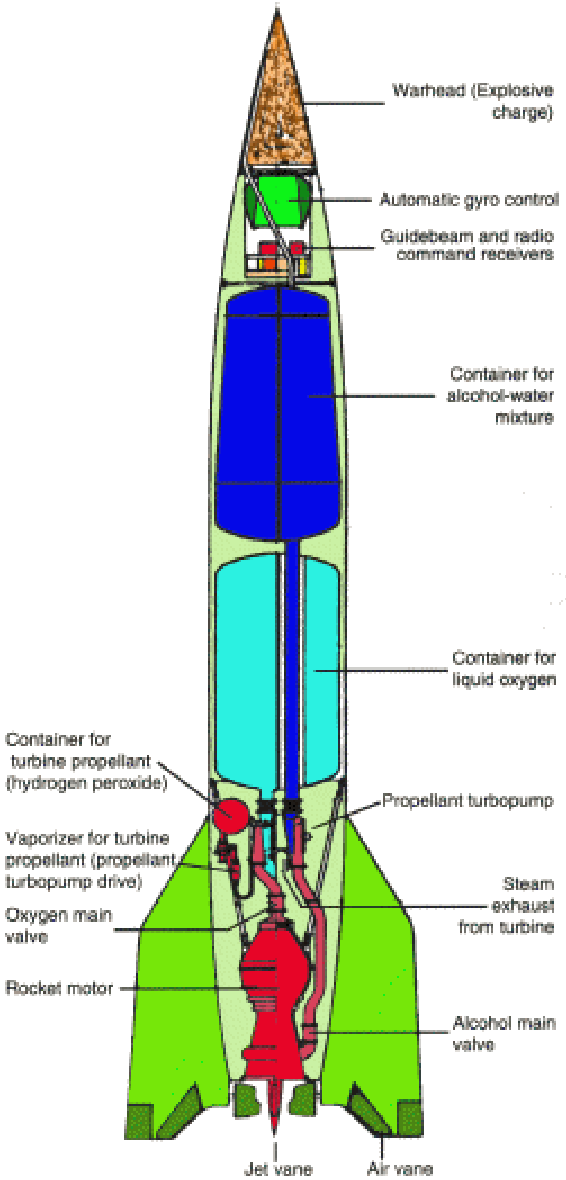


FIGURE 2.1-1 The Systems Engineering Engine (NPR 7123.1)

NASA Systems Engineering Handbook



German V-2 (A-4) Missile

What is Systems Engineering?

Systems Engineering is an *interdisciplinary approach* and means to enable the realization of successful systems.

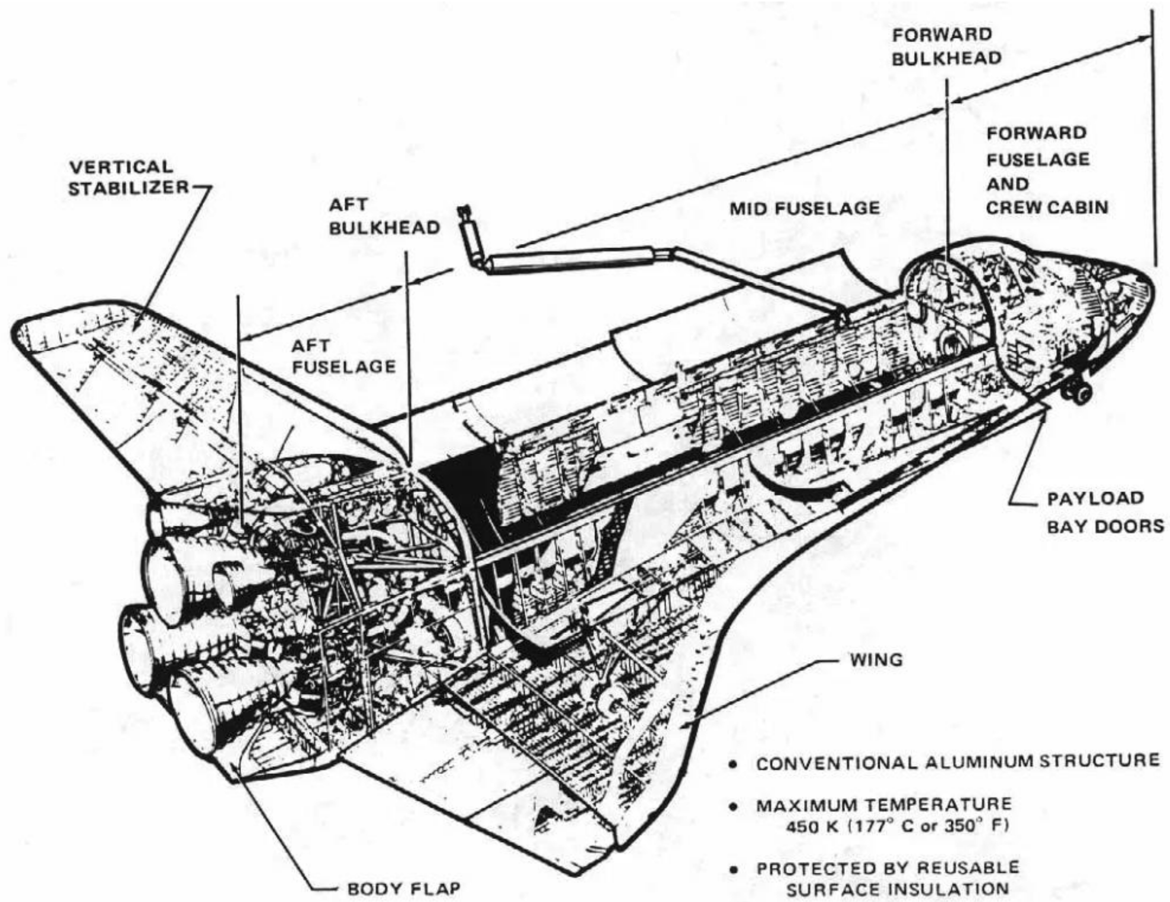
It focuses on defining *customer needs* and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem:

- Operations
- Performance
- Test
- Manufacturing
- Cost & Schedule
- Training & Support
- Disposal

What is Systems Engineering?

Systems Engineering *integrates* all of the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation.

Systems Engineering considers the operational needs and engineering requirements in order to deliver operational capability.



NASA, DOD and Industry Call For More and Better Systems Engineers

All of the factors identified by NASA that contributed to program failure and significant cost overrun are **systems engineering factors**, e.g.,

- **Inadequate requirements management**
- Poor systems engineering processes
- Inadequate heritage design analyses in early phases
- Inadequate systems-level risk management

Reference: NASA, Office of Program Analysis and Evaluation, Systems Engineering and Institutional Transitions Study, April 5, 2006. Reproduced in National Academies book - Building a Better NASA Workforce: Meeting the Workforce Needs for the National Vision for Space Exploration.

Systems Engineering

The components of a standard systems engineering process that can be applied to any project regardless of scope and scale include the following: Well-defined goals and expectations (qualitative) Performance objectives or measures of effectiveness (quantitative) A concept of operations (CONOPS) that includes the way the system is intended to operate, and the way the design, test, manufacturing, and deployment process is intended to operate Requirements definitions that include functional, performance, and interface requirements Defined constraints that include itemized cost, schedule, policy, logistics, human factors, and technology Risk assessments that are itemized and time dependent with evolving mitigation plan The program's milestone objectives and lifecycle reviews

-Boord, Warren J.; Hoffman, John B.. Air and Missile Defense Systems Engineering (pp. 14-15). CRC Press.

The Role of the System Engineer

Any engineer acts as a systems engineer when responsible for the design and implementation of a total system.

The difference with “traditional engineering” lies primarily in the greater emphasis on defining goals, the creative generation of alternative designs, the evaluation of alternative designs, and the coordination and control of the diverse tasks that are necessary to create a complex system.

The role of Systems Engineer is one of ***Manager*** that utilizes a structured value delivery process

The Systems Engineering Process

The major steps in the completion of a typical systems engineering project are the following: (1) problem statement; (2) identification of objectives; (3) generation of alternatives; (4) analysis of these alternatives; (5) selection of one of them; (6) creation of the system, and, finally, (7) operation.

Some examples of Systems Engineering Process activities are:

Defining needs, operational concept, and requirements

Functional analysis, decomposition, and allocation

System modeling, systems analysis, and tradeoff studies

Requirements allocation, traceability, and control

Prototyping, Integration, and Verification

System Engineering Product and Process control

Configuration and Data Management

Risk Management approaches

Engineering technical reviews and their purposes

Systems Engineering

TABLE 2.1-1 Alignment of the 17 SE Processes to AS9100

SE Process	AS9100 Requirement
Stakeholder Expectations	Customer Requirements
Technical Requirements Definition	Planning of Product Realization
Logical Decomposition	Design and Development Input
Design Solution Definition	Design and Development Output
Product Implementation	Control of Production
Product Integration	Control of Production
Product Verification	Verification
Product Validation	Validation
Product Transition	Control of Work Transfers; Post Delivery Support, Preservation of Product
Technical Planning	Planning of Product Realization; Review of Requirements; Measurement, Analysis and Improvement
Requirements Management	Design and Development Planning; Purchasing
Interface Management	Configuration Management
Technical Risk Management	Risk Management
Configuration Management	Configuration Management; Identification and Traceability; Control of Nonconforming Product
Technical Data Management	Control of Documents; Control of Records; Control of Design and Development Changes
Technical Assessment	Design and Development Review
Decision Analysis	Measurement, Analysis and Improvement; Analysis of Data

-NASA Systems Engineering Handbook

Systems Engineering

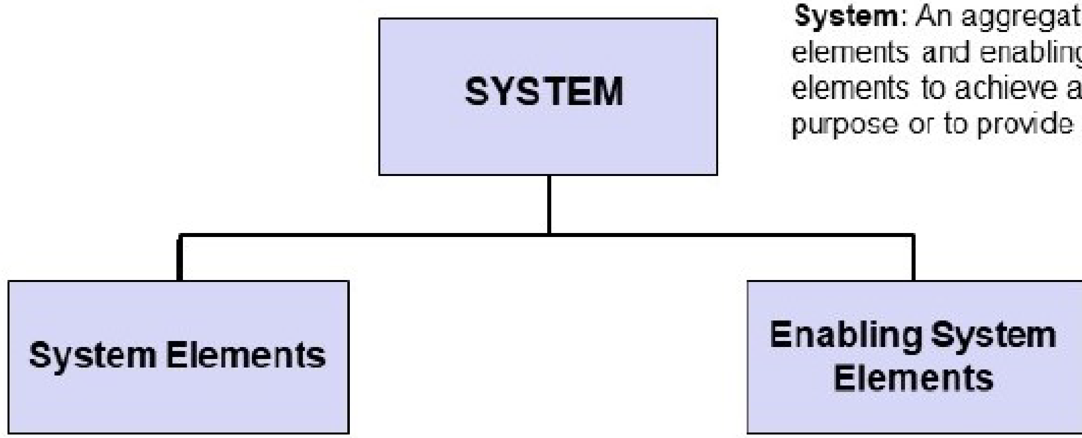
TABLE 2.2-1 Project Life Cycle Phases

Phase		Purpose	Typical Outcomes
Pre-Formulation	**Pre-Phase A** Concept Studies	To produce a broad spectrum of ideas and alternatives for missions from which new programs/projects can be selected. Determine feasibility of desired system, develop mission concepts, draft system-level requirements, assess performance, cost, and schedule feasibility; identify potential technology needs, and scope.	Feasible system concepts in the form of simulations, analysis, study reports, models, and mock-ups
Formulation	**Phase A** Concept and Technology Development	To determine the feasibility and desirability of a suggested new system and establish an initial baseline compatibility with NASA's strategic plans. Develop final mission concept, system-level requirements, needed system technology developments, and program/project technical management plans.	System concept definition in the form of simulations, analysis, engineering models and mock-ups, and trade study definition
	Phase B Preliminary Design and Technology Completion	To define the project in enough detail to establish an initial baseline capable of meeting mission needs. Develop system structure end product (and enabling product) requirements and generate a preliminary design for each system structure end product.	End products in the form of mock-ups, trade study results, specification and interface documents, and prototypes
Implementation	**Phase C** Final Design and Fabrication	To complete the detailed design of the system (and its associated subsystems, including its operations systems), fabricate hardware, and code software. Generate final designs for each system structure end product.	End product detailed designs, end product component fabrication, and software development
	Phase D System Assembly, Integration and Test, Launch	To assemble and integrate the system (hardware, software, and humans), meanwhile developing confidence that it is able to meet the system requirements. Launch and prepare for operations. Perform system end product implementation, assembly, integration and test, and transition to use.	Operations-ready system end product with supporting related enabling products
	Phase E Operations and Sustainment	To conduct the mission and meet the initially identified need and maintain support for that need. Implement the mission operations plan.	Desired system
	Phase F Closeout	To implement the systems decommissioning/disposal plan developed in Phase E and perform analyses of the returned data and any returned samples.	Product closeout

-NASA Systems Engineering Handbook

THE SYSTEM

-DoD Systems Engineering Guidebook



System: An aggregation of system elements and enabling system elements to achieve a given purpose or to provide a capability.

System Elements: Also referred to as configuration items, subsystems, segments, components, assemblies, or parts.

Enabling System Elements: Provide the means for putting a capability into service, keeping it in service, or ending its service, e.g., processes or products used to enable system development, test, production, training, deployment, support, and disposal.

DoD Systems Engineering V

-DoD Systems Engineering Guidebook

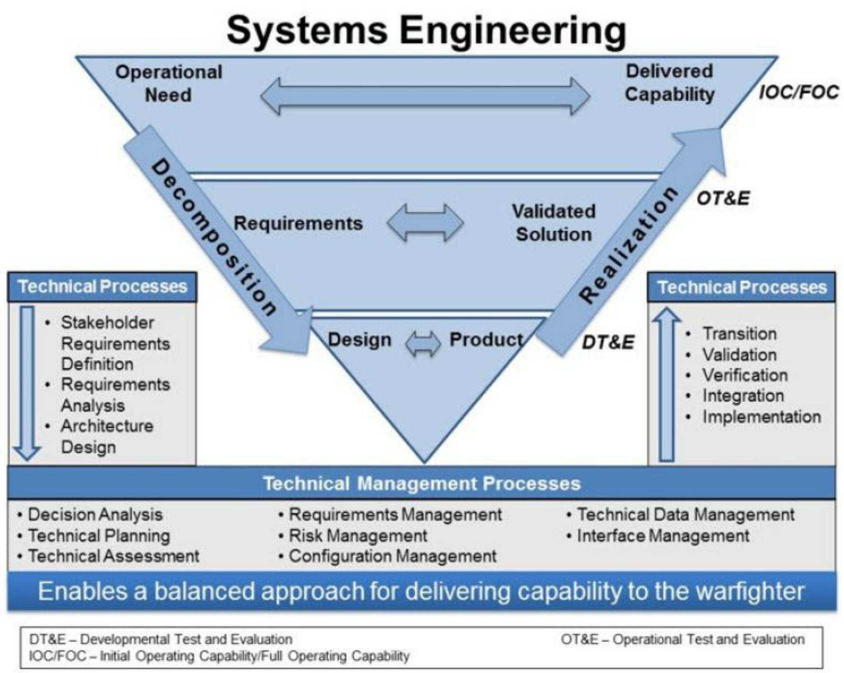


Figure 1-2. Systems Engineering Processes

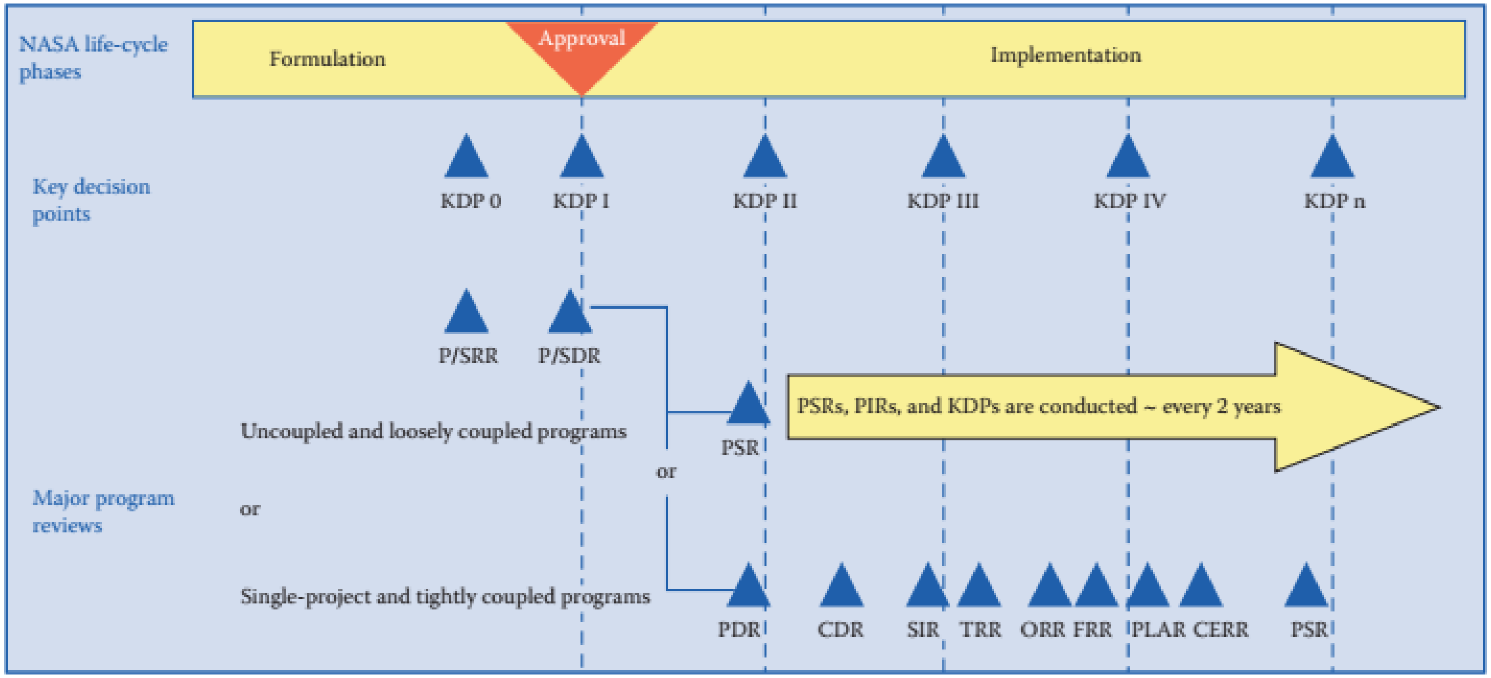
DoD SE Policies

-DoD Systems Engineering Guidebook

Table 1-1. Systems Engineering-Related Policy

Systems Engineering–Related Policy	Source
DoD Directive 5000.01, The Defense Acquisition System	Office of the Under Secretary of Defense for Acquisition and Sustainment, September 9, 2020
DoD Instruction 5000.02, Operation of the Adaptive Acquisition Framework	Office of the Under Secretary of Defense for Acquisition and Sustainment, January 23, 2020
DoD Directive 5137.02, Under Secretary of Defense for Research and Engineering (USD(R&E))	Office of the Chief Management Officer of the Department of Defense, July 15, 2020
DoD Instruction 5000.88, Engineering of Defense Systems	Office of the Under Secretary of Defense for Research and Engineering, November 18, 2020

Checks Through the Life Cycle



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		

FIGURE 6.1
NASA program life cycle shows the steps of a large-scale development space program. (Courtesy of NASA.)

Taylor, Travis S.. Introduction to Rocket Science and Engineering. CRC Press.

Decomposition

Many types of decomposition

Requirements Decomposition

Functional Decomposition

- Functional Architecture

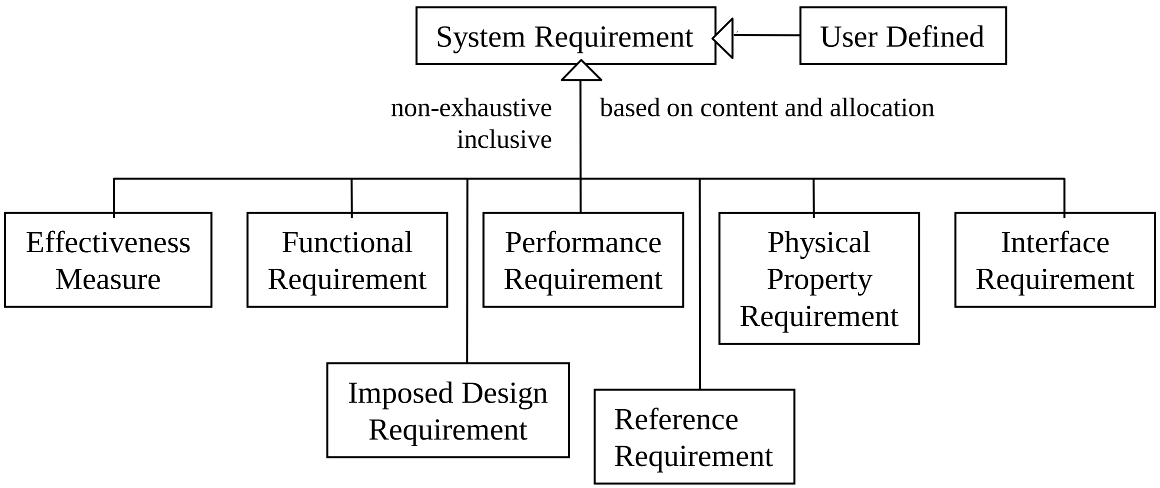
Physical Decomposition

- Physical Architecture

Operational Architecture

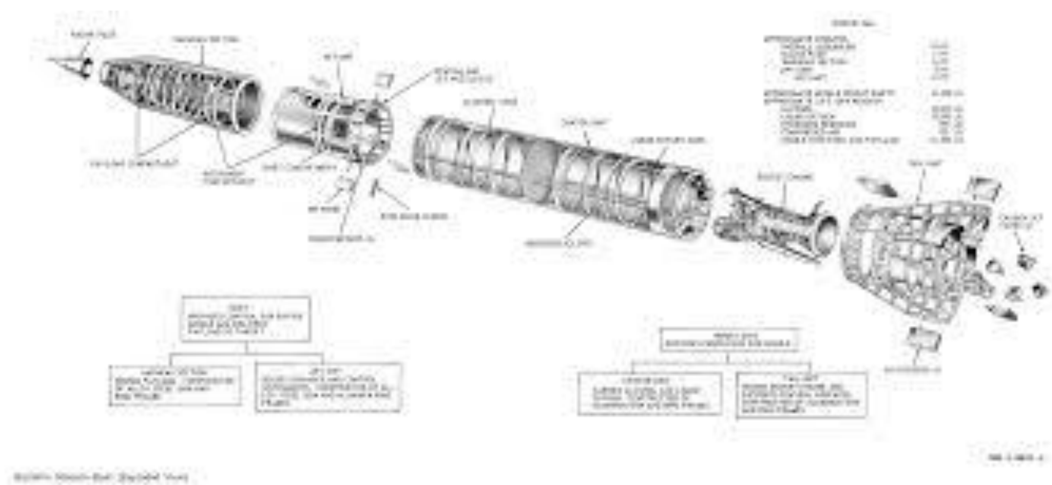
- Allocates functions to physical subsystems
- Provides complete description of the system design
- Integrates the requirements decomposition with the functional and physical architectures

Decomposition



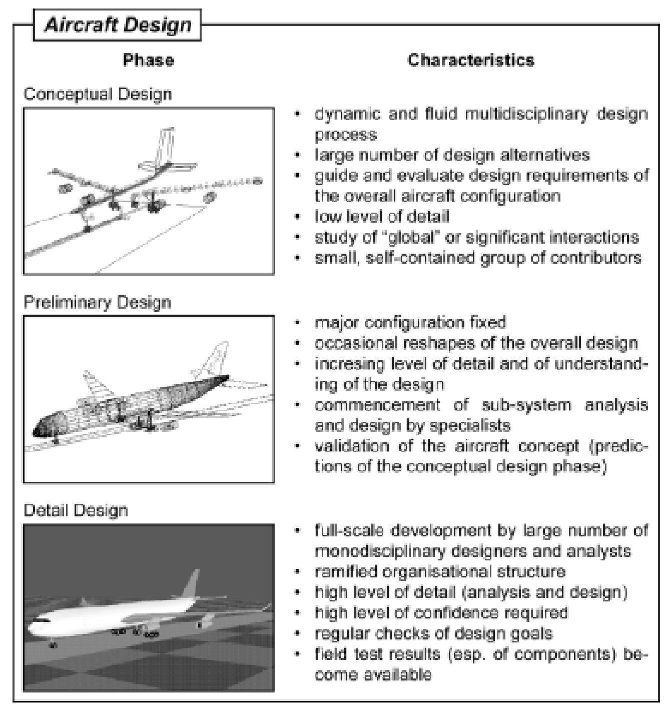
Drivers in Hypersonic Missile Design

- Propulsion/Thrust/Speed
  - Weight
- Thermal Protection Systems
- Payload capacity



The Aircraft Design Process

- Aircraft design is typically done in three phases
  - Conceptual design
  - Preliminary design
  - Detailed design
- Conceptual design usually requires estimation tools that are ±10% accurate
- Traditionally 80% of the cost of the vehicle is determined in the first 20% of the design by a small team of people



https://www.researchgate.net/figure/Main-Characteristics-of-an-Aircraft-Design-Process_fig3_36421809

Verification

- Verification: "Did I build the System Right?"
- Each quirquirement must be verified
- Verification Methods: Test, Analysis, Inspection and Demonstration
- Rule #1: "Test wherever possible"
  - Perform Analysis and Inspection, where Test is not possible
  - Pay careful attention to validity of simulators and models
- Rule #2: "Test the way you use, use the way you test"
  - Identify what is not tested in flight configuration
    - Careful review to assure items are properly verified by a combination of Analysis, Inspection or Test.
    - Review of the assumptions and interfaces of element verified in pieces
    - Attention to validity of simulators and simulations
  - Careful review to assure these items are properly verified by a combination of Analysis, Inspection or Test.
- Rule #3: "Test the system end-to-end"
  - Carefully review the assumptions and interfaces of any elements verified in pieces
- Rule #4: "Verify Off-Nominal Conditions"
  - Verify Redundancy and Graceful Degradation Modes along with On Board Fault Protection and Ground Contingency Procedures
  - Stress Testing and Negative Testing to find Latent Flaws

Validation

- Validation: "Did I design or build the Right System?"
- Validation shows that the Design when used according to the Operations Concept meets the Requirements and the Customers Goals and Objectives and can be produced within the Cost, Schedule and Risk constraints
- Validation Methods: Analysis, Predictions, Trade Studies, Test
- The requirements flow is also validated to show that "Parent" requirements have valid "Child" requirements, and that "Orphan" requirements are not driving the system design or implementation.
- Initial Validation during Phase A and B is critical to proceeding into Phase C where detail design occurs
  - Otherwise, the detail design proceeds on the "Wrong" system
- Validation also occurs in parallel with verification where End to End Tests, Mission Simulations show that the "Right System" has been built

DoD TPM Hierarchy

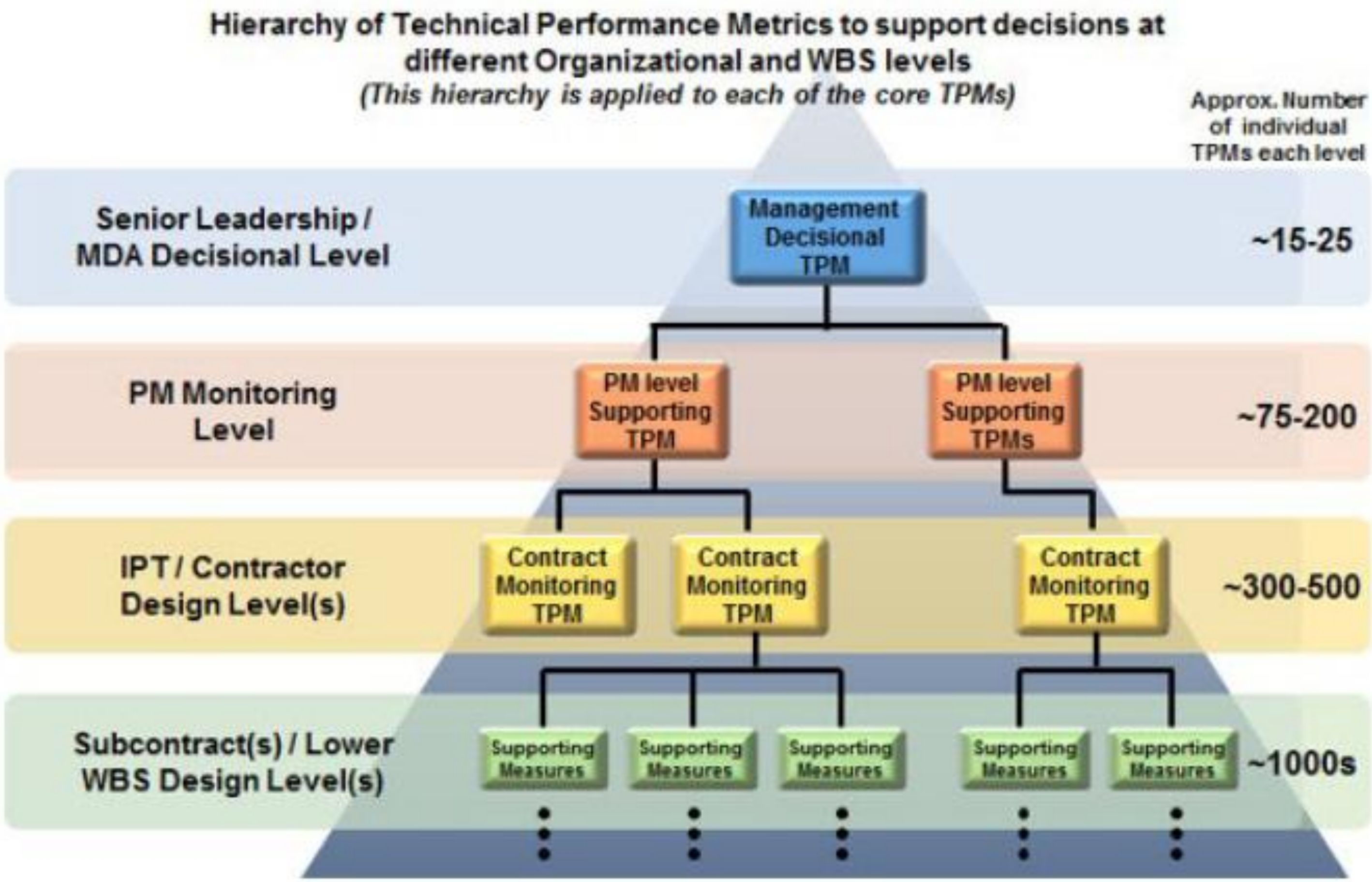


Figure 4-5. TPM Hierarchy

-DoD Systems Engineering Guidebook

Naval Integrated Modeling Environment

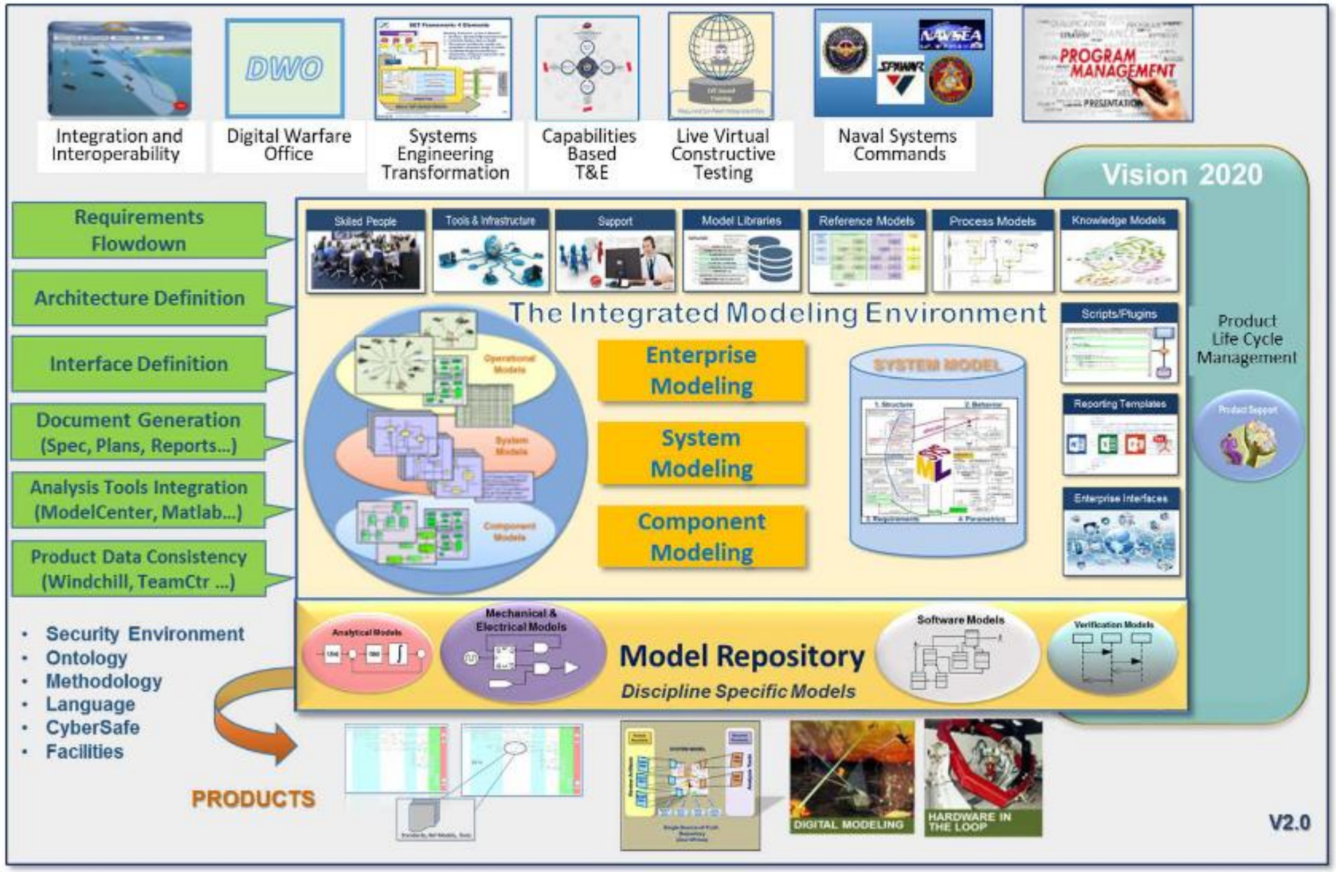


Figure 1 – Naval Enterprise Integrated Modeling Environment

- US Navy & Marine Corps Digital Systems Engineering Transformation Strategy

What is "Requirements Engineering"?

Requirements Engineering (RE) is:

- The activity of development, elicitation, specification, analysis, and management of the stakeholder requirements, which are to be met by a new or evolving system
- RE is concerned with identifying the purpose of a software system… and the contexts in which it will be used
  - How/where the system will be used
  - Big picture is important
- Captures real world needs of stakeholders affected by a software system and expresses them as artifacts that can be implemented by a computing system
  - Bridge to design and construction
  - How to communicate and negotiate?
  - Is anything lost in the translation between different worlds?

Requirements

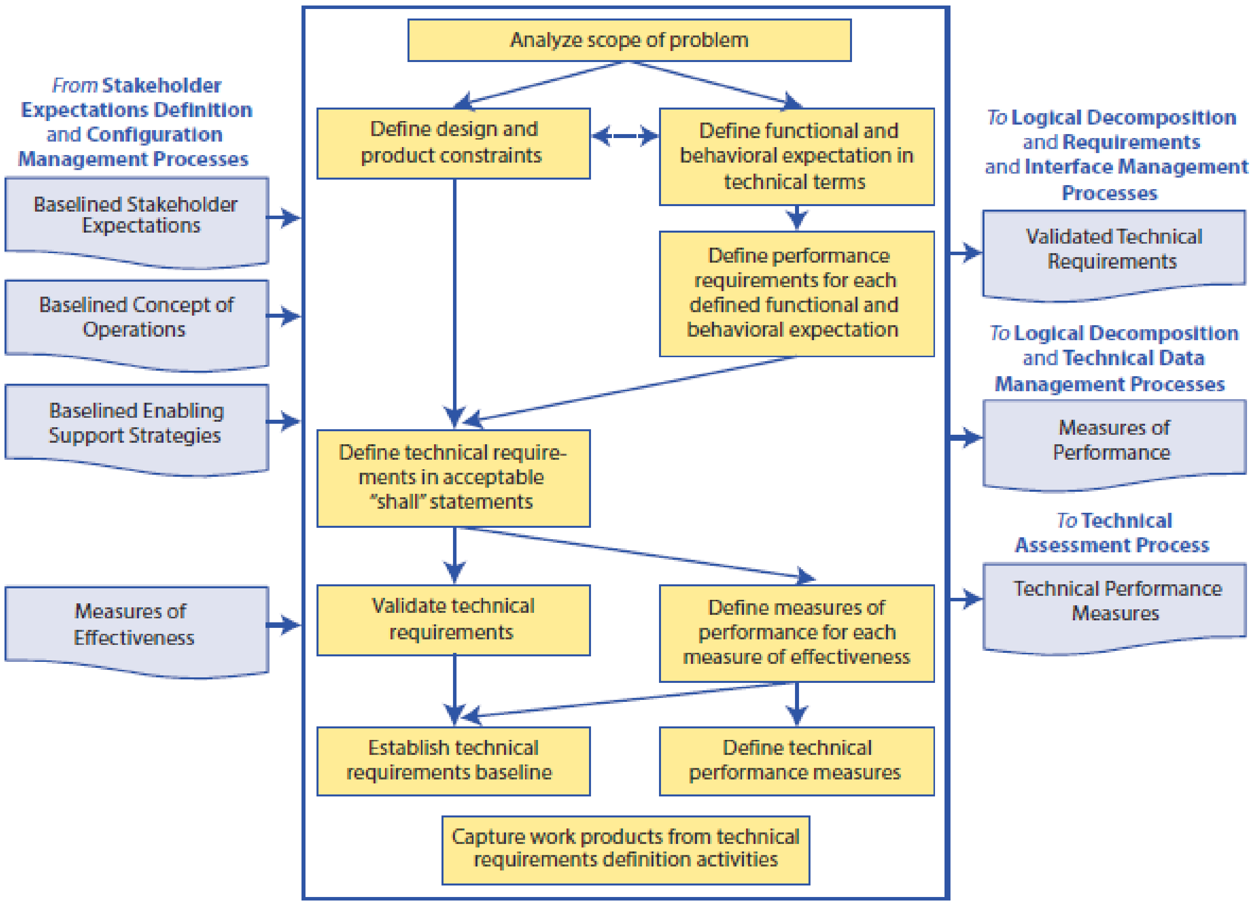


FIGURE 4.2-1 Technical Requirements Definition Process

NASA Systems Engineering Handbook

Requirements

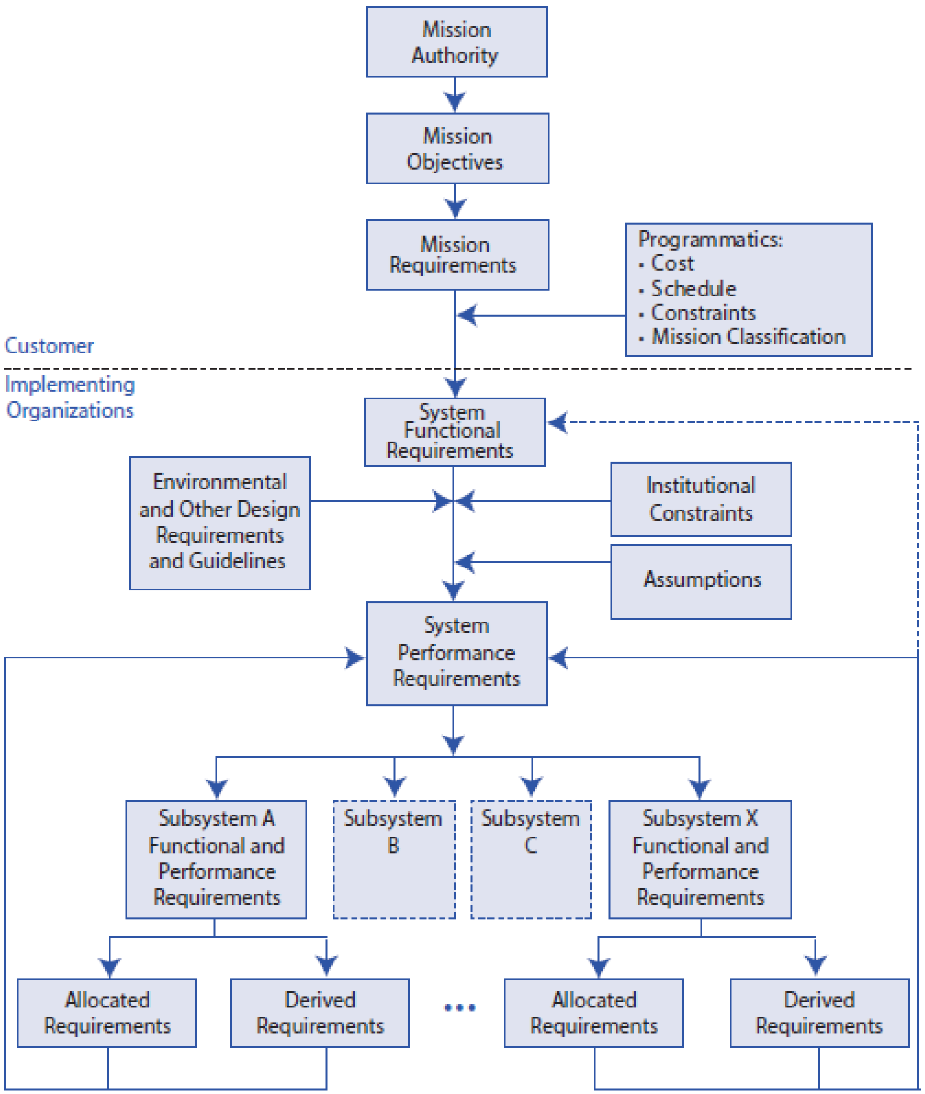
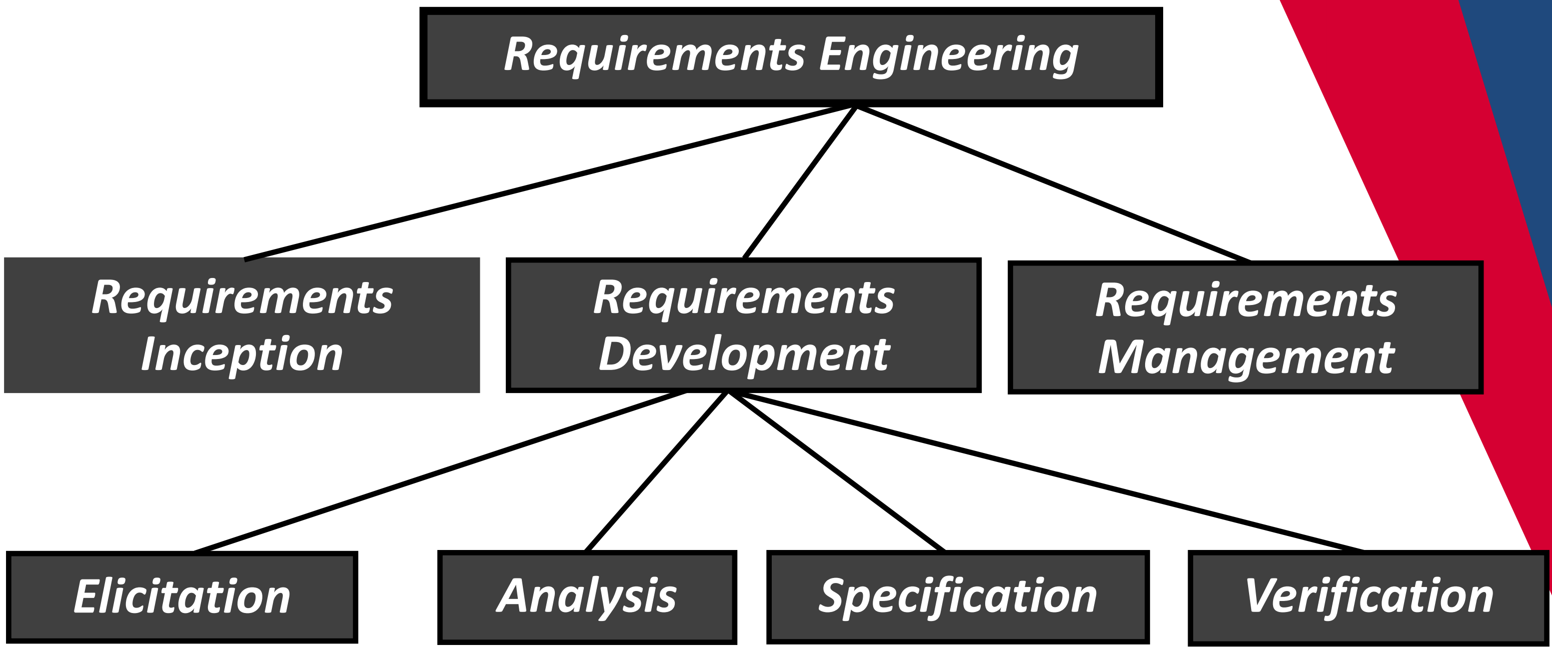


FIGURE 4.2-3 The Flowdown of Requirements

NASA Systems Engineering Handbook

REQUIREMENTS ENGINEERING ACTIVITIES



Source: Larry Boldt, Trends in Requirements Engineering People-Process-Technology, Technology Builders, Inc., 2001

RE ACTIVITIES

- **Inception**
  - Start the process operational need, operational requirements, , feasibility study, system scope, risks, etc.
- **Requirement's elicitation**
  - Requirements discovered through consultation with stakeholders
- **Requirement's analysis and negotiation**
  - Requirements are analyzed and conflicts resolved through negotiation
- **Requirement's specification**
  - A precise requirements document is produced
- **Requirement's validation**
  - The requirements document is checked for consistency and completeness
- **Requirements management**
  - Needs and contexts evolve, and so do requirements!

Types of System Requirements

Types of System Requirement	Description
Functional Requirements	Describe qualitatively the system functions or tasks to be performed in operation.
Performance Requirements	Define quantitatively the extent, or how well and under what conditions a function or task is to be performed (e.g. rates, velocities). These are quantitative requirements of system performance and are verifiable individually. Note that there may be more than one performance requirement associated with a single function, functional requirement, or task.
Usability Requirements	Define the quality of system use (e.g. measurable effectiveness, efficiency, and satisfaction criteria).
Interface Requirements	Define how the system is required to interact or to exchange material, energy, or information with external systems (external interface), or how system elements within the system, including human elements, interact with each other (internal interface). Interface requirements include physical connections (physical interfaces) with external systems or internal system elements supporting interactions or exchanges.
Operational Requirements	Define the operational conditions or properties that are required for the system to operate or exist. This type of requirement includes: human factors, ergonomics, availability, maintainability, reliability, and security.
Modes and/or States Requirements	Define the various operational modes of the system in use and events conducting to transitions of modes.
Adaptability Requirements	Define potential extension, growth, or scalability during the life of the system. System Requirements
Physical Constraints	Define constraints on weight, volume, and dimension applicable to the system elements that compose the system.
Design Constraints	Define the limits on the options that are available to a designer of a solution by imposing immovable boundaries and limits (e.g., the system shall incorporate a legacy or provided system element, or certain data shall be maintained in an online repository).
Environmental Conditions	Define the environmental conditions to be encountered by the system in its different operational modes. This should address the natural environment (e.g. wind, rain, temperature, fauna, salt, dust, radiation, etc.), induced and/or self-induced environmental effects (e.g. motion, shock, noise, electromagnetism, thermal, etc.), and threats to societal environment (e.g. legal, political, economic, social, business, etc.).
Logistical Requirements	Define the logistical conditions needed by the continuous utilization of the system. These requirements include sustainment (provision of facilities, level support, support personnel, spare parts, training, technical documentation, etc.), packaging, handling, shipping, transportation.
Policies and Regulations	Define relevant and applicable organizational policies or regulatory requirements that could affect the operation or performance of the system (e.g. labor policies, reports to regulatory agency, health or safety criteria, etc.).
Cost and Schedule Constraints	Define, for example, the cost of a single exemplar of the system, the expected delivery date of the first exemplar, etc.

-https://sebokwiki.org/wiki/Stakeholder_Requirements_Definition

Characteristics of Individual Requirements

Characteristic	Description
Necessary	The requirement defines an essential capability, characteristic, constraint, and/or quality factor. If it is not included in the set of requirements, a deficiency in capability or characteristic will exist, which cannot be fulfilled by implementing other requirements
Appropriate	The specific intent and amount of detail of the requirement is appropriate to the level of the entity to which it refers (level of abstraction). This includes avoiding unnecessary constraints on the architecture or design to help ensure implementation independence to the extent possible
Unambiguous	The requirement is stated in such a way so that it can be interpreted in only one way
Complete	The requirement sufficiently describes the necessary capability, characteristic, constraint, or quality factor to meet the entity need without needing other information to understand the requirement
Singular	The requirement should state a single capability, characteristic, constraint, or quality factor
Feasible	The requirement can be realized within entity constraints (e.g., cost, schedule, technical, legal, regulatory) with acceptable risk
Verifiable	The requirement is structured and worded such that its realization can be proven (verified) to the customer's satisfaction at the level at which the requirement exists
Correct	The requirement must be an accurate representation of the entity need from which it was transformed
Conforming	The individual requirements should conform to an approved standard template and style for writing requirements, when applicable

-https://sebokwiki.org/wiki/Stakeholder_Requirements_Definition

Pitfalls with definition of system requirements

- https://sebokwiki.org/wiki/Stakeholder_Requirements_Definition

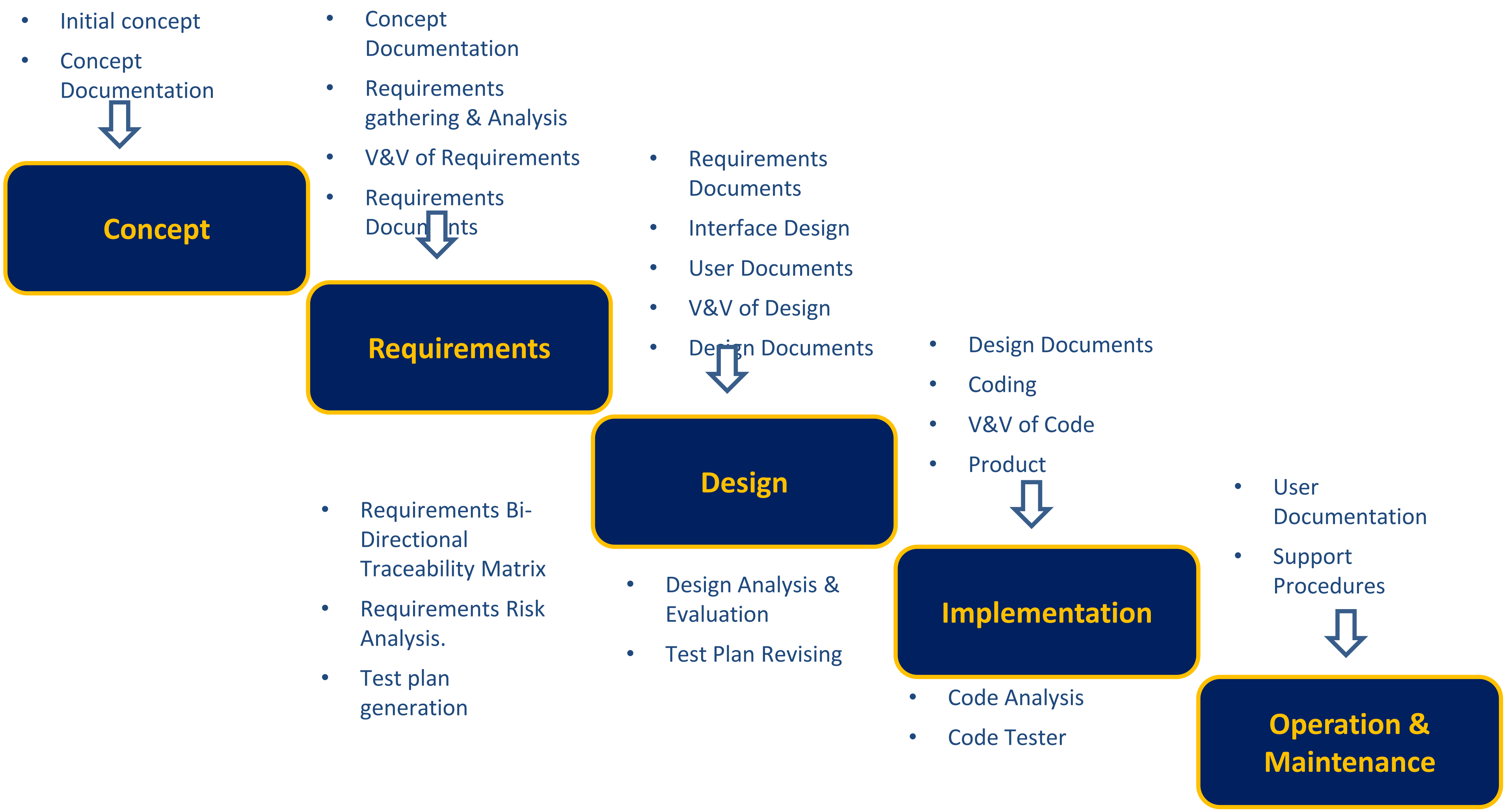
Pitfall	Description
Insufficient Analysis of Stakeholder Requirements	If the receivers of the stakeholder requirements do not perform a sufficient critical analysis of them, the consequence could be difficulties translating them into system requirements and the obligation to come back to the stakeholders, losing time.
Insufficient Analysis of Operational Modes and Scenarios	The operational modes and operational scenarios are not sufficiently analyzed or defined by the person in charge of writing the system requirements. Those elements allow the structuring of the system and its use early in the engineering process and help the designer to remember functions and interfaces.
Incomplete Set of System Requirements	If the system requirements are not sufficiently precise and complete, there is a great risk that the design will not have the expected level of quality and that the verification and validation of the system will be delayed.
Lack of Verification Method	Delaying the capture of verification methods and events for each system requirement; identification of the verification approach for each requirement often provides additional insight as to the correctness and necessity of the requirement itself.
Missing traceability	Incorrect or missing traceability of each requirement, both to an upper-level "parent" requirement as well as allocation to an inappropriate system or system element.

Requirements Management (Continued)

ID	DESCRIPTION	REQUIREMENT	TRACED FROM	PERFORMANCE	MARGIN	Comments	REF
M1	Mission Orbit	575 +/-15 km Sun-synchronous dawn-dusk orbit	S3, S11, P3	Complies	NA	Pegasus XL with HAPS provides required launch injection dispersion accuracy	F.2.c
M2	Launch Vehicle	Pegasus XL with HAPS	P2, P4	Complies	NA		F.2.c
M3	Observatory Mass	The NEXUS Observatory total mass shall not exceed 241 kg.	M1, M2	192.5 kg	25.20%		F.5.b
M4	Data Acquisition Quality	The NEXUS mission shall deliver 95% data with better than 1 in 100,000 BER.	P1	Complies	NA	Standard margins and systems baselined, formal system analysis to be completed by PDR	F.7
M5	Communication Band	The mission shall use S-band SQPSK at 5 Mbps for spacecraft downlink and 2 kbps uplink.	S12, P4	Complies	NA	See SC27, SC28 and G1, G2	F.3.f, F.7
M7	Tracking	MOC shall use NORAD two line elements for observatory tracking	P4	Complies	NA		F.7
M8	Data Latency	Data Latency shall be less than 72 hours	P12	Complies	NA		F.7
M9	Daily Data Volume	Accommodate average daily raw science data volume of 10.8 Gbits	P1, S12	Complies	12%	Margin based on funded ground contacts	F.3.e, F.7
M10	Ground Station	The Mission Shall be Compatible With the Rutherford Appleton Laboratory Ground Station and the Poker Flat Ground Station	P1	Complies	NA		F.7
M11	Orbital Debris (Casualty Area)	Design NEXUS observatory for demise upon reentry with < 1/10,000 probability of injury	P3	1/51,000	400%	See Orbital Debris Analysis in Appendix M-6	F.2.e, App.6
M12	Orbital Debris (Lifetime)	Design NEXUS observatory for re-entry <25 years after end of mission	P3	< 10 years	15 years	See Orbital Debris Analysis in Appendix M-6	F.2.e, App.6

Table 13

Systems Process



Dr. Chuck Easttom, M.Ed, MSDS, MBA, MSSE, Ph.D.², D.Sc.

System Requirements Review

The SRR is a multi-disciplined technical review to ensure that the developer understands the system requirements and is ready to proceed with the initial system design.

A SRR or System Functional Review (SFR) is mandatory per DoDI 5000.88, Section 3.5.a. This review assesses whether the system requirements as captured in the system performance specification (sometimes referred to as the System Requirements Document (SRD)):

- Are consistent with the preferred materiel solution (including its support concept)
- Are consistent with technology maturation plans
- Adequately consider the maturity of interdependent systems
- Are clearly stated and are measurable and testable

All system requirements and performance requirements derived from the applicable requirements document should be defined and consistent with cost, schedule, risk and other system constraints and with end-user expectations. Also important to this review is a mutual understanding (between the program office and the developer) of the technical risk inherent in the system performance specification.

- DoD Systems Engineering Guidebook

ARCHITECTURE DEFINITION

As stated in ISO/ IEC/ IEEE 15288, [6.4.4.1] The purpose of the Architecture Definition process is to generate system architecture alternatives, to select one or more alternative(s) that frame stakeholder concerns and meet system requirements, and to express this in a set of consistent views.

HYPERSONIC ARCHITECTURE

1. Airframe and Aerodynamics

- Configuration: Typically lifting-body or blended wing–body designs, optimized for hypersonic lift-to-drag ratios. Pointed noses, sharp leading edges (sometimes blunted to manage heating), and carefully shaped inlets/outlets are common.
- Flow Regime: Dominated by shock waves, boundary layer interactions, and viscous effects. These define the shape of the fuselage, wings, and engine integration.
- Control Surfaces: Must remain effective despite shock layers and plasma effects, often requiring novel designs or reaction control systems at extreme altitudes.

2. Propulsion Architecture

- Rocket-based systems: Provide initial boost to hypersonic speeds (especially for weapons or launch vehicles).
- Air-breathing systems:
  - Ramjets (Mach 3–6) and scramjets (Mach 6+).
  - Engines are integrated into the fuselage ("waverider" concepts), where the vehicle's body acts as part of the intake to compress air efficiently.
- Combined-cycle engines: Blend rockets, ramjets, and scramjets for broader speed envelopes.

HYPERSONIC ARCHITECTURE

3. Thermal Protection and Structures

- Thermal Protection Systems (TPS): Ablative shields, ultra-high-temperature ceramics, or metallic TPS for reusability.
- Materials: Titanium alloys, carbon–carbon composites, refractory ceramics. These are chosen for high-temperature resilience, low density, and thermal shock resistance.
- Structural Design: Must balance strength, weight, and thermal expansion, while preventing catastrophic failure due to heating and dynamic pressures.

4. Guidance, Navigation, and Control (GNC)

- Stability Challenges: Aerodynamic instabilities at hypersonic Mach numbers make control very difficult.
- Plasma Blackout: High-speed ionized flow can block radio-frequency signals, requiring alternative comms (e.g., relay satellites, magnetic windows).
- Precision Navigation: In military contexts, high maneuverability for unpredictable trajectories is a key architectural requirement.

HYPERSONIC ARCHITECTURE

5. Mission-Specific Architectures

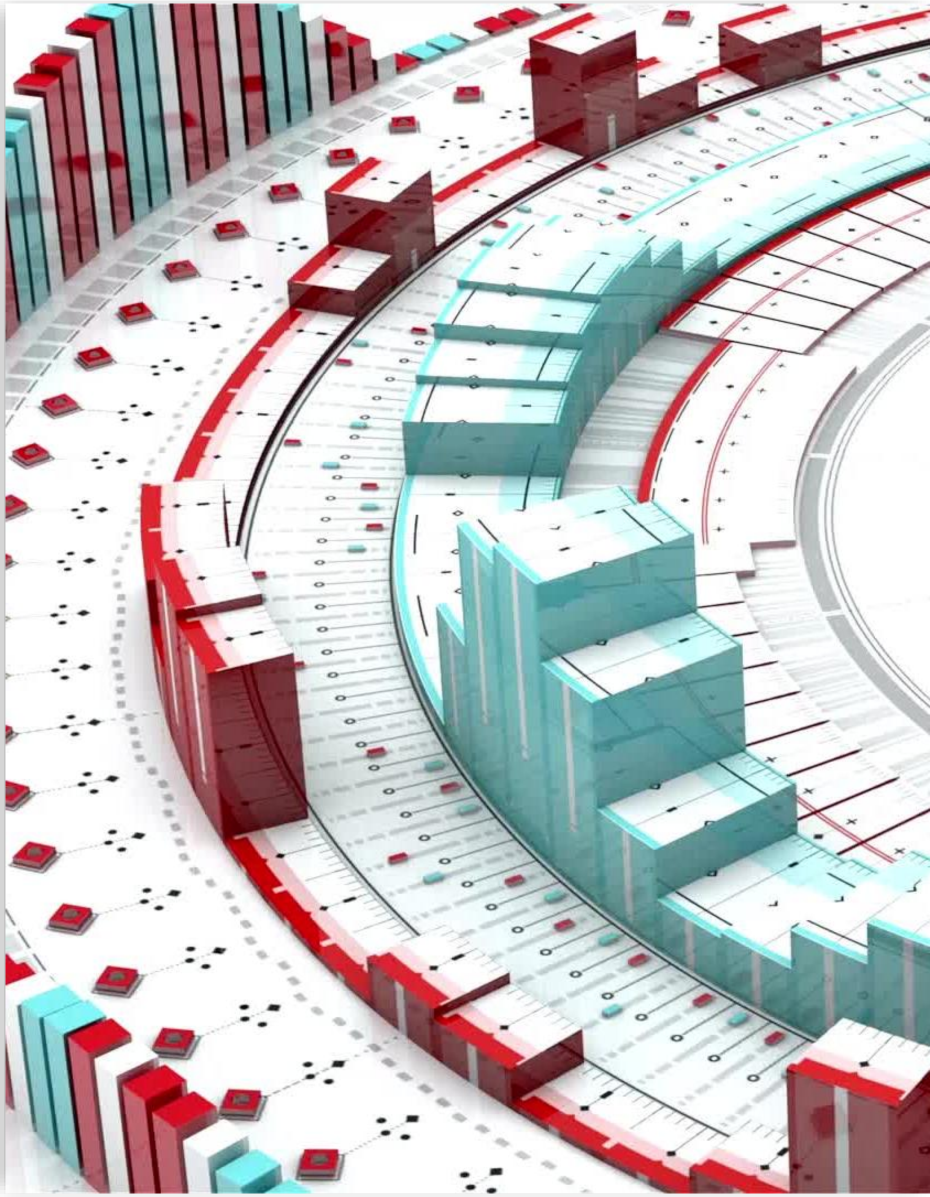
- Boost-Glide Vehicles: Rocket-boosted, then glide unpowered at hypersonic speeds (e.g., Avangard, DARPA HTV-2).
- Air-breathing Cruise Vehicles: Sustain hypersonic speeds with scramjets, optimized for range and reusability (e.g., HAWC).
- Reusable Hypersonic Aircraft/Spaceplanes: Aim for multiple flights, with robust TPS and efficient combined-cycle engines (e.g., experimental designs like Skylon).

DESIGN DEFINITION PROCESS

- As stated in ISO/ IEC/ IEEE 15288, [6.4.5.1] The purpose of the Design Definition process is to provide sufficient detailed data and information about the system and its elements to enable the implementation consistent with architectural entities as defined in models and views of the system architecture.

PHYSICAL ARCHITECTURE

- A physical architecture model is an arrangement of physical elements, (system elements and physical interfaces) that provides the solution for a product, service, or enterprise. It is intended to satisfy logical architecture elements and system requirements ISO/IEC/IEEE 26702 (ISO 2007). It is implementable through technological system elements. System requirements are allocated to both the logical and physical architectures. The resulting system architecture is assessed with system analysis and when completed becomes the basis for system realization.
- -https://sebokwiki.org/wiki/Physical_Architecture



ACTIVITIES IN THE ARCHITECTURE PROCESS

1. Partition and allocate functional elements to system elements

2. Constitute candidate physical architecture models.

3. Assess physical architecture model candidates and select the most suitable one

4. Synthesize the selected physical architecture model

A DESIGN PROPERTY

- A design property is a property that is obtained during system architecture and created through the assignment of non-functional requirements, estimates, analyses, calculations, simulations of a specific aspect, or through the definition of an existing element associated with a system element, a physical interface, and/or a physical architecture. If the defined element complies with a requirement, the design property will relate to (or may equal) the requirement. Otherwise, one has to identify any discrepancy that could modify the requirement or design property and detect any deviations. .- https://sebokwiki.org/wiki/Physical_Architecture

ACTIVITIES IN THE ARCHITECTURE PROCESS

1. Partition and allocate functional elements to system elements
2. Constitute candidate physical architecture models.
3. Assess physical architecture model candidates and select the most suitable one
4. Synthesize the selected physical architecture model

ARTIFACTS OF THE ARCHITECTURE PROCESS

- Physical block diagrams (PBD)
- SysML block definition diagrams (BDD)
- Internal block diagrams (IBD) (OMG 2010)
- Executable architecture prototyping

CRITICAL DESIGN REVIEW

A multi-disciplined technical review, conducted at both system-level and component-level, ensures that the initial product baseline is established. The component-level CDRs should be successfully completed for each major component before conducting the system-level CDR. It completes the process of defining the technical requirements for each component, which are documented in the item performance specification of each component. A successful completion of CDR provides a sound technical basis for proceeding into fabrication, integration, and developmental test and evaluation. At completion of the CDR, the *initial product baseline* is normally taken under contractor configuration control at least until the physical configuration audit (PCA).

ANALYSIS OF ALTERNATIVES (AOA)

The AoA assesses potential materiel solutions to mitigate the capability gaps documented in the validated Initial Capabilities Document (ICD). The AoA focuses on identification and analysis of alternatives, measures of effectiveness (MOE), cost, schedule, concepts of operation, and overall risk. This includes the sensitivity of each alternative to possible changes in key assumptions or variables. The AoA addresses trade space to minimize risk and also assesses critical technology elements associated with each proposed materiel solution. This includes technology maturity, integration risk, manufacturing feasibility, and, where necessary, technology maturation and demonstration needs. The AoA normally occurs during the Materiel Solution Analysis (MSA) phase of the Acquisition process, is a key input to the Capability Development Document (CDD), and supports the materiel solution decision at Milestone A. (Sources: DoDI 5000.02 and JCIDS Manual)

BATTLESPACE ANALYSIS

To complete a preliminary design level battlespace analysis, we first consider first defining battlespace depth of fire (DOF) or firepower followed by an engagement analysis. Defining the DOF requires determining for each AMD preliminary design configuration where, how many, and which interceptor variants can reach the target sets. The engagement analysis will tell us which interceptors and variants can successfully engage the targets and how many it will take to achieve the system Pk requirement. The target set is defined by speed, altitude, signature, and other environmental considerations for the battlespace evaluation. The engagement analysis requires the addition of any target defense penetration features that are uniquely intended to defeat the interceptor such as evasive maneuver.

- Boord, Warren J.; Hoffman, John B.. Air and Missile Defense Systems Engineering. CRC Press.

CAPABILITIES BASED ASSESSMENT (CBA)

- A Joint Capabilities Integration and Development System (JCIDS) analytic process. The CBA identifies capability requirements and associated capability gaps. Results of a CBA or other study provide the source material for one or more Initial Capabilities Documents (ICDs), or other JCIDS documents in certain cases when an ICD is not required

- A number of DoDAF views are to be used to capture results of a CBA, facilitating reuse in JCIDS documents, acquisition activities, and capability portfolio management. When one or more studies or analyses are used in place of a CBA, the Sponsor may need to consolidate the data from those studies into a single set of DoDAF products appropriate for the scope of the ICD.

NASA INTEGRATION PROCESS

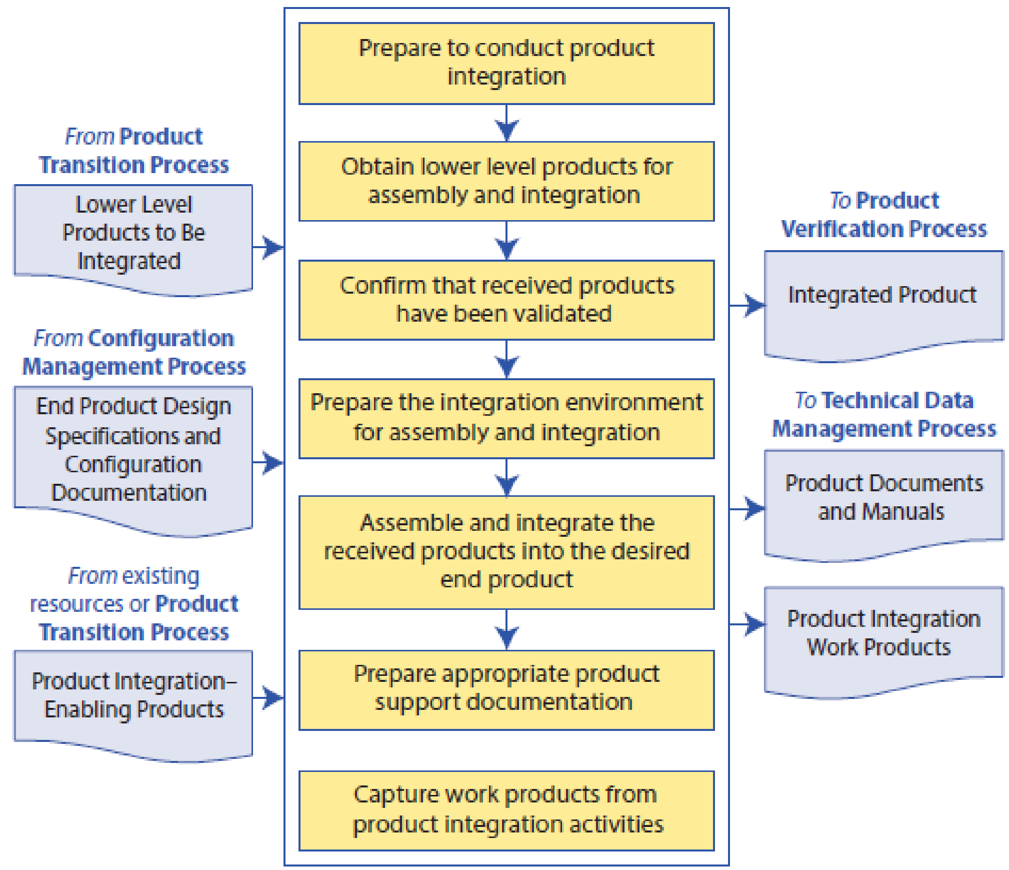


FIGURE 5.2-1 Product Integration Process

-NASA Systems Engineering Handbook

HYPERSONIC INTEGRATION

Systems Integration

- Hypersonic vehicles cannot be designed as isolated parts; the engine, fuselage, and control systems are fully integrated.
- **Engine–airframe integration:** The intake geometry, shock control, and fuselage lift must be harmonized with propulsion needs.
- **Cooling systems:** Fuel is often used as a heat sink (pre-cooling hydrogen or hydrocarbons before combustion).

INTEGRATION

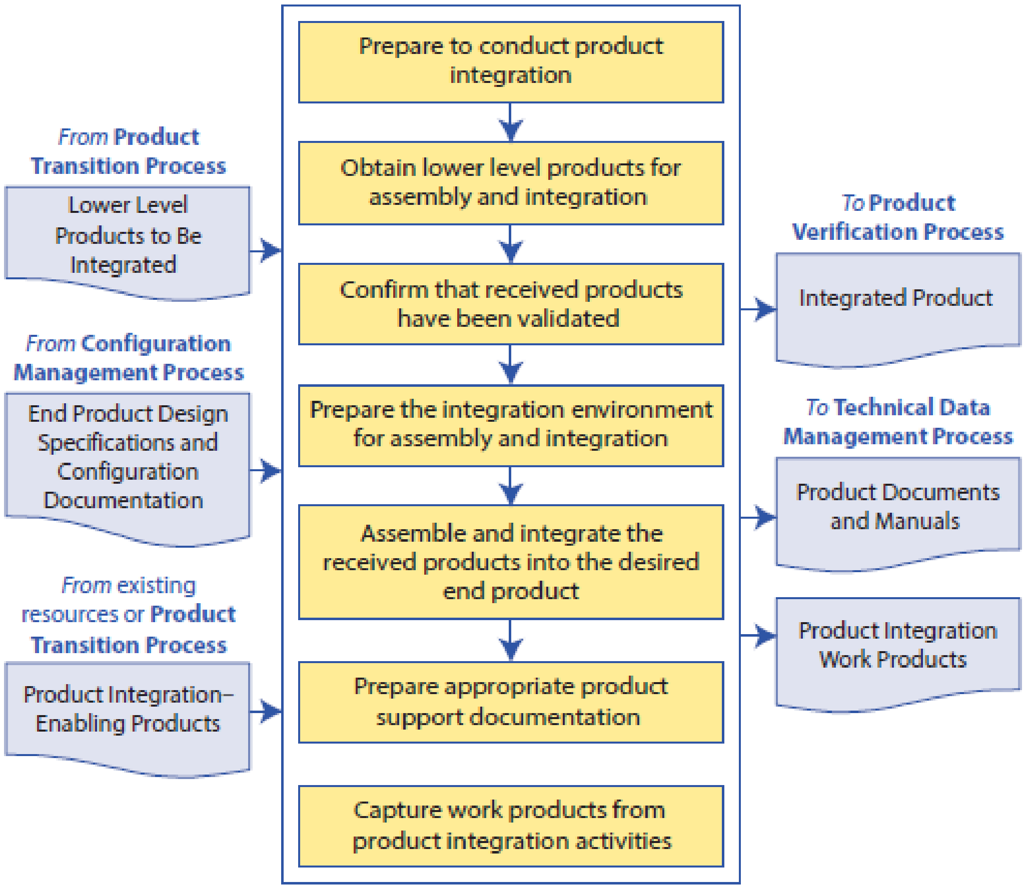
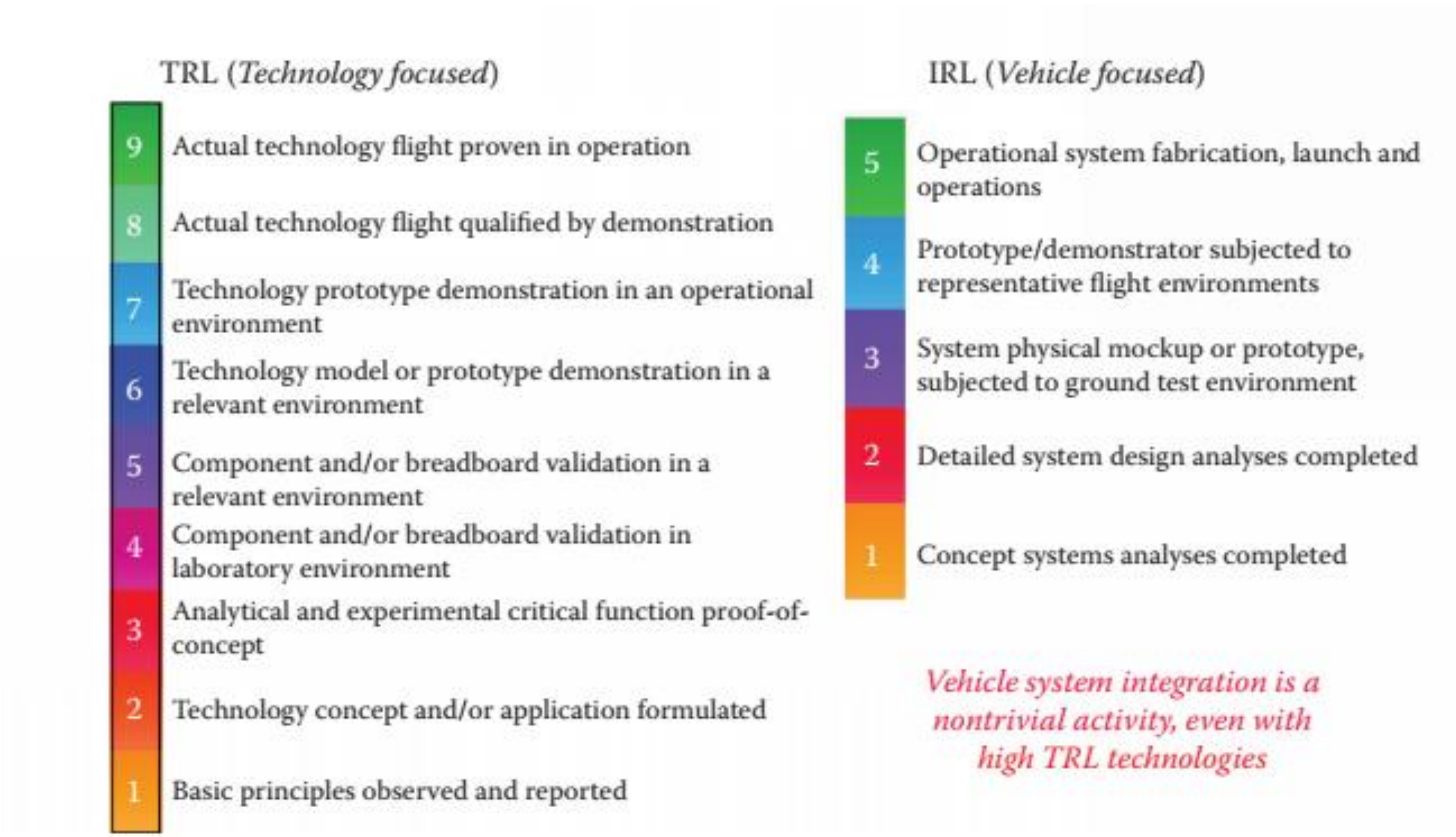


FIGURE 5.2-1 Product Integration Process

NASA TRL



Taylor, Travis S.. Introduction to Rocket Science and Engineering. CRC Press.

INSENSITIVE MUNITIONS

- The term “Insensitive Munitions” (IM) implies that unanticipated stimuli will not produce an explosive yield, in accordance with MIL-STD-2105 (Hazard Assessment Tests for Non-Nuclear Munitions). IM minimizes the probability of inadvertent initiation and the severity of subsequent collateral damage to weapon platforms, logistic systems, and personnel when munitions are subjected to unanticipated stimuli during manufacture, handling, storage, transport, deployment, or disposal, or because of accidents or action by an adversary.
- -DoD Systems Engineering Guidebook

RESOURCES

- **NASA SEMP Guideline**
https://www.nasa.gov/consortium/SystemsEngineeringManagementPlanTechnicalContent
- **SEMP Template**
https://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section8/8_4_2.cfm
- **SeBOK StRS**
- https://www.sebokwiki.org/wiki/Stakeholder_Needs_and_Requirements
- **SRD Example**
- https://wiki.services.eoportal.org/tiki-download_wiki_attachment.php?attId=634
- **SRD Example**
- https://man.fas.org/dod-101/sys/ac/equip/srd_an-alq-172-srda2.htm
- **SDD Template**
- https://www.cs.fsu.edu/~lacher/courses/COP3331/sdd.html
- **NASA SDD Template**
- https://www.its.dot.gov/research_archives/msaa/pdf/MSAA_SystemDesignFINAL.pdf

AI AND HYPERSONICS

Dr. Chuck Easttom, M.Ed, MSDS, MBA, MSSE, Ph.D.[2], D.Sc.

AI Hypersonic News

The Space Development Agency selected California-based EpiSci to develop a software tool capable of detecting hypersonic missiles in flight from satellite data, a challenging task given the extreme speeds of these weapons. https://spacenews.com/ai-company-developing-software-to-detect-hypersonic-missiles-from-space/

The IRIS-T SLM air defense system currently lacks the capability to intercept ballistic and hypersonic missiles. In response, Diehl Defence and Hensoldt have announced plans to integrate artificial intelligence into the system and its radar components. https://missiledefenseadvocacy.org/missile-defense-news/iris-t-slm-vs-hypersonic-missiles-germany-bets-on-ai-in-race-against-ballistic-threats/

AI and Hypersonics

The ability to predict and manage aerothermodynamic effects is crucial for the design of hypersonic vehicles, yet traditional Computational Fluid Dynamics (CFD) simulations require hours or even days of processing time.
However, artificial intelligence (AI) is now transforming this field, enabling engineers to set up and execute high-fidelity CFD simulations in just minutes—a breakthrough that could redefine hypersonic aircraft development.

AI-driven CFD acceleration combines machine learning (ML), neural networks, and data-driven modeling to drastically reduce simulation setup and run times. One of the most significant improvements comes from AI-powered mesh generation and optimization. Traditionally, engineers manually create and refine computational meshes, a process that can take hours. AI can now automate this step by analyzing flow conditions and generating high-quality meshes in seconds, reducing errors and improving simulation accuracy.

- https://idstch.com/space/ai-driven-hypersonic-aerothermodynamics-revolutionizing-high-speed-flight-with-cfd/