# Systems Engineering of Autonomy

## Aligning Autonomy to Customers and Technology

July 2020


Michael Woudenberg – MFC OA Autonomy Lead

Jerry Franke – LM ATL Fellow – MUMT Lead

Matt Dorsey – MFC OA Autonomy Analyst

Mark Waltensperger – MFC OA MUMT Lead

Troy Shideler – CETO MUMT Lead

Kevin Schlosser – RMS Engineering Fellow


**Disclaimer:** The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of any agency of the U.S. government. Examples of analysis performed within this article are only examples. Assumptions made within the analysis are not reflective of the position of any U.S. government entity.

LOCKHEED MARTIN




PIRA: CET202005003

# Purpose

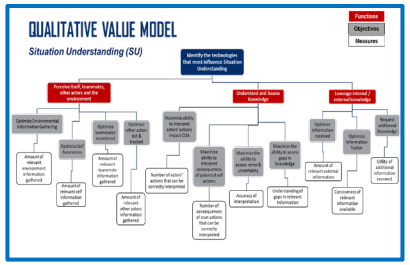
This presentation articulates three primary concepts:

1. Conceptualization of autonomy
2. Analysis frameworks for autonomy
3. Solving systems lifecycle design issues

LM Autonomy:
- Concept
- Analysis
- Design

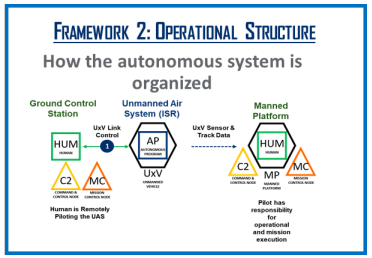
# Conceptualizing Autonomy

# Aligning from Customer to Technology



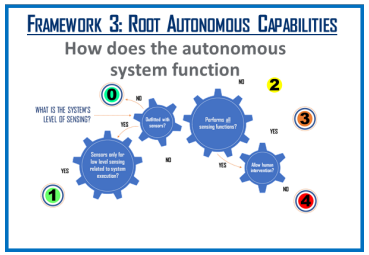

**Customer Needs**
- Defining value

- System Performance
- System Cost
- Tactics Techniques & Procedures




**System Architecture**
- Capturing Opportunities

- Architecting to maximize value
- Modeling Performance
- Defining System Relationships




**Autonomy Determination**
- Derived from Needs and Architecture

- Identifying Autonomy Gradient
- Trade Space for Autonomy
- Identifying Enabling Technology

Ability to align customer need with enabling technology

Sense and Perception | Higher Level Reasoning (Situational Understanding) | Battle Management | Theory of Mind | Human System Integration | Communications Management

Trust and Reliability

Learning Algorithms

**Enabling Technology**
- Aligning Research and Investment

- Balancing Solution TRL
- Identifying Discriminators
- Informing Future Investment

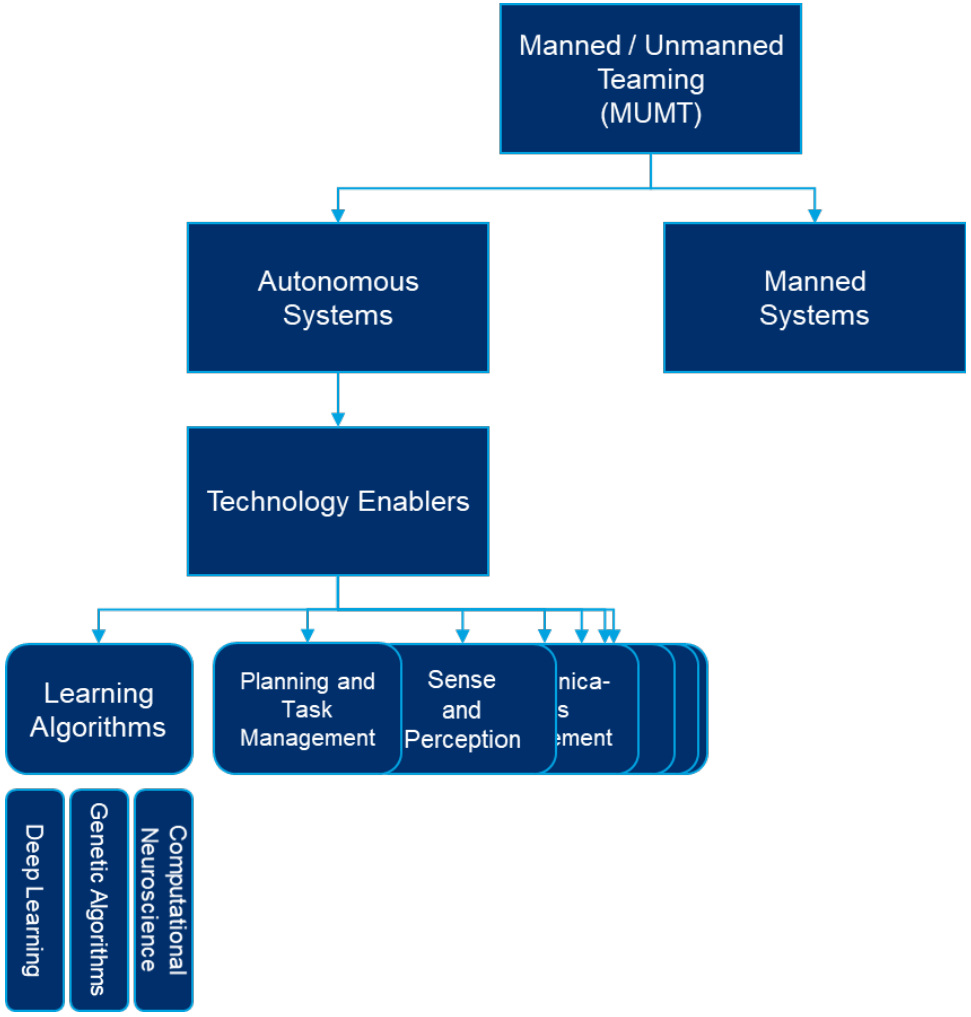
# Lockheed Martin Autonomy Baseline

- For the sake of the solutions that Lockheed Martin develops for the customer an autonomous system is:

  **A system that composes, selects, and executes decisions with varying levels of human influence.**

  - **Autonomous systems can be characterized by systems "in motion" where autonomous actions control the movement of mechanical systems, and systems "at rest" where autonomous actions do not include physical movements.**

- Autonomous Systems are integrated into Manned / Unmanned Teaming(MUMT) environments and are supported by technology enablers
  - Technologies like Artificial Intelligence (AI) are enablers for autonomy to improve teaming with humans



# Autonomy is an Enabler

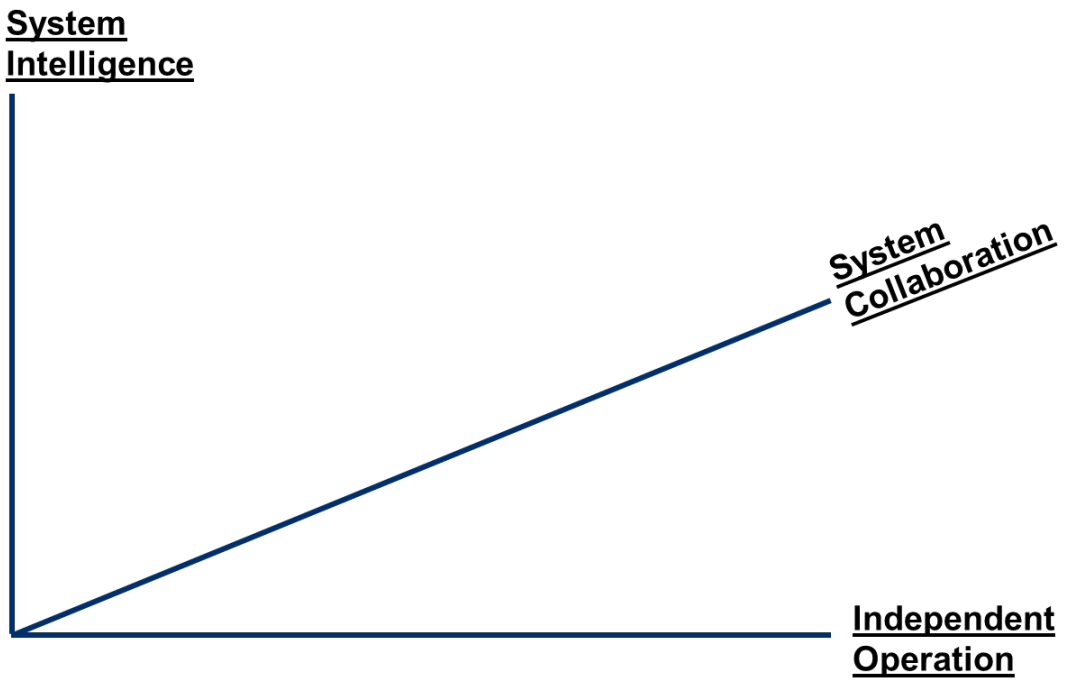
- **Too often we focus on autonomy as the end state of a technology**
  - Focuses on autonomy as the goal
  - Overlooks simpler, less costly solutions
  - Difficult to develop, test and ensure trust

- **Autonomy is, instead, an enabler to improve systems performance**
  - Improves manned/ unmanned teaming
  - Support machine augmentation of human processes
  - Quickly respond to customer needs
  - Establish intelligent trade spaces for innovation
  - Leverage existing technologies to meet today's needs

AUTONOMY ENABLES IMPROVED PERFORMANCE AND CAPABILITIES

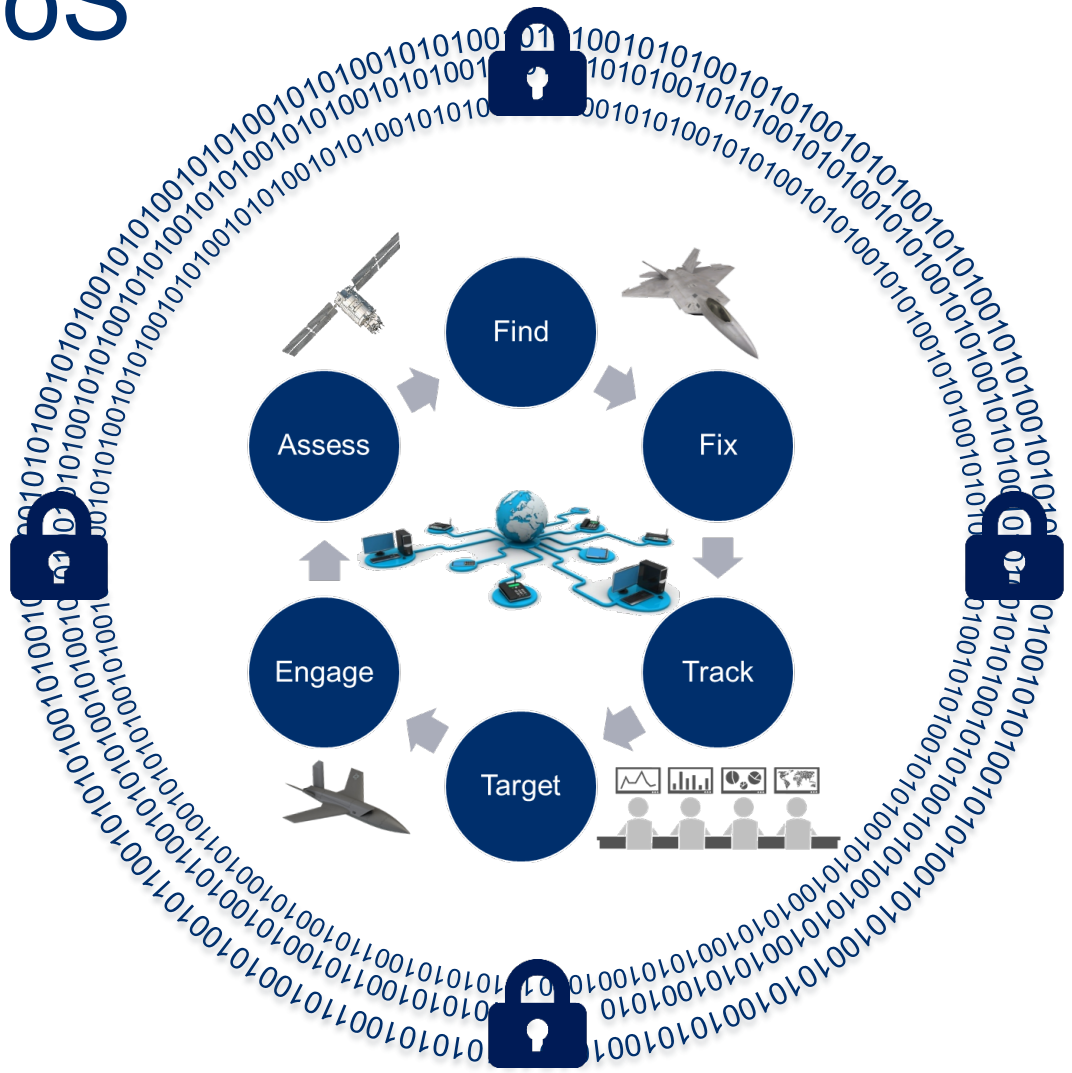
# 3 Dimensions of Autonomy

- Autonomous Systems are mapped with three axes
  - **System Intelligence:** Degree to which a system has intelligence
    - Enables a system to perform complex computations and behaviors aligned with cognitive science
    - Captures what is referred to as Artificial Intelligence (AI)
    - Also includes technologies like Machine Learning (ML)
  - **Independent Operation:** Degree to which a system relies on human interaction
    - Measures separation of human involvement from systems performance
    - Can include automated, rules based systems
  - **System Collaboration:** Degree to which a system partners with humans and other systems
    - Identifies the Manned-Unmanned Teaming (MUMT) behavior considerations
    - Identifies the inter-relationships between systems and within a systems of systems (SoS) view



# Applying Autonomy to the SoS

- Autonomy benefits are achieved across a Systems of Systems Approach (SoS)
  - **Entity Design:** Making a system smarter
    - Networked, collaborative
    - Improved AI
    - Discrete and encapsulated R&D environment
  - **Integrated System:** Collapsing the kill chain
    - Highly complex AI enabled mission planning
    - Integrating the kill chain from detection through mission planning to weapon engagement
    - Reusable, adaptable, updatable, scaleable
  - **System Security:** Protect and Assure
    - Real-time monitoring and resilient security of autonomous systems
    - AI based cyber defense
    - Improved trust in system integrity
  - **Infrastructure:** Discriminators across the Enterprise
    - The same Entity, Integrated System and Security approach can be applied to development and manufacturing environments
    - Able to produce products with higher quality and faster rates with reduced cost

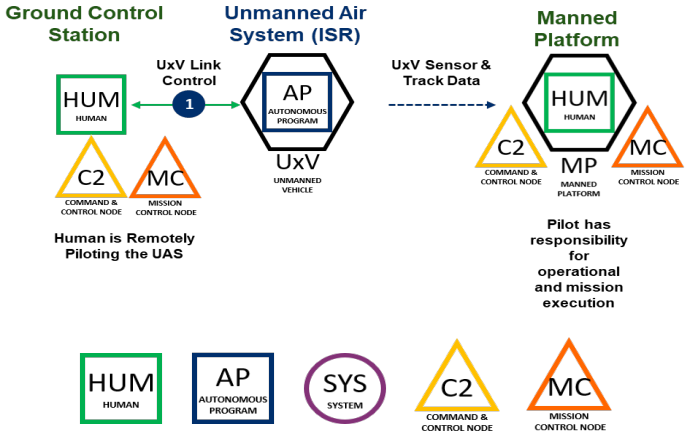


# Analyzing Autonomy

# LM Autonomy Frameworks

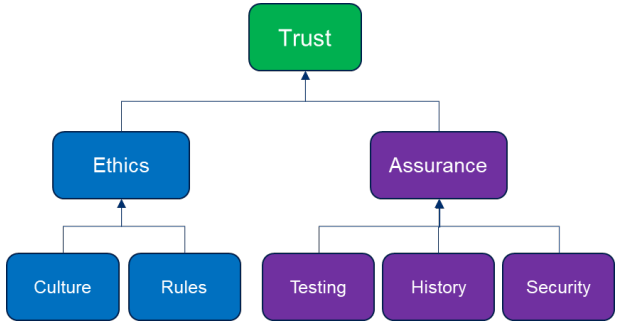
## Operational Configuration Framework

Visually represent how the system is organized



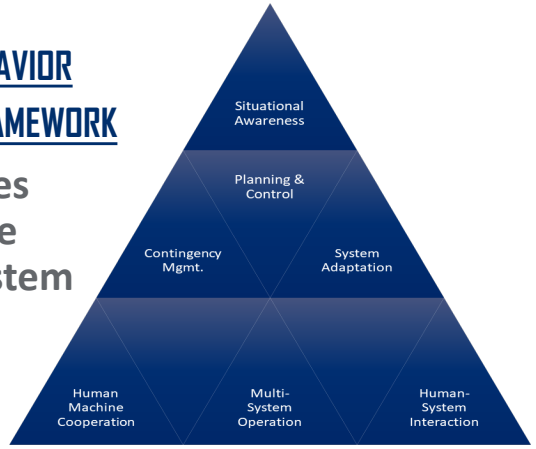

## Trust Framework (in process)

Ethics and Assurance considerations of autonomous systems




## Autonomous Behavior Characteristics Framework

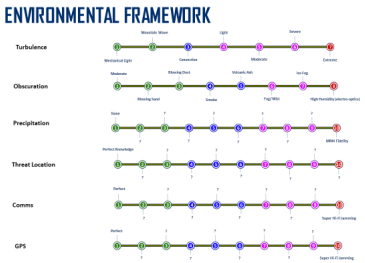
List capabilities organic to the autonomous system




***A family of frameworks now exists!***

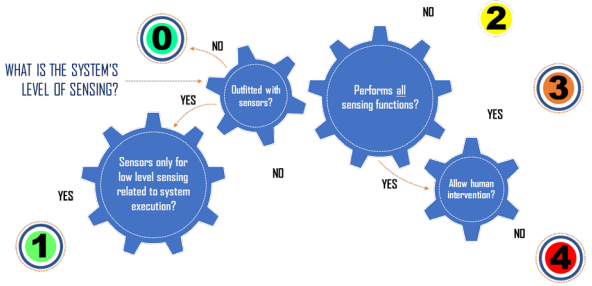
## Environmental Framework (in process)

In what context does the system operate?



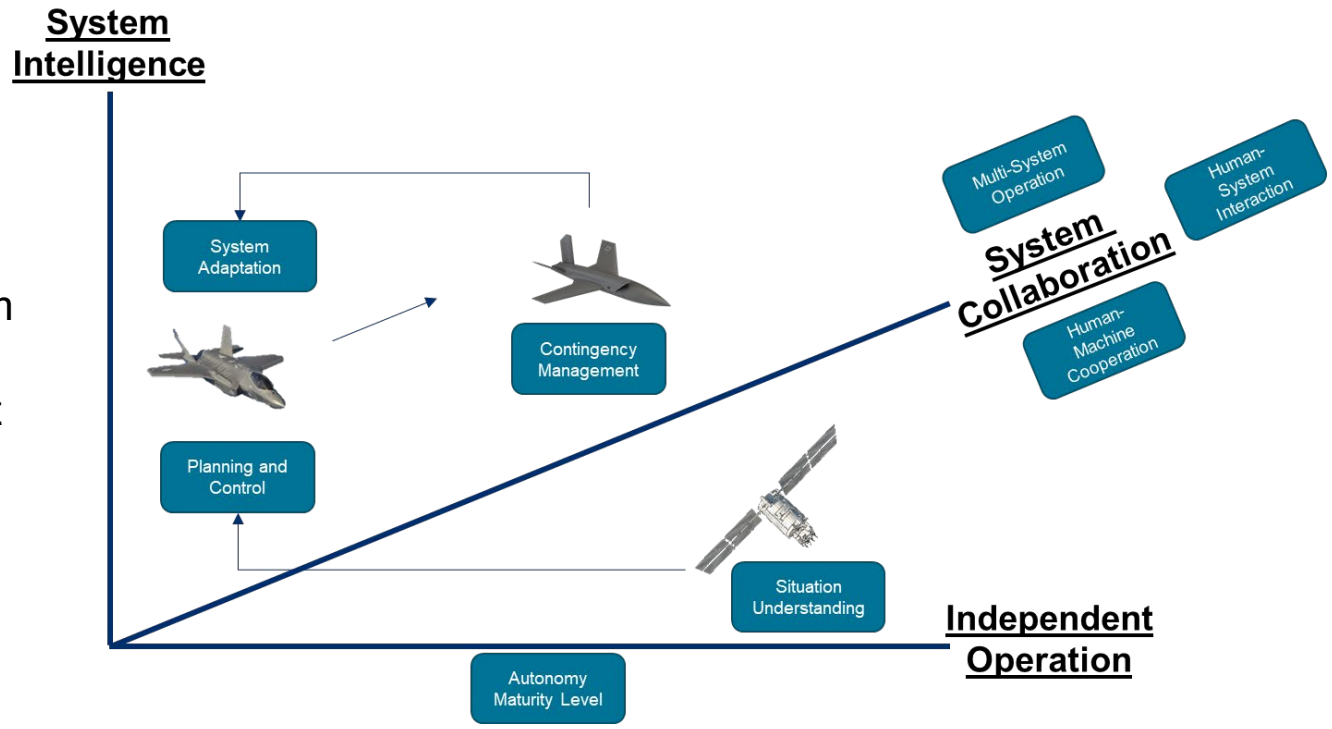

## Root Autonomous Capabilities Framework

Make the system function



# 3 Dimensions with Autonomous Behavior Characteristics

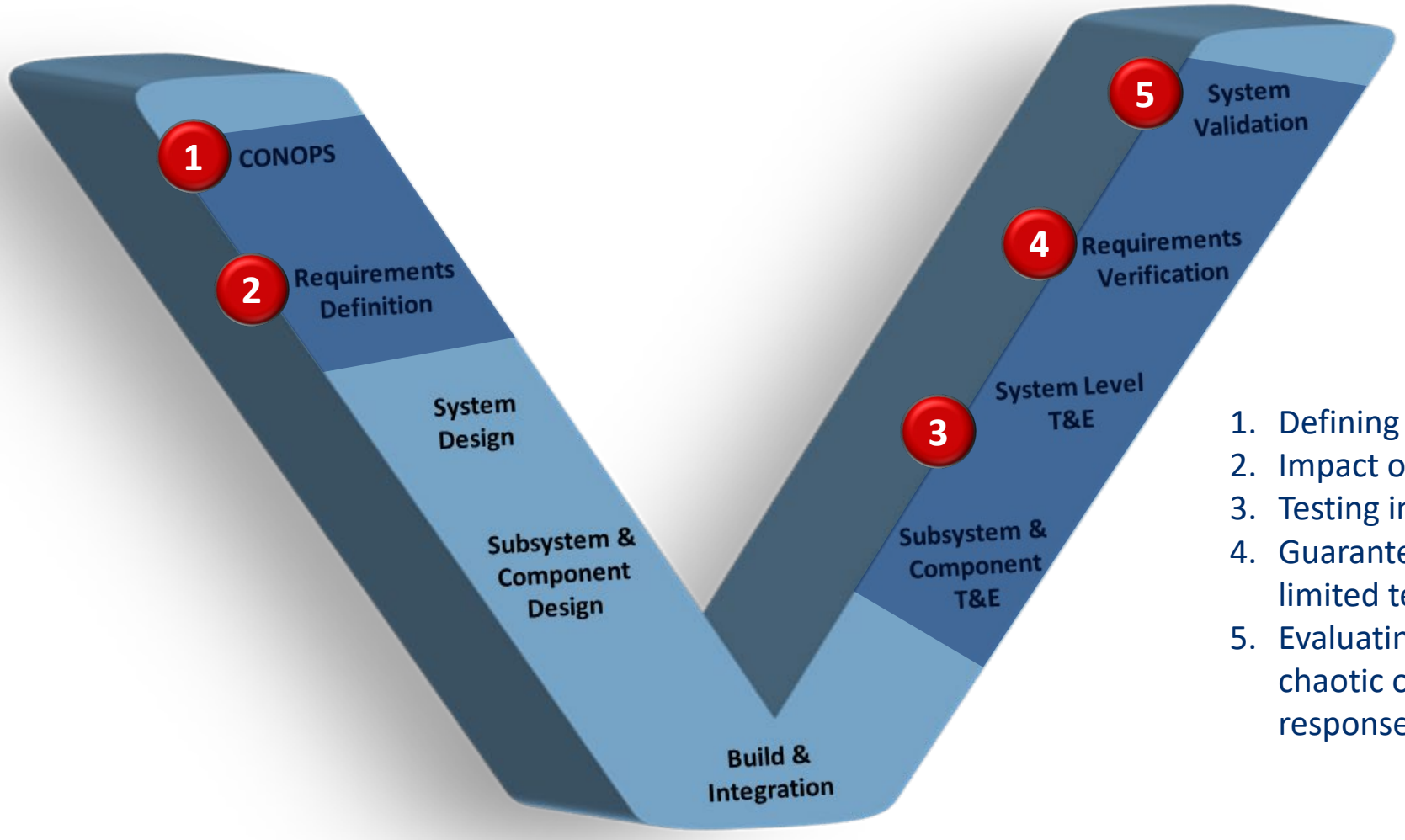
- A system can inherit or incorporate different levels of autonomy from integrated sub-systems
  - A Sensor can achieve Situation Understanding as part of a network of sensors
  - Situation Understanding can be passed to a Planning and Control (mission planning) system
  - A cruise missile can be provided Planning and Control and execute Contingency Management
  - As the cruise missiles engage, based on Contingency Management that can provide feedback for System Adaptation
  - The networked sensors provide updated feedback to the Planning and Control along with the cruise missile feedback enabling System Adaptation




Maximizing Autonomy Performance through Collaboration

# Designing Autonomy

# Autonomy Introduces 5 Key Challenges for Design




1. Defining requirements
2. Impact of system design
3. Testing in infinite state space
4. Guarantee of safety with limited testing
5. Evaluating test results give chaotic or non-deterministic responses

# Lockheed Research Focus Areas

**MUMT**

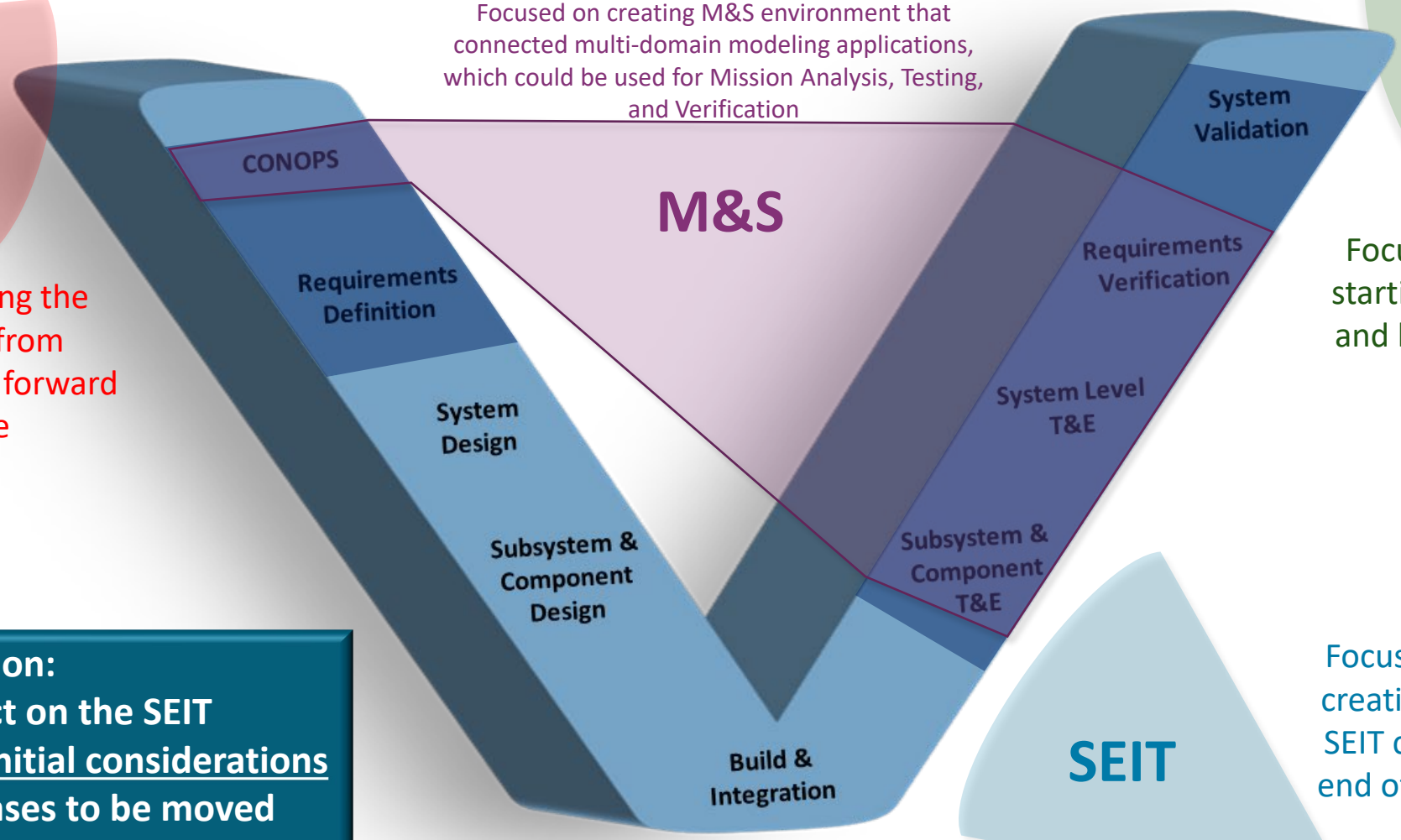
Focused on modeling the mission, starting from CONOPS and looking forward in the lifecycle

Focused on creating M&S environment that connected multi-domain modeling applications, which could be used for Mission Analysis, Testing, and Verification

**M&S**

**MV&V**

Focused on V&V solutions, starting from end of lifecycle and looking backward in the lifecycle




**Collective Conclusion:**
**Autonomy's impact on the SEIT lifecycle requires initial considerations for all lifecycle phases to be moved left, *before* System Design**

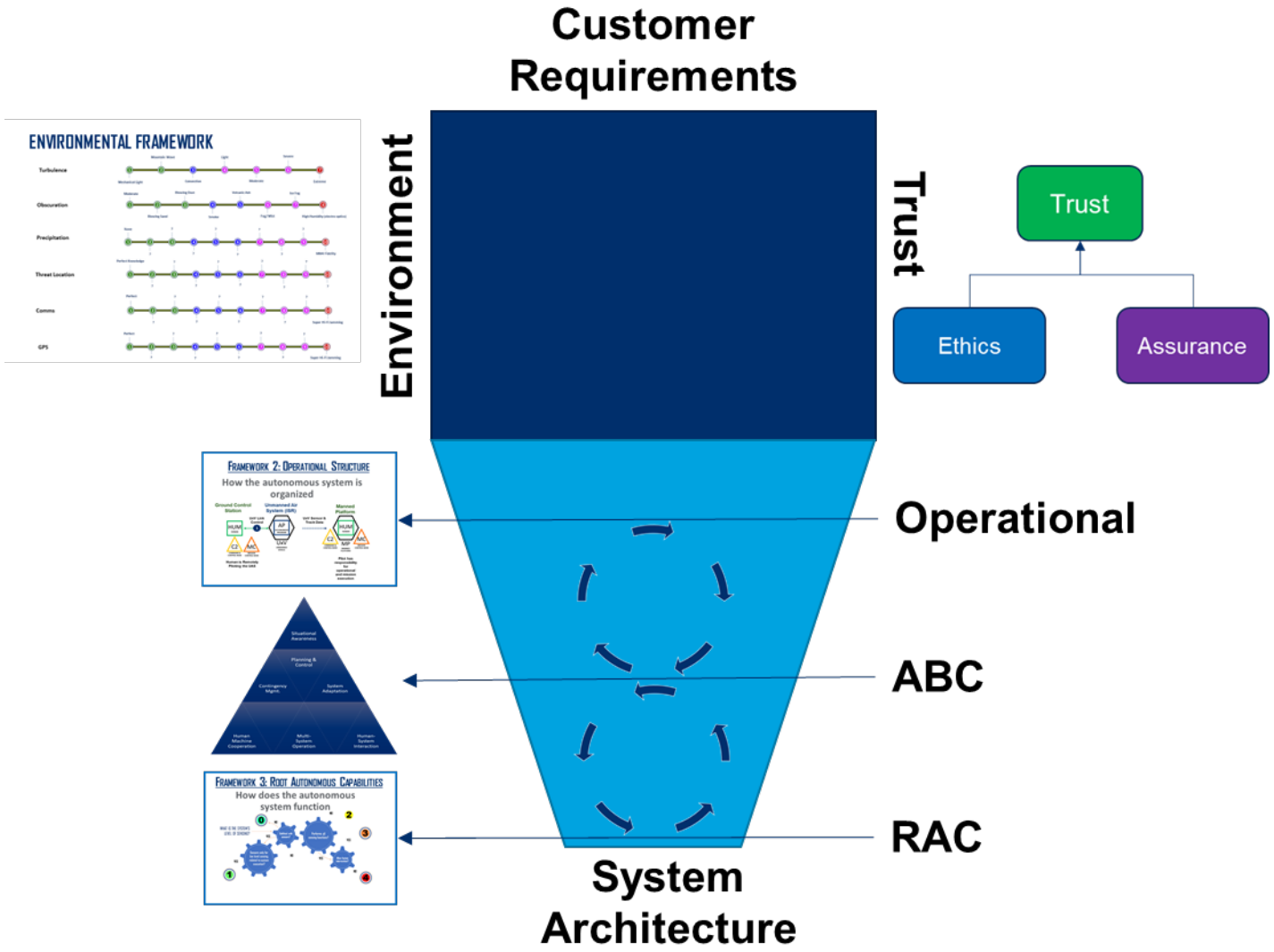
**SEIT**

Focused on full SEIT lifecycle, creating continuous thread of SEIT capabilities from start to end of lifecycle (which include MUMT & V&V)

1. Defining requirements

# Autonomy Systems Architecture Dev.

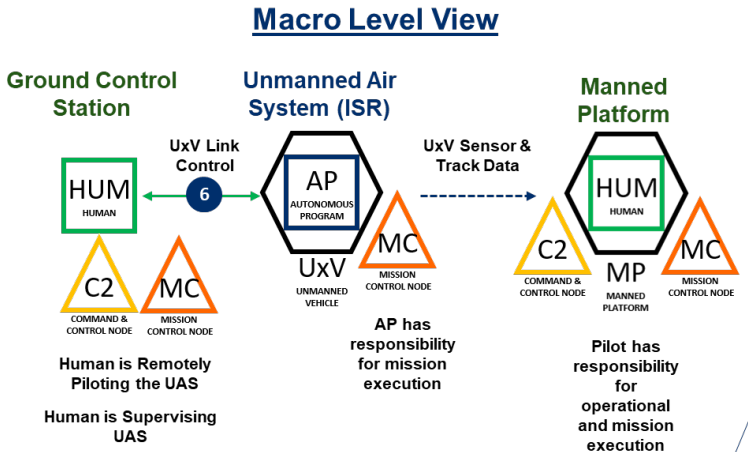
- Applying the frameworks against a customer requirement enables a multi-faceted analysis of the design space
- Environmental and Trust Frameworks bracket the initial design space
- Behavioral, Operational and Root Autonomous Capabilities Frameworks provide trade space considerations for systems architecture

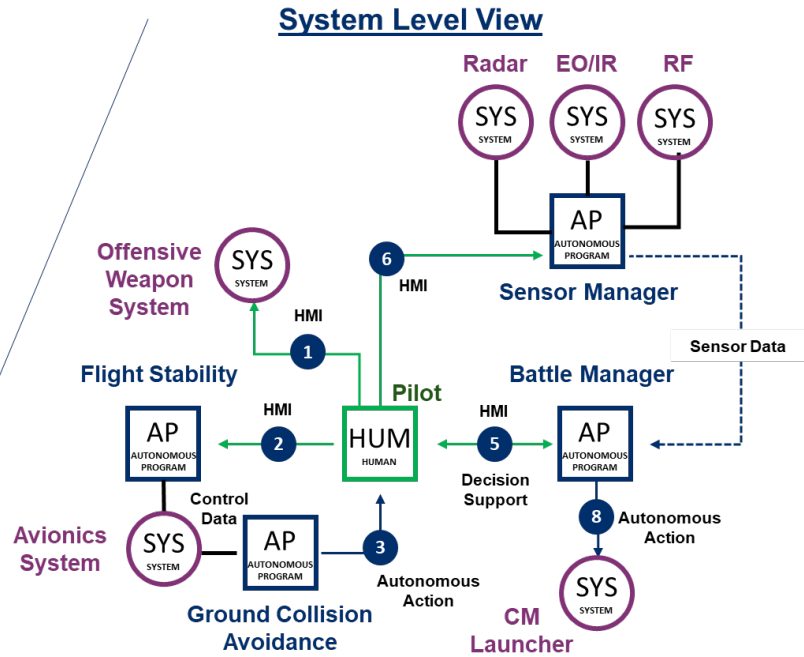


1. Defining requirements

# Autonomy Systems Architecture Dev

- Development of the Operational Framework provides the foundation for the identification of:
  - Root Autonomous Capabilities
  - Enabling Technology
- The Operational Framework is also used to begin developing a Modeling and Simulation environment to quantify testable architecture designs.

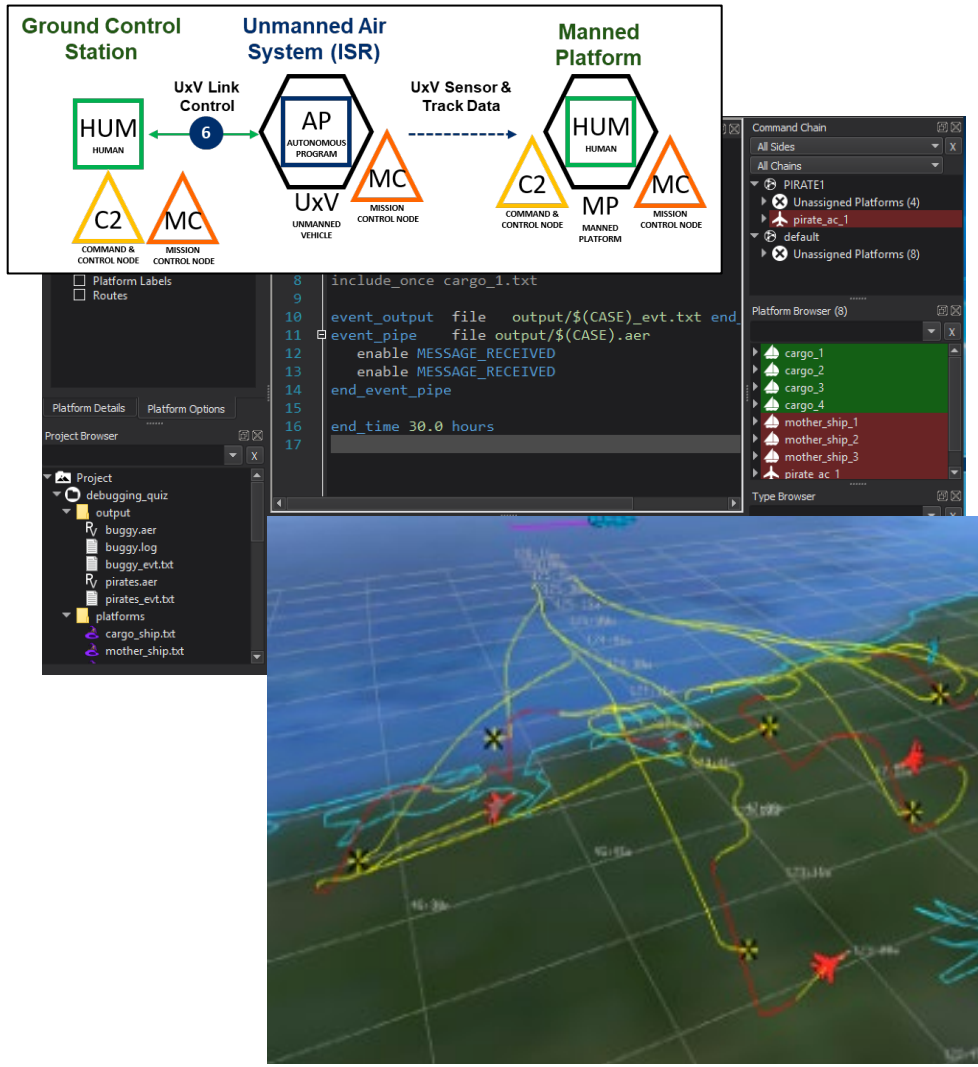


1. Defining requirements

# Autonomy Systems Architecture Modeling

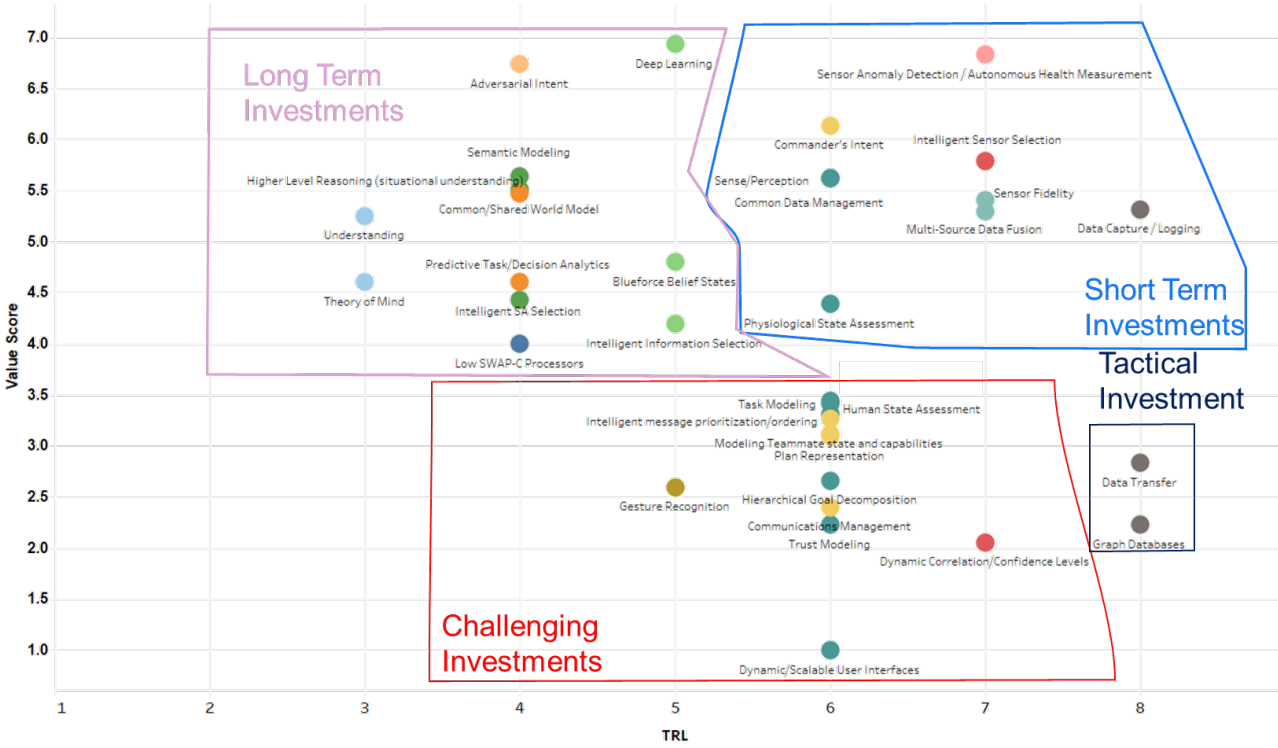
- Leveraging the Operational Framework architecture provides a strong foundation to begin modeling and simulation of the design.
  - Autonomous Behavior Characteristics levels provide frameworks to develop a Design of Experiments
  - Trades between environment, trust and architecture can be quantified
  - Modeling of enabling technology can validate design assumptions
- Proactive V&V engagement in the modeling and simulation environment informs subsequent detailed design and verification and validation



1. Defining requirements

# Autonomy Systems Architecture Dev.

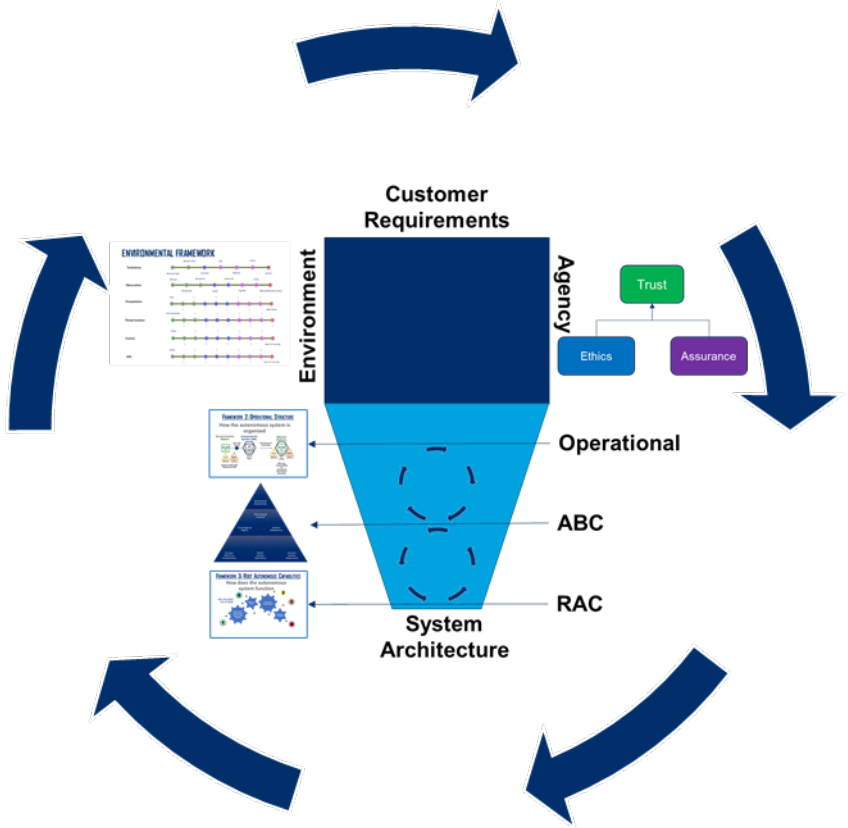
- Architecting from customer requirements to enabling technology requires the understanding of the value and technology readiness level (TRL)
  - Lockheed Martin developed a Value Focused Thinking analysis of enabling technology:
    - Independent Operations
    - Situation Understanding
    - Planning and Control
    - Contingency Management
    - Multi-System Operations
    - Human – Machine Cooperation
    - Human – System Interaction
  - These enabling technologies were then binned by TRL and value impact
    - Enables balancing TRL
    - Identifying discriminators
    - Informing future investment



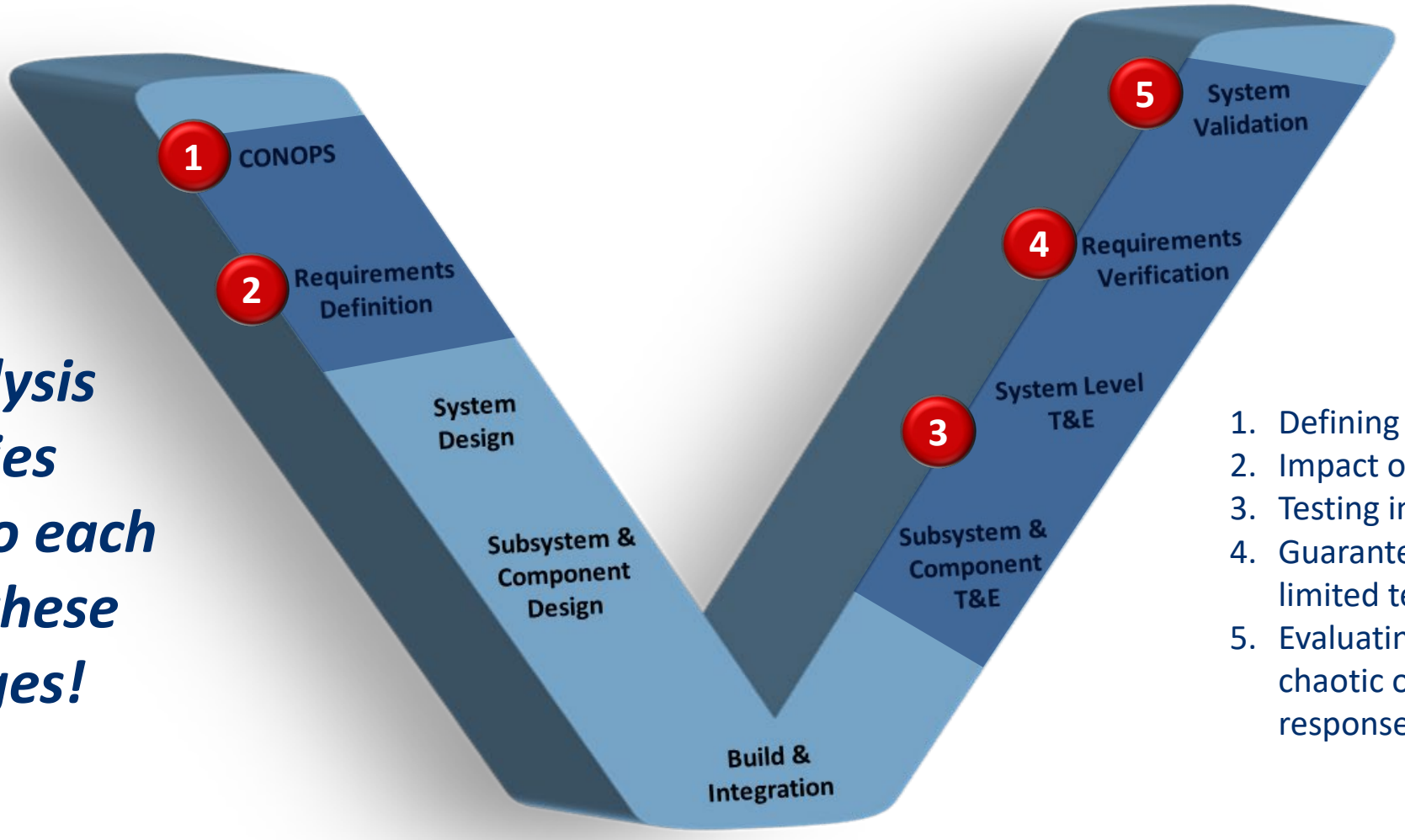
1. Defining requirements

# Autonomy Systems Architecture Iterations

- The Autonomy Systems Architecture frameworks are designed to be an iterative approach.
  - Customer requirements, Trust and Environment provide trade space dimensions
  - The Autonomy Behavior Characteristics, Operational Framework, and Enabling Technologies provide design opportunities
  - Modeling of the architectures against the requirements, environment and trust provide feedback for
- Multiple iterations are expected to trade within these frameworks to best balance customer expectations, schedule, scope, and budget of systems designs.



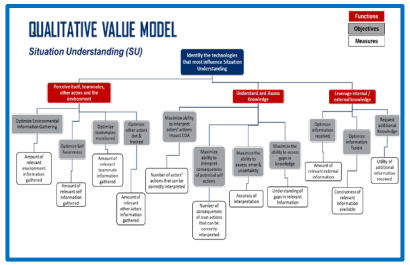
# Identified Solutions to the 5 Key Challenges




***The analysis identifies solutions to each of these these challenges!***

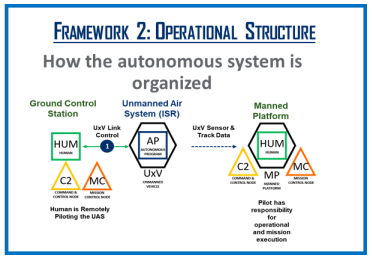
1. Defining requirements
2. Impact of system design
3. Testing in infinite state space
4. Guarantee of safety with limited testing
5. Evaluating test results give chaotic or non-deterministic responses

# Aligning from Customer to Technology



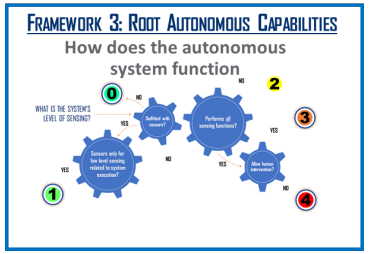

**Customer Needs**
- Defining value

- System Performance
- System Cost
- Tactics Techniques & Procedures




**System Architecture**
- Capturing Opportunities

- Architecting to maximize value
- Modeling Performance
- Defining System Relationships




**Autonomy Determination**
- Derived from Needs and Architecture

- Identifying Autonomy Gradient
- Trade Space for Autonomy
- Identifying Enabling Technology

Ability to align customer need with enabling technology

Sense and Perception | Higher Level Reasoning (Situational Understanding) | Battle Management | Theory of Mind | Human System Integration | Communications Management

Trust and Reliability

Learning Algorithms

**Enabling Technology**
- Aligning Research and Investment

- Balancing Solution TRL
- Identifying Discriminators
- Informing Future Investment