An Intersection of Needs, Trends, and Methods in Cyber-Physical Systems Engineering

Department of Industrial and Systems Engineering &
Engineering Management

Dr. Dale Thomas, Professor & Eminent Scholar

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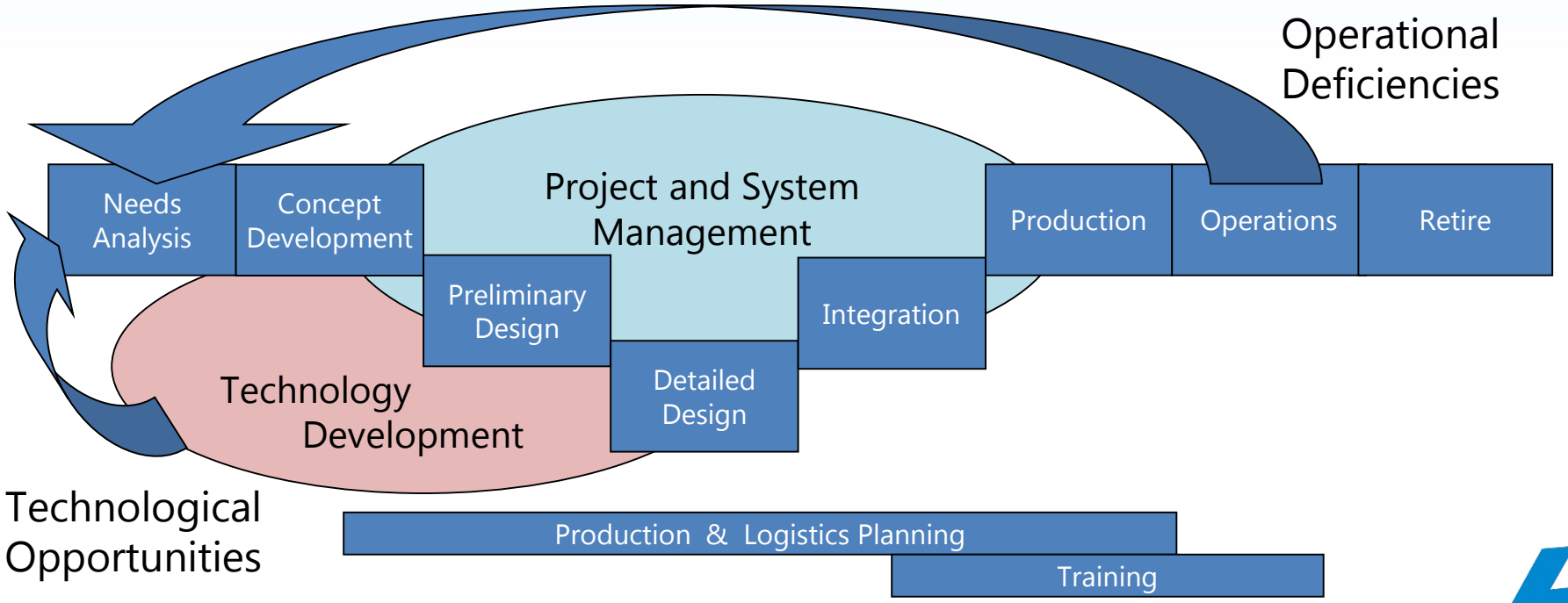
Bottom Line up Front

- UAH in unique position to leverage emergent systems engineering methodologies to achieve quantum breakthroughs in the rapid development of complex cyber-physical systems utilizing advanced technologies within predictable budgets.

The Starting Point

- Successful system developments are a marriage of technological opportunity and operational deficiency.



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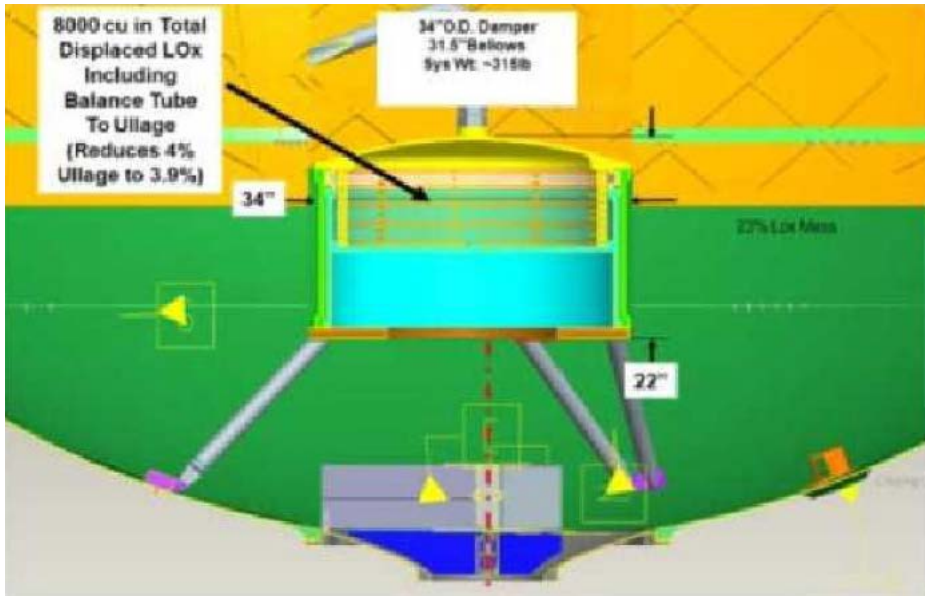
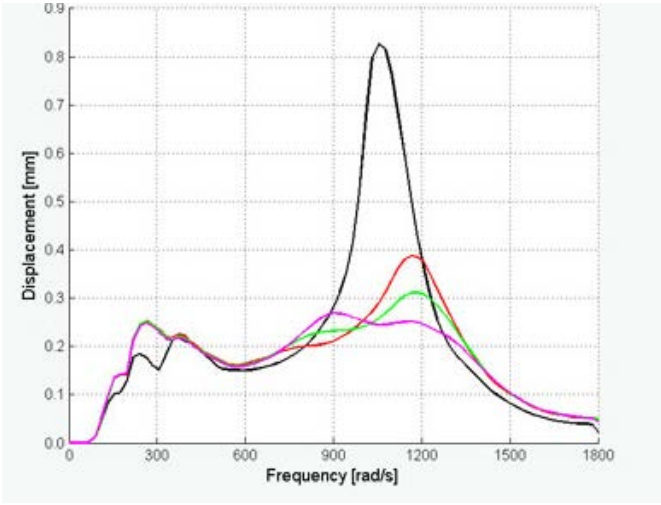
Technological Opportunity

- A fluid-structure coupling device was developed during NASA's Constellation Program to mitigate vibrations in the Orion crew cabin caused by thrust oscillation near the end of first stage propellant burnout.

(ref: Morring, 2013)





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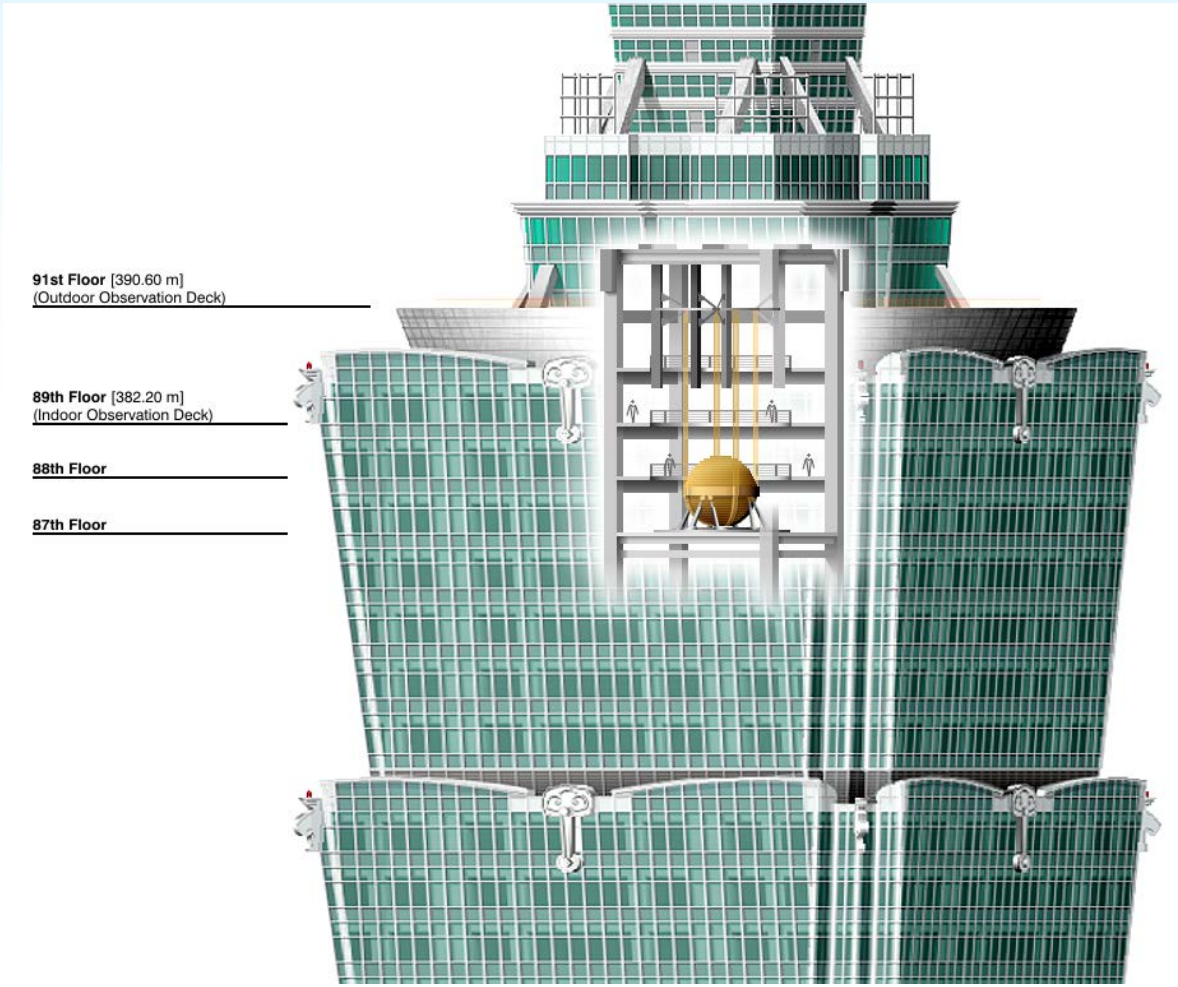
Operational Deficiency – Structural Vibration in Skyscrapers



- Forces acting on a structure, such as wind or earthquake, can cause a structural resonance resonance that may be destructive.
  - Recall Verrazano Narrow's bridge.
- Tuned mass dampers employed to control structural vibrations.

(ref: Wikipedia)

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Successful Technology Infusion

- "Tower B2 at Pacific Park, in Brooklyn, New York, is the first commercial property to have this new DTM installed. The decision came after the engineering firm Thornton Tomasetti made a site visit to Marshall to view the building test."

  (ref: Pierce, 2016)

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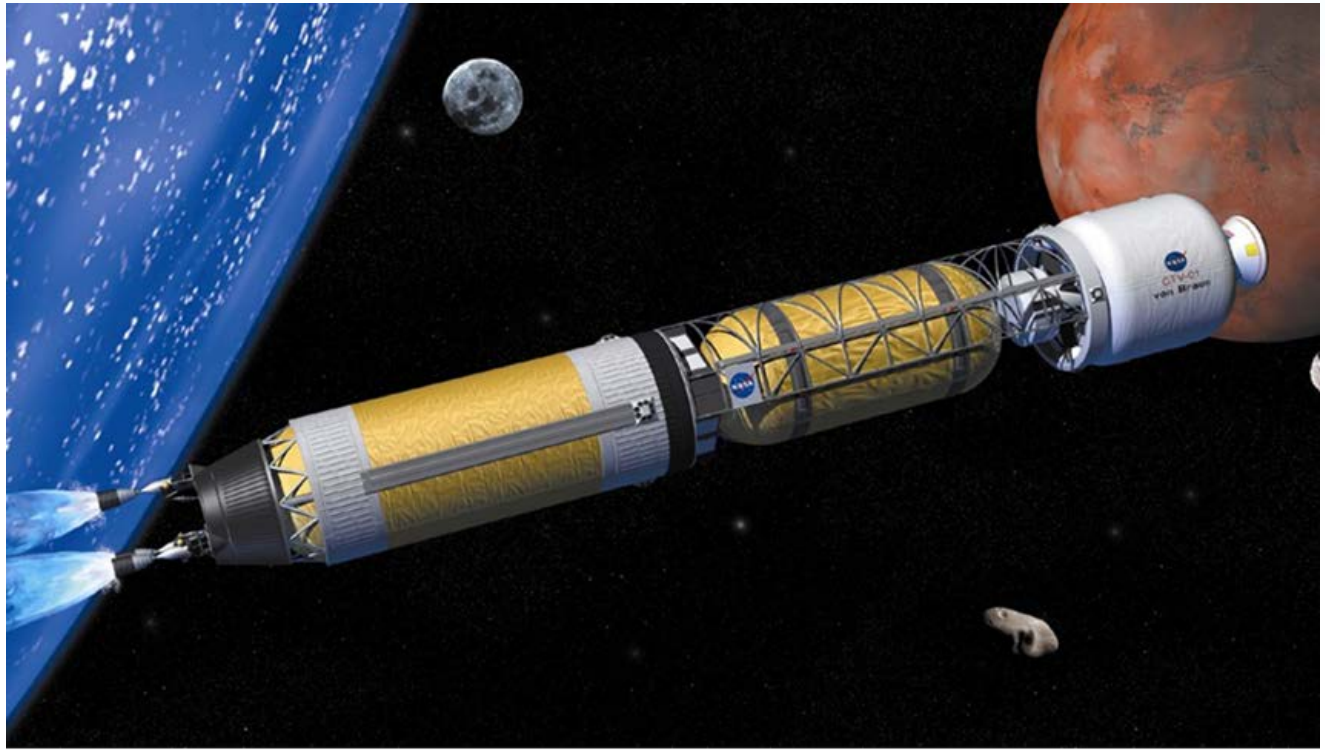
An Operational Deficiency

- Mission plans for a Human Mission to the Planet Mars require 9-12 months transit one-way, leading to a 3 year mission round trip.



Deficiency: envisioned in-space transportation vehicles one-way transit time to Mars is **9-12 months**. Need transit time in **weeks.**

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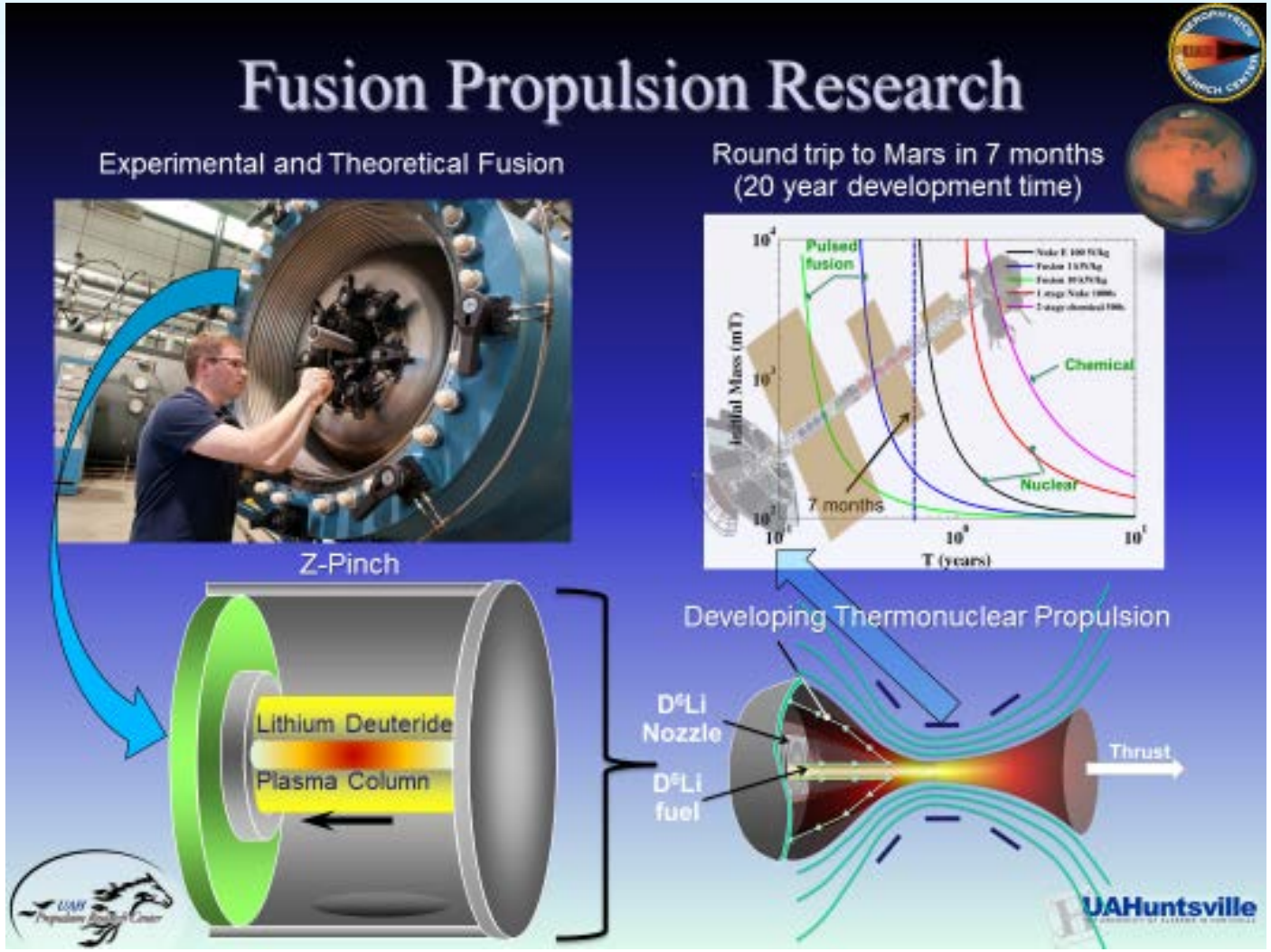
A Technological Opportunity



- Human missions to Mars are not planned until the mid-30s. Fusion propulsion looks like a magic bullet solution.
- So why is fusion propulsion not in NASA's propulsion system trade space for Mars missions?

(ref: Cassibry, et.al., 2015)

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A Tale of Two Spacecraft

- Originally projected to cost $500M, the Hubble Space Telescope (HST) cost $1.5B to launch
  - Originally planned to launch in 1983, it launched in 1990

- Originally projected to cost $1.1B, the Chandra X-ray Observatory cost $1.1B to launch
  - Originally planned to launch in December 1998, it launched in July 1999

(ref: Hefner, 2004)

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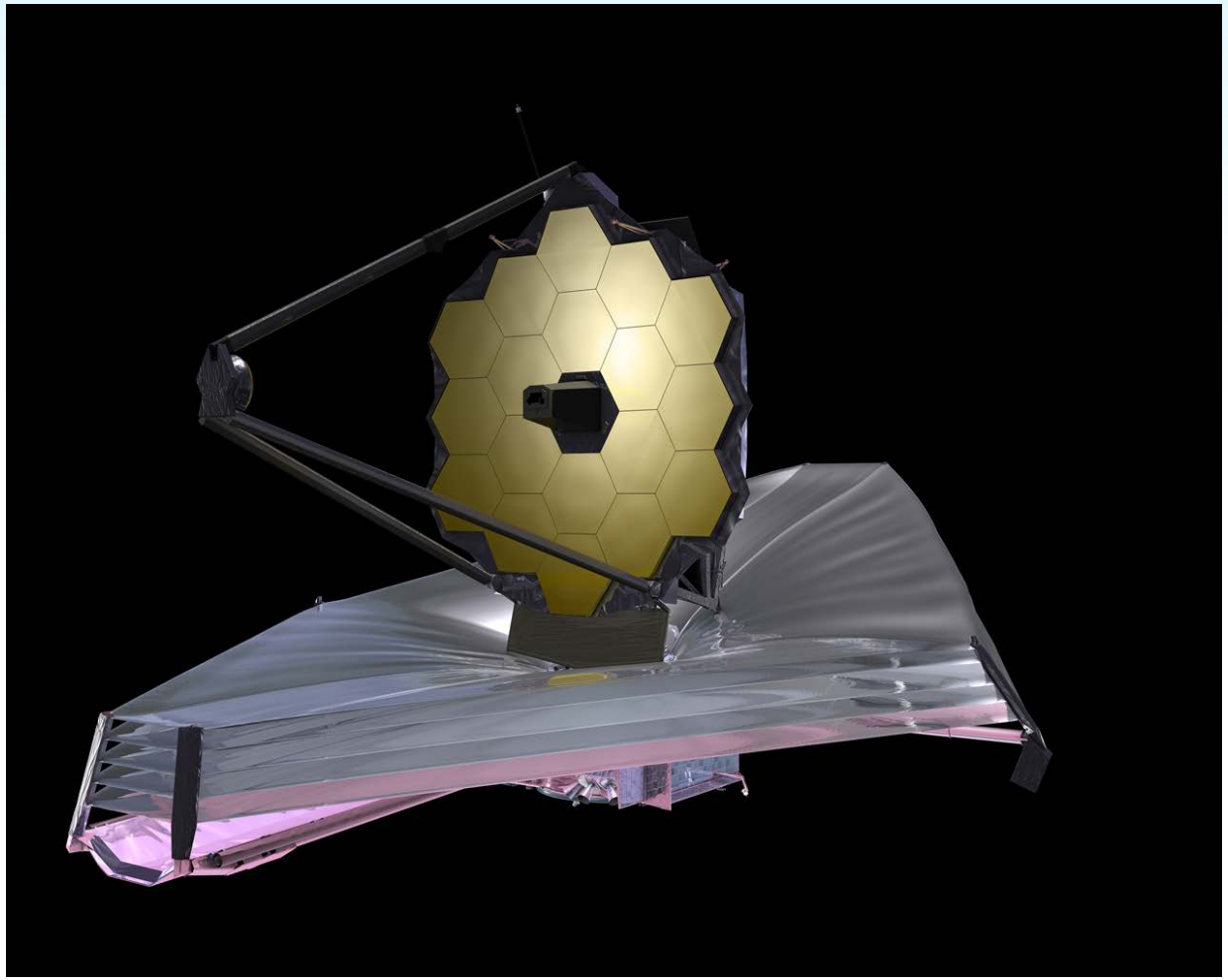
And the 3rd: James Webb Space Telescope



- In 2011, JWST was re-baselined with a life cycle cost estimate of $8.8 billion and a launch readiness date in October 2018 — almost nine times the cost and more than a decade later than originally projected in 1999.

(ref: GAO, 2012)

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Not just a NASA Phenomena

- Since 2001, F-35 experienced approximately $113 billion in cost growth. The program has also experienced a significant loss in buying power as this cost growth occurred despite quantities dropping by more than 400 aircraft since the start of system development.

  (ref: GAO/DoD, 2015)

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Not just a US Government Phenomena

- Boeing added $579 million in deferred production, tooling and other costs in the third quarter, raising the total deferred amount to $32.2 billion.

  (ref.: Ostrower, 2015)

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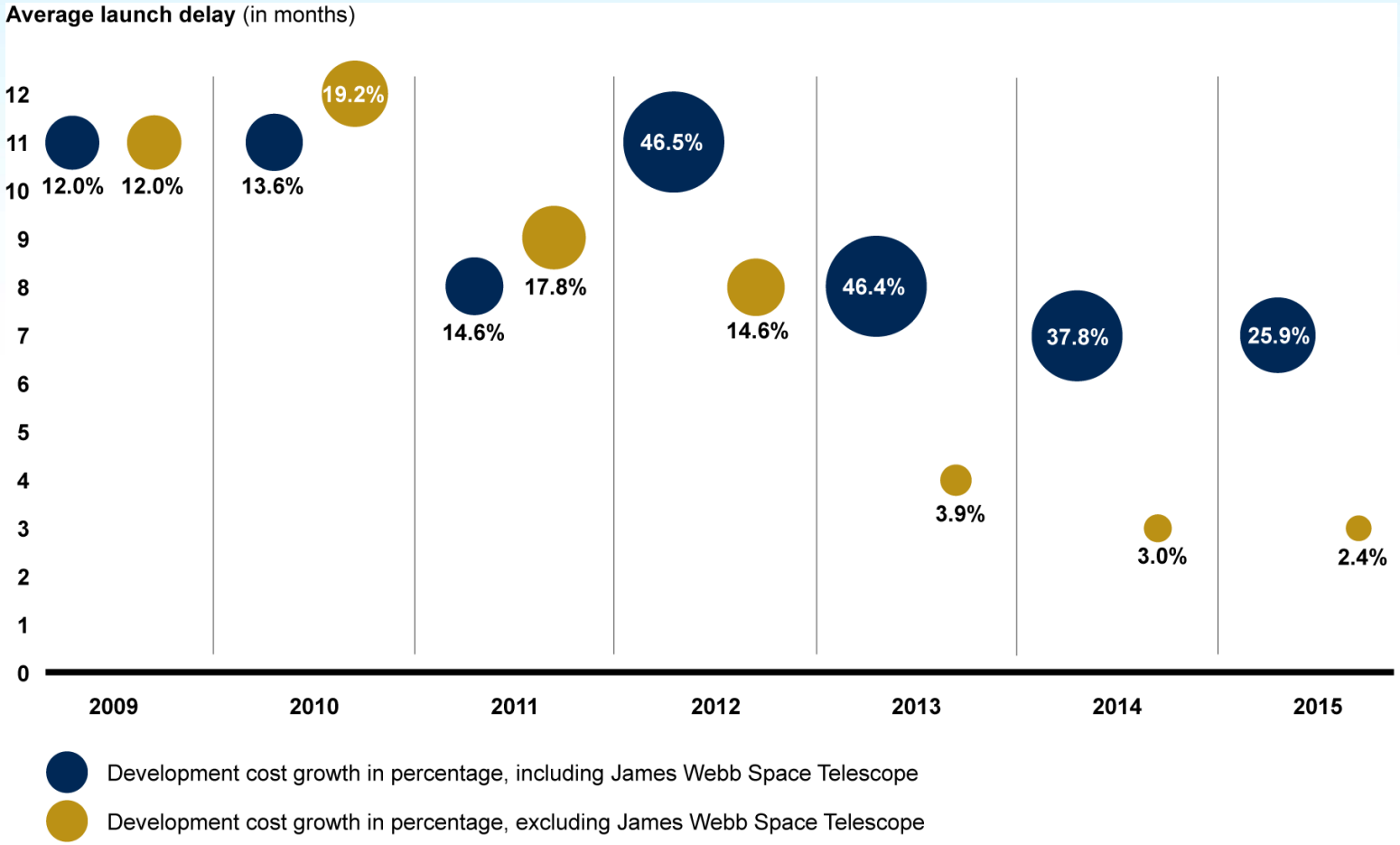
NASA Getting Projects Under Control



Source: GAO analysis of NASA data. | GAO-15-320SP

- Trending downward in both cost and schedule growth.

  (ref: GAO/NASA, 2015)

- That's good – right?

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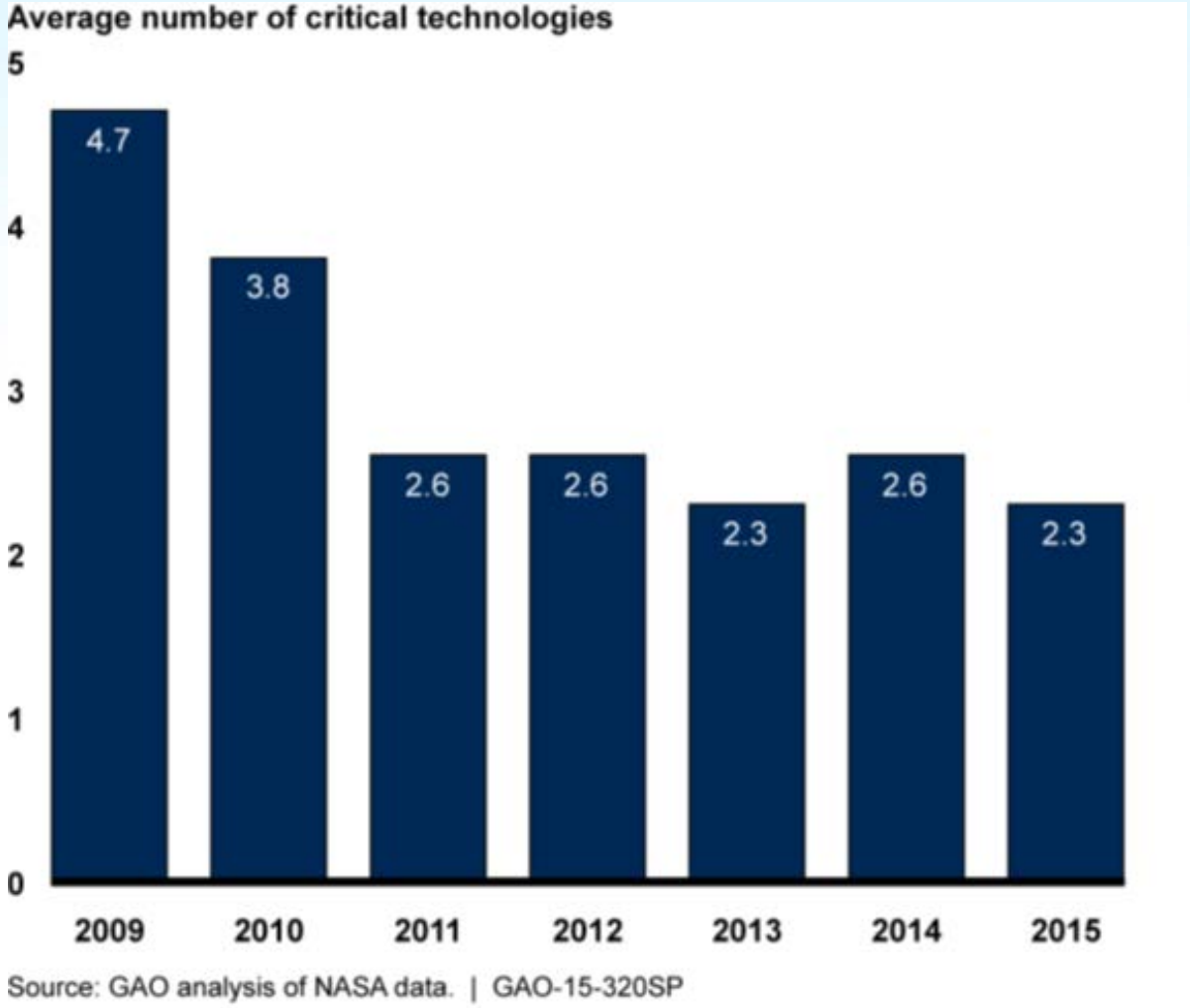
This is NOT the Solution We Want



- "Over the past 7 years, the majority of new projects added to NASA's portfolio have generally relied on the use of existing technology and planned less technology development."

  (ref: GAO/NASA, 2015)

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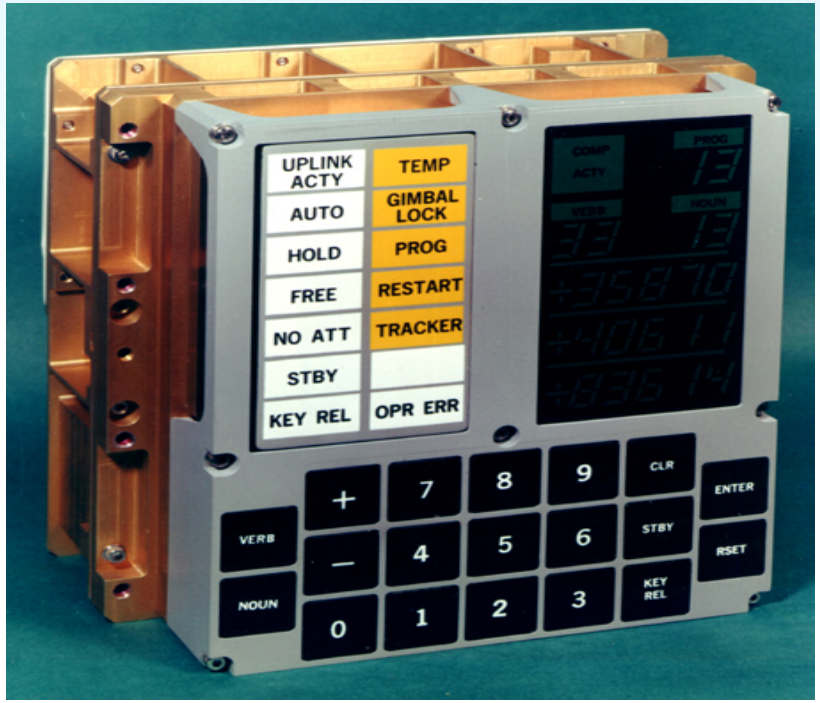
A Contextual Trend

Apollo Guidance Computer



- 1200 transistors
- 70 lbs
- 4K memory
- 1 mhz processor
- $150,000

iPhone 6

- 2 billion transistors
- 4.5 ounces
- 128 Gb memory
- 1.4 Ghz (Dual Core)
- $399

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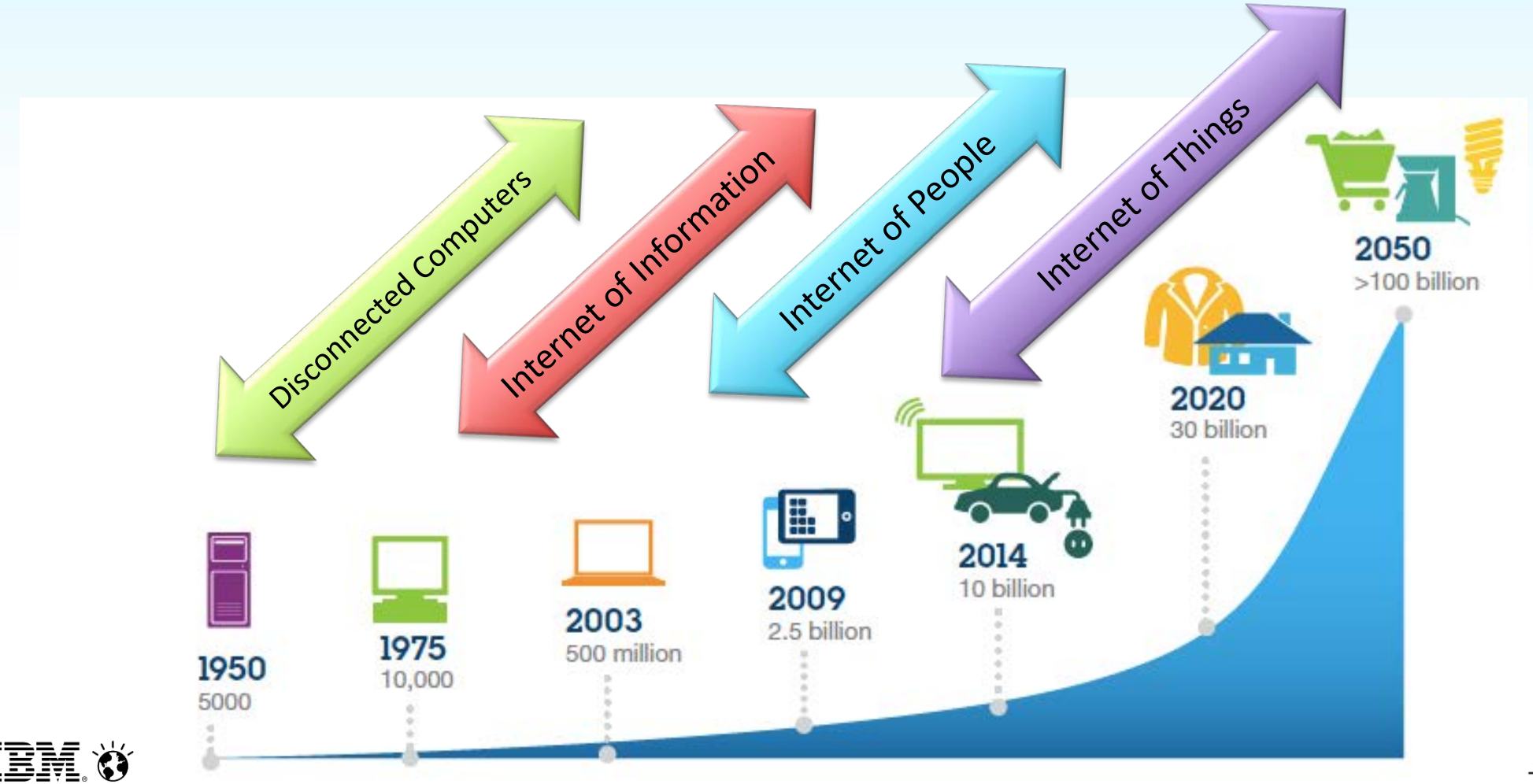
We are Witnessing Continued Exponential Growth in Computing



The Emergence of Cyber-Physical Systems

Automated Driving

Medical Robots

Automated Agriculture

Human-Robot Collaboration

Another Contextual Trend

- **C-130 Likely To Be Used For Over 100 Straight Years.**
  - In *Forbes* (1/16), Loren Thompson writes that the purchase of 32 C-130Js from Lockheed Martin by the Department of Defense has "special historical significance" because it will likely make the C-130 "the first military aircraft in history to stay in continuous service for a hundred years."

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A New, But "Similar," Airframe

- Over the past few years, CH-53s have been recalled from "boneyard" storage at Davis-Monthan AFB in Tucson, AZ, in order to maintain fleet numbers in the face of recent losses and forced retirements.

- Enter the Heavy Lift Replacement (HLR) program, now known as the CH-53K. It aims to offer notable performance improvements over the CH-53E, in a similar airframe.

(ref: Osborn, 2014)

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Radical Re-purposing

Black Hawk drone: Unmanned chopper passes critical Pentagon test
(*Washington Times*, October 30, 2015)

- Aircraft maker Sikorsky announced plans last year to convert a retired Black Hawk helicopter into an "optionally piloted" aircraft, and Army officials said on Thursday that a recent test of the prototype proved to be a success.

- This week the custom-built chopper was able to pick up payload and deliver it several miles away all on its own.

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What We've Been Hearing Locally

- Trends
  - Increasing "cyber" in cyber-physical systems
  - More upgrades to and technology infusion into existing system platforms
- Needs
  - Model Based Systems Engineering
  - Curricula needs in systems integration

CUMMINGS RESEARCH PARK
HUNTSVILLE, ALABAMA

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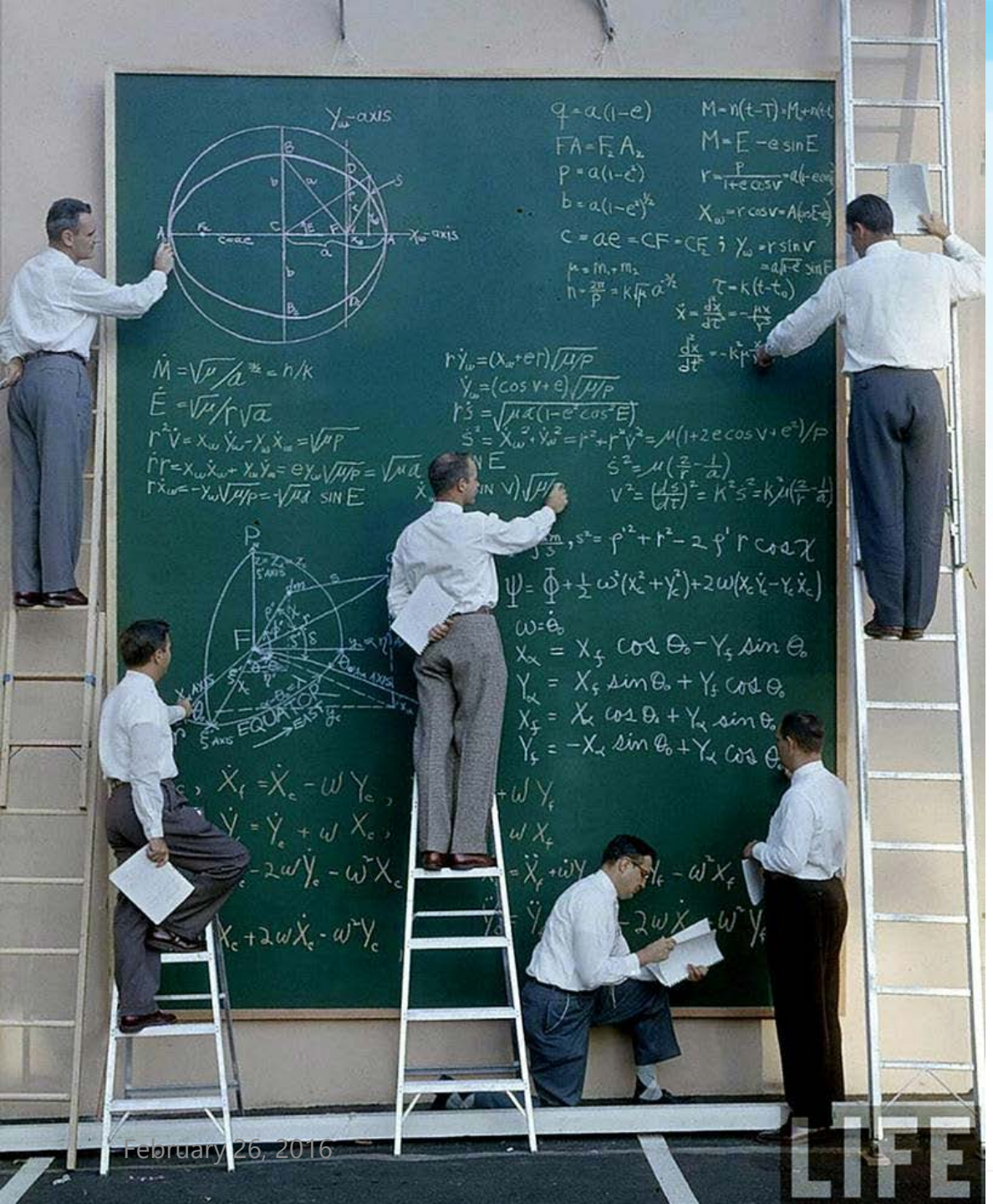

Rocket Science before PowerPoint.

The physics are the same.

How we develop systems needs to change!

UAH Systems Engineering Program

- Engagement with Government & Industry
  - Relevance of research portfolio
  - Advisory Board
- Collaboration
  - Within UAH
  - Across the US via NASA & DoD SERC
  - Engagement in Conferences and Workshops
- UAH research portfolio
  - Research into novel systems engineering tools and techniques
  - Leverage state-of-the-art systems engineering tools and techniques

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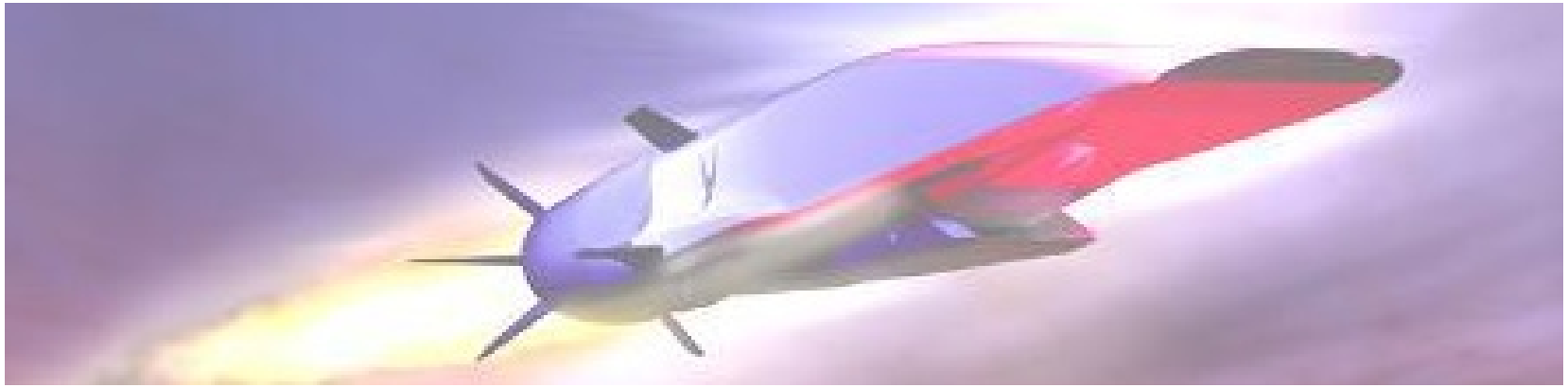
Systems Engineering Mission

The systems engineering program at UAH develops theoretically grounded practitioners capable of advancing and utilizing rigorous mathematical methods to rapidly produce *novel and dependable systems within predictable budgets* focusing on complex aerospace and defense systems.



Boeing X-51 Waverider
Artist's conception
The Boeing Company

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Systems Engineering Research Team

- Dr. Paul Collopy
  - Professor & Department Chair

- Dr. Phil Farrington
  - Professor

- Dr. Bryan Mesmer
  - Assistant Professor

- Dr. Dale Thomas
  - Professor & Eminent Scholar

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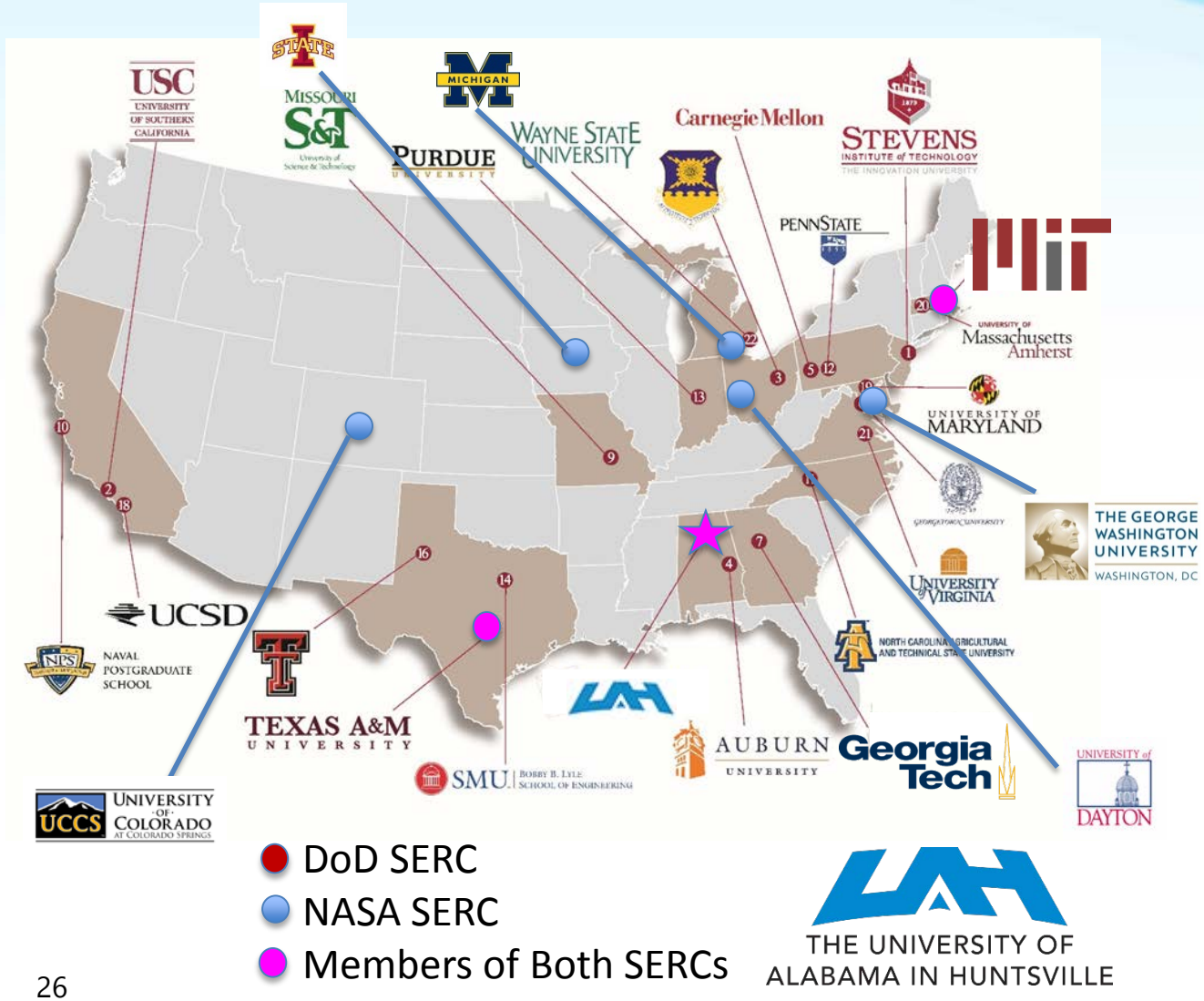
Collaborations in the Systems Engineering Research Community

- UAH leads the NASA Systems Engineering Research Consortium
- UAH collaborates in the DoD Systems Engineering Research Center



CSER 2016
conference on systems engineering research

FROM PRACTICE TO THEORY- and Back Again
March 22-24, 2016, Huntsville, Alabama

The University of Alabama in Huntsville will host CSER 2016. At CSER 2016, researchers from around the world will be presenting papers that push the boundaries of systems engineering research and respond to new challenges for systems architecting and engineering.

Sponsors: Dynetics, MITRE, Aerospace, GEOCENT, Davidson Technologies (Missiles • Aerospace • Cyber • Intelligence), NASA, Systems Engineering Research Center, QTEC, Northrop Grumman, Aerojet Rocketdyne, INCOSE International Council on Systems Engineering, Lockheed Martin, COLSA Corporation, The University of Alabama in Huntsville

UAH Systems Engineering Research Foci

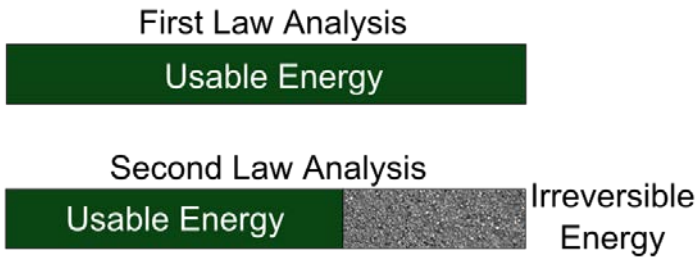
- Systems Science and Theory
- Systems Design and Development
- System End User Modeling
- Value Driven Design, Modeling, and Analysis
- Model Based Systems Engineering

Systems Science & Theory

- Theoretical Foundations of Systems Engineering

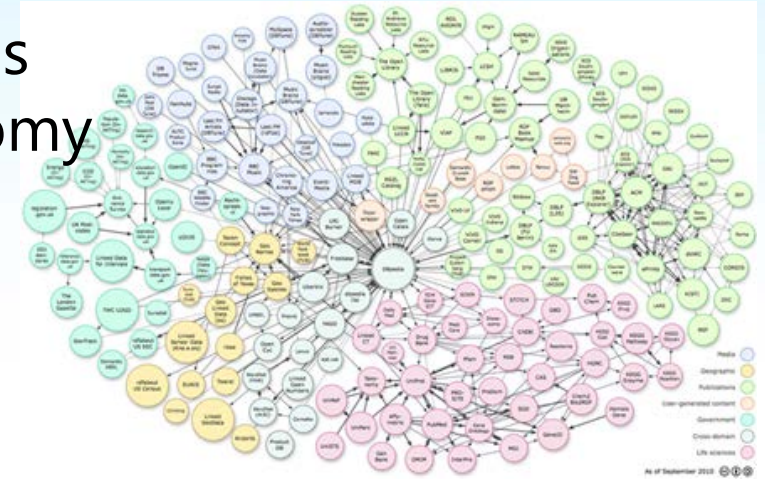
Group	Pretest	Treatment	Posttest
Intervention Group (Randomly Assigned)	O	X	O
Control Group (Randomly Assigned)	O		O

- Exergy Analysis

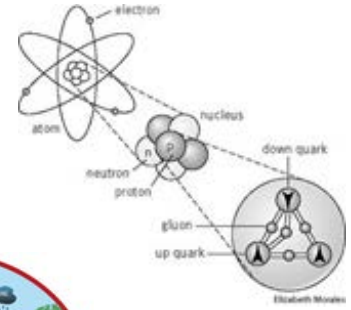


- Systems Generational Evolution

- Systems Taxonomy



- Component Interaction



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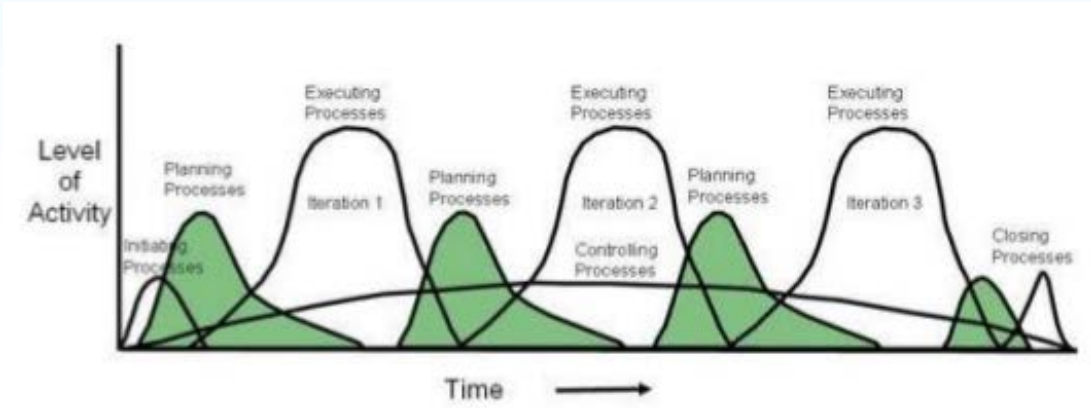
Systems Design & Development

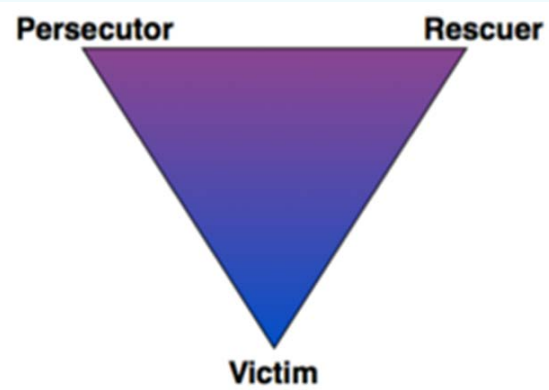
- Epistemological Approach to System Validation
- Anthropological Study of Design Reviews
- Simulation of a Detailed Design Organization
- Agile Systems Engineering Methods



End User Modeling

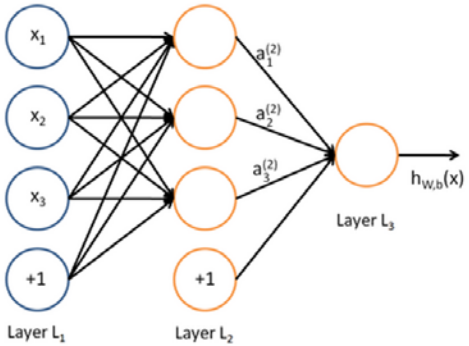
- Rotorcraft End-User Model

- Storytelling in Systems Engineering



- Gamification of Systems Engineering

- Predictive Controllers in Design



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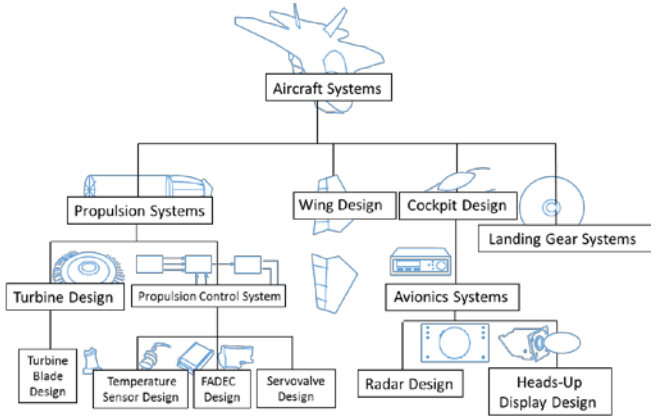
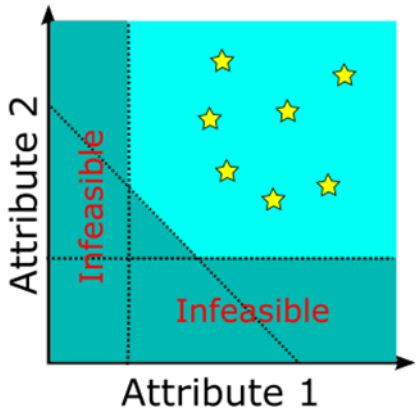
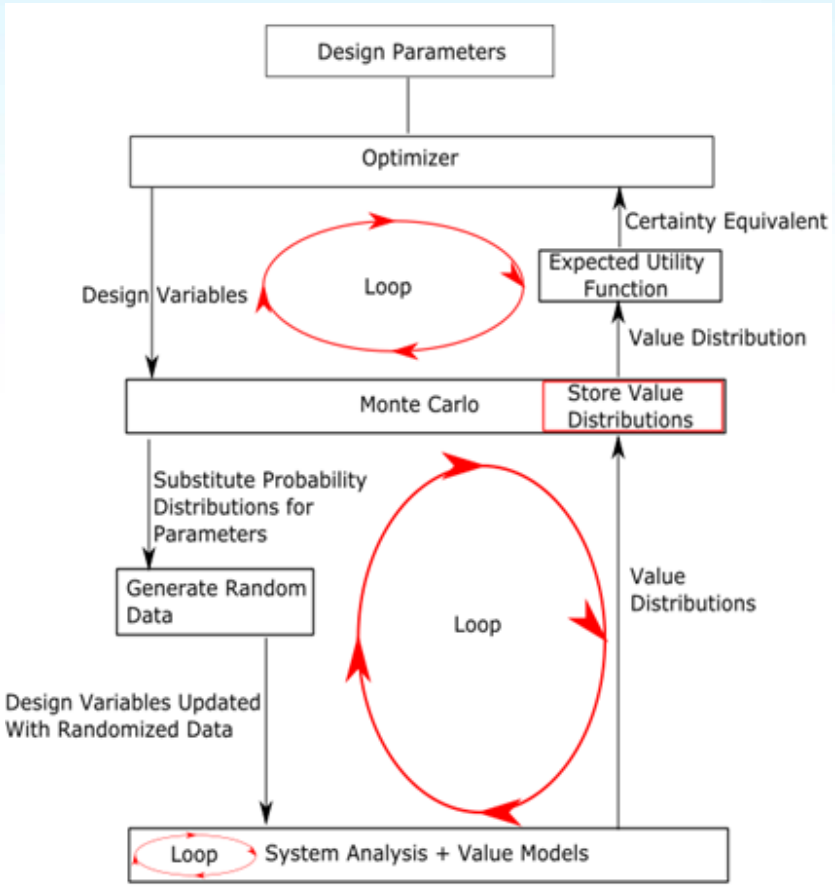
Value Driven Design, Modeling & Analysis

- Practical Decision Analysis
- Value function formation
- Incorporation of risk preferences
- Merging Preferences across Multiple Stakeholders
- Capturing end-user consumer models in a demand model







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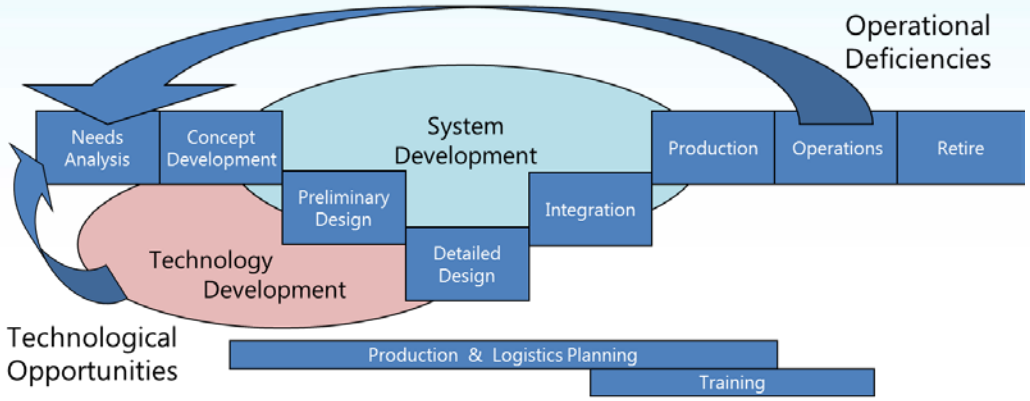
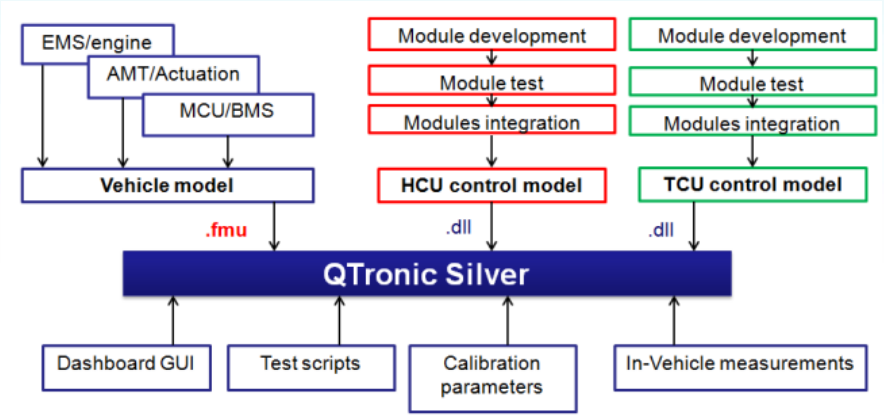
Model Based Systems Engineering

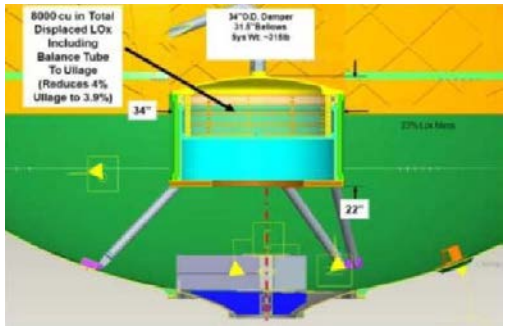
- System Architecture Analysis



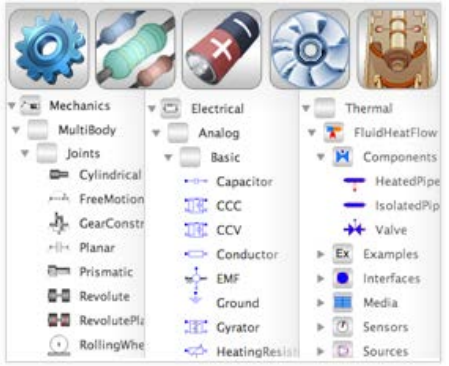
- Virtual Systems Integration



- Technology Infusion



- Virtual Component Model Library



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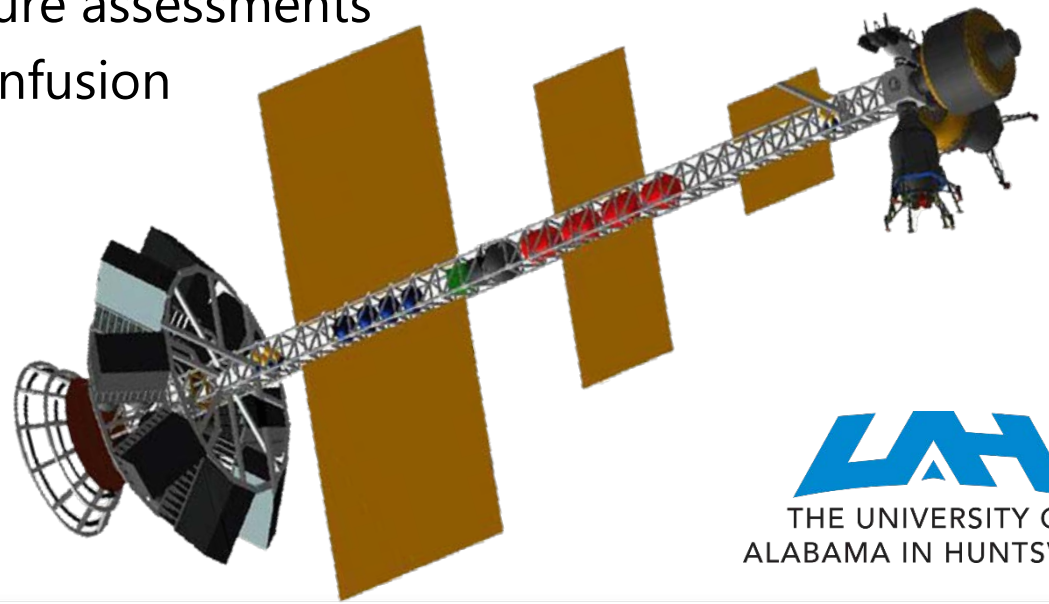
Systems Engineering Modeling Research

- Advanced Systems Engineering of Transportation Architectures for Deep Space Human Exploration Missions
  - Research proposal submitted to Alabama Space Grant Consortium in response to NASA EPSCoR solicitation
- Two systems engineering modeling research thrusts
  - Incorporation of value models for architecture assessments
  - Virtual systems integration for technology infusion
- Research Team
  - Dr. Dale Thomas (PI)
  - Dr. Phil Ligrani (co-PI)
  - Dr. Paul Collopy (co-I)
  - Dr. Robert Frederick (co-I)



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The End Game

- https://www.youtube.com/watch?v=DZaAFADoF1M

Building J.A.R.V.I.S. ⇒ Model Based Systems Engineering Provides a Key Ingredient

"one could posit that MBSE is a disruptive technology since it so changes the game of traditional SE process that expected outcomes are radically different. "
(ref: Long, et.al., 2014)

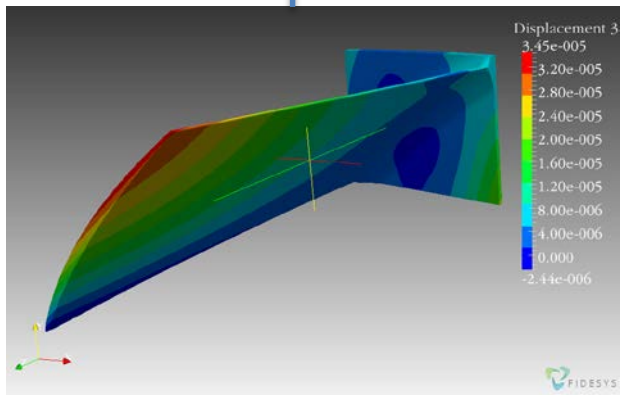
CAM

MBSE

Watson

CAD

CAE



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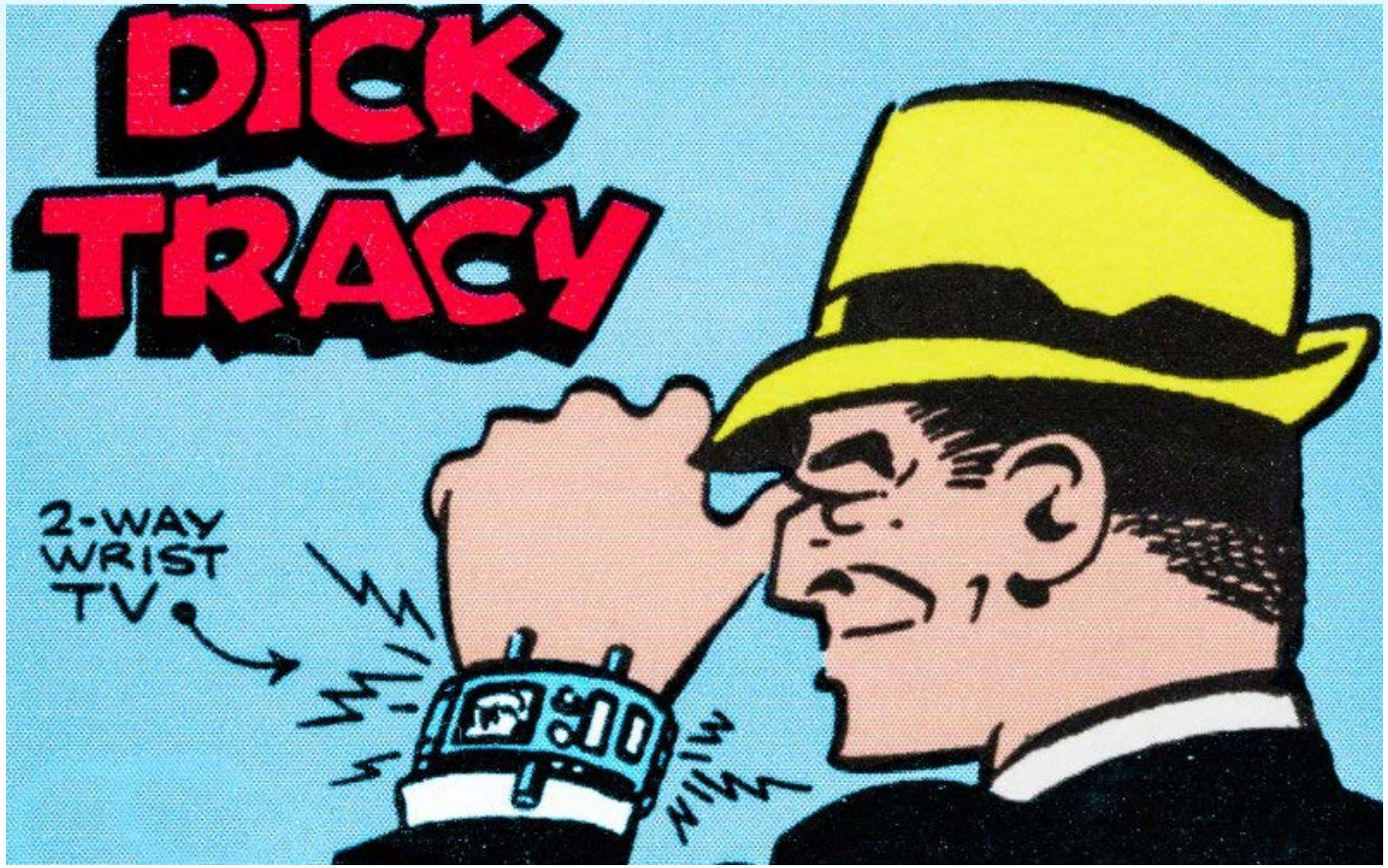
Maybe not so far fetched...



We Know the History – What's the Future?

"It is difficult to say what is impossible, for the dream of yesterday is the hope of today and the reality of tomorrow."
Robert H. Goddard

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