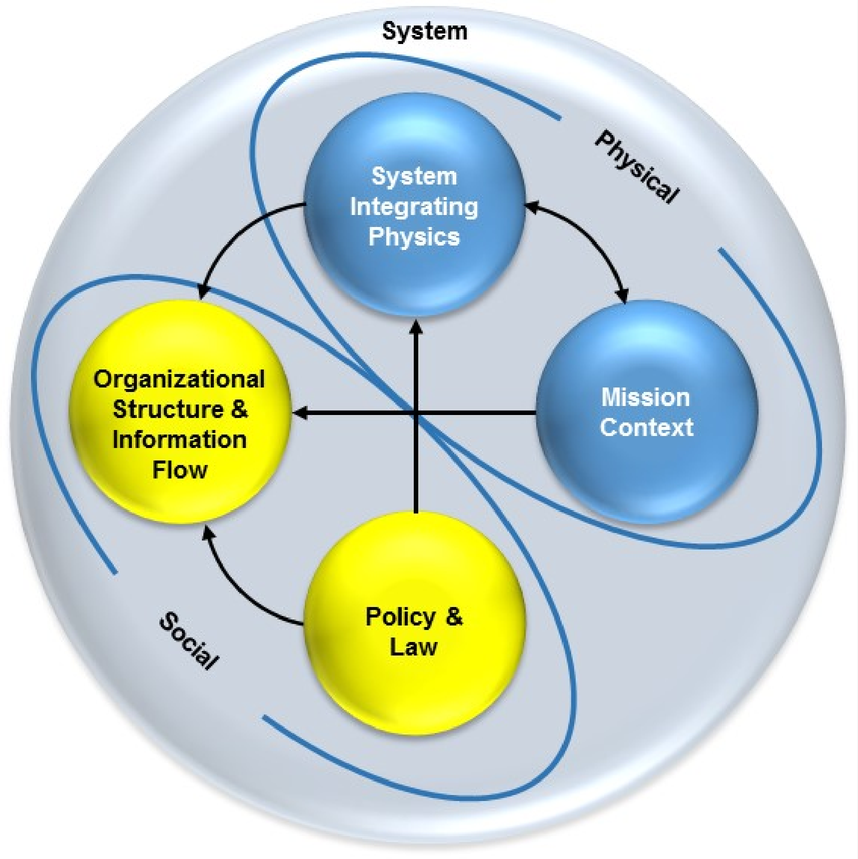
# Understanding Systems Engineering

- **Definition – System Engineering is the engineering discipline which integrates the system functions, system environment, and the engineering disciplines necessary to produce and/or operate an elegant system.**
  - Elegant System - A system that is robust in application, fully meeting specified and adumbrated intent, is well structured, and is graceful in operation.

- **Primary Focus**
  - System Design and Integration
    - Identify system couplings and interactions
    - Identify system uncertainties and sensitivities
    - Identify emergent properties
    - Manage the effectiveness of the system
  - Engineering Discipline Integration
    - Manage flow of information for system development and/or operations
    - Maintain system activities within budget and schedule

- **Supporting Activities**
  - Process application and execution



# Systems Engineering Postulates

| |
|---|
| System Integration (physical/logical system) |
| Discipline Integration (social system) |
| Both System and Discipline Integration |

- **Postulate 1: Systems Engineering is product and environment specific, and context dependent.**
- **Postulate 2: The Systems Engineering domain consists of subsystems, their interactions among themselves, and their interactions with the system environment**
- **Postulate 3: The function of Systems Engineering is to integrate engineering disciplines in an elegant manner**
- **Postulate 4: Systems engineering influences and is influenced by organizational structure and culture**
- **Postulate 5: Systems engineering influences and is influenced by budget, schedule, policy, and law**
- **Postulate 6: Systems engineering spans the entire system life-cycle**
- **Postulate 7: Understanding of the system evolves as the system development or operation progresses**
  - Postulate 7 Corollary: Understanding of the system degrades during operations if system understanding is not maintained.

# Systems Engineering Principles

- **Principle 1: Systems engineering integrates the system and the disciplines considering the budget and schedule constraints**

- **Principle 2: Complex Systems build Complex Systems**

- **Principle 3: The focus of systems engineering during the development phase is a progressively deeper understanding of the interactions, sensitivities, and behaviors of the system**
  - Sub-Principle 3(a): Requirements and models reflect the understanding of the system
  - Sub-Principle 3(b): Requirements are specific, agreed to preferences by the developing organization
  - Sub-Principle 3(c): Requirements and design are progressively defined as the development progresses
  - Sub-Principle 3(d): Hierarchical structures are not sufficient to fully model system interactions and couplings
  - Sub-Principle 3(e): A Product Breakdown Structure (PBS) provides a structure to integrate cost and schedule with system functions

- **Principle 4: Systems engineering spans the entire system life-cycle**
  - Sub-Principle 4(a): Systems engineering obtains an understanding of the system
  - Sub-Principle 4(b): Systems engineering models the system
  - Sub-Principle 4(c): Systems engineering designs and analyzes the system
  - Sub-Principle 4(d): Systems engineering tests the system
  - Sub-Principle 4(e): Systems engineering has an essential role in the assembly and manufacturing of the system
  - Sub-Principle 4(f): Systems engineering has an essential role during operations and decommissioning

# Systems Engineering Principles

- **Principle 5: Systems engineering is based on a middle range set of theories**
  - Sub-Principle 5(a): Systems engineering has a technical basis specific to the system
  - Sub-Principle 5(b): Systems engineering has a mathematical basis
    - Systems Theory Basis
    - Decision & Value Theory Basis (Decision Theory and Value Modeling Theory)
    - Model Basis
    - State Basis (System State Variables)
    - Goal Basis (Value Modeling Theory)
    - Control Basis (Control Theory)
    - Knowledge Basis (Information Theory)
    - Predictive Basis (Statistics and Probability)
  - Sub-Principle 5(c): Systems engineering has a sociological basis specific to the organization

- **Principle 6: Systems engineering maps and manages the discipline interactions within the organization**

- **Principle 7: Decision quality depends on the coverage of the system knowledge present in the decision-making process**

- **Principle 8: Both Policy and Law must be properly understood to not overly constrain or under constrain the system implementation**

- **Principle 9: Systems engineering decisions are made under uncertainty accounting for risk**

# Systems Engineering Principles

- **Principle 10: Verification is a demonstrated understanding of all the system functions and interactions in the operational environment**
  - Ideally requirements are level and balanced in their representation of system functions and interactions
  - In practice requirements are not balanced in their representation of system functions and interactions
- **Principle 11: Validation is a demonstrated understanding of the system's value to the system stakeholders**
- **Principle 12: Systems engineering solutions are constrained based on the decision timeframe for the system need**

# System Engineering Hypotheses

- **Hypothesis 1: If a solution exists for a specific context, then there exists at least one ideal Systems Engineering solution for that specific context**
  - Hamilton’s Principle shows this for a physical system
    - $\int_{t_1}^{t_2} (\delta T - \delta V + \delta W) dt = 0$
- **Hypothesis 2: System complexity is greater than or equal to the ideal system complexity necessary to fulfill all system outputs**
- **Hypothesis 3: Key Stakeholders preferences can be represented mathematically**
- **Hypothesis 4: The real physical system is the perfect model of the system**
  - Kullback-Liebler Information shows this for ideal information representations of systems
    - $I(f, g) = \int f(x) \log(f(x))\, dx - \int f(x) \log(g(x|\theta))\, dx = 0$

# Consortium

- **Research Process**
  - Multi-disciplinary research group that spans systems engineering areas
  - Selected researchers who are product rather than process focused

- **List of Consortium Members**
  - Air Force Research Laboratory – Wright Patterson, Multidisciplinary Science and Technology Center: Jose A. Camberos, Ph.D., Kirk L. Yerkes, Ph.D.
  - George Washington University: Zoe Szajnfarber, Ph.D.
  - Iowa State University: Christina L. Bloebaum, Ph.D., Michael C. Dorneich, Ph.D.
  - Missouri University of Science & Technology: David Riggins, Ph.D.
  - NASA Langley Research Center: Anna R. McGowan, Ph.D., Peter A. Parker, Ph.D.
  - The University of Alabama in Huntsville: Phillip A. Farrington, Ph.D., Dawn R. Utley, Ph.D., Laird Burns, Ph.D., Paul Collopy, Ph.D., Bryan Mesmer, Ph.D., P. J. Benfield, Ph.D., Wes Colley, Ph.D.
  - Doty Consulting: John Doty, Ph.D.
  - The University of Michigan: Panos Y. Papalambros, Ph.D.
  - Ames Research Center: Peter Berg
  - Glenn Research Center: Karl Vaden

- **Previous Consortium Members**
  - Massachusetts Institute of Technology: Maria C. Yang, Ph.D.
  - The University of Texas, Arlington: Paul Componation, Ph.D.
  - Texas A&M University: Richard Malak, Ph.D.
  - Tri-Vector Corporation: Joey Shelton, Ph.D., Robert S. Ryan, Kenny Mitchell
  - The University of Colorado – Colorado Springs: Stephen B. Johnson, Ph.D.
  - The University of Dayton: John Doty, Ph.D.
  - Stevens Institute of Technology – Dinesh Verma
  - Spaceworks – John Olds (Cost Modeling Statistics)
  - Alabama A&M – Emeka Dunu (Supply Chain Management)
  - George Mason – John Gero (Agent Based Modeling)
  - Oregon State – Irem Tumer (Electrical Power Grid Robustness)
  - Arkansas – David Jensen (Failure Categorization)

~40 graduate students and 5 undergraduate students supported to date