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21st Century Manufacturing Modeling & Simulation Research Needs

AMMEP Planning Workshop
Georgia Institute of Technology
September 14, 2011

Dr. Al Sanders
Chairman NDIA AMEC Committee

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NAE Engineering Grand Challenges

Make Solar Energy Economical

Provide Energy from Fusion

Develop Carbon Sequestration Methods

Manage the Nitrogen Cycle

Provide Access to Clean Water

Restore and Improve Urban Infrastructure

Advance Health Informatics

Engineer Better Medicines

Reverse-Engineer the Brain

Prevent Nuclear Terror

Secure Cyberspace

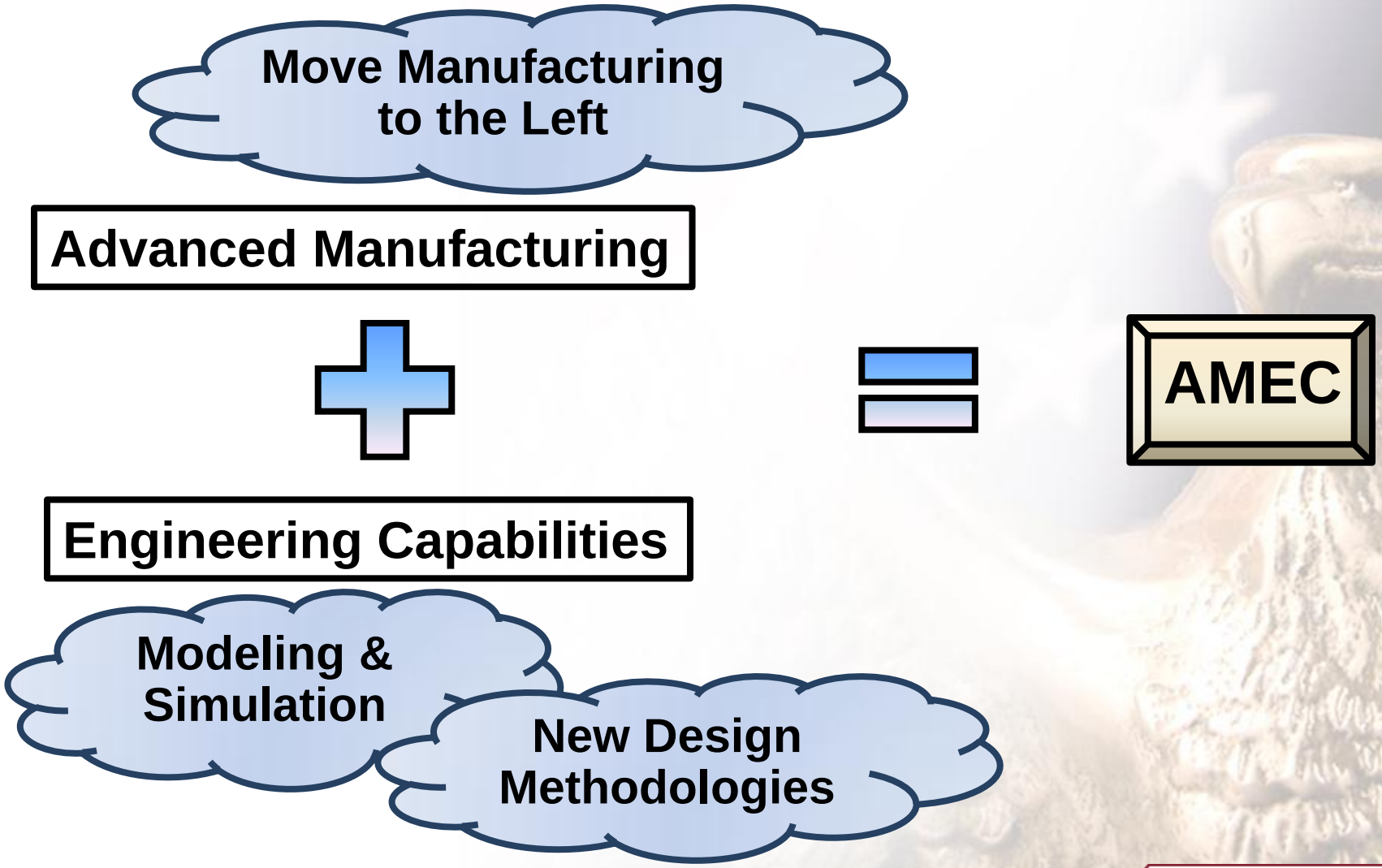
Enhance Virtual Reality

Advance Personalized Learning

Engineer the Tools of Scientific Discovery

What About Manufacturing and Making A&D Systems Affordable?

AMEC Charter & Mission



AMEC M&S Roadmap Scope

"Identify industry *M&S analysis* needs to facilitate the integration of *producibility* considerations into the earliest phases of the system engineering process for complex *aerospace and defense* system design"

- **In-Scope**
  - Product & process centric analyses to guide design decisions
  - Factory & supply chain analyses to guide industrial base design
  - Methods to integrate producibility into early SE trade studies
- **Out of Scope**
  - Development of M&S data standards & interoperability rqmts
  - Virtual collaboration tools and enhancements to existing SW
  - IT-enabled PLM software and modeling language improvements

Focus is Identification of M&S Capabilities that do not Presently Exist

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AMEC M&S White Paper

- **Based on 18 month study on current DFM practices***
  - **Analytical producibility analysis tools lacking**
  - **Many producibility issues inadvertently designed-in**
  - **Current commercial DFM analysis tools inadequate**
  - **Manufacturing M&S a critical missing research area**

- **Roadmap development underway for key focus areas**
  - **Systems engineering trade study and design methodologies**
  - **System integration, assembly, and test modeling**
  - **Enterprise level supply chain design and analysis methods**
  - **Electrical, mechanical, and assembly yield modeling**
  - **Quantitative DFX analyses including complexity characterization**
  - **Life cycle cost modeling including uncertainty and risk impact**

*NDIA Manufacturing Division White Paper, "21st Century Manufacturing Modeling & Simulation Research and Investment Needs," Released May 2011.

Why Focus on Producibility?

- **Production cost components**
  - **Direct material and labor costs**
  - **Factory overhead/burden costs**
- **Producer vs. user LCC drivers**
  - **Low yield & process inefficiencies**
  - **Manufacturing process complexity**
  - **Excessive quality specs/controls**
- **Product cost reduction strategies**
  - **Post-NPI value engineering**
  - **Lean out existing processes**
  - **New material/process technologies**

Inadvertently Designed-In Producibility Issues Drive Significant "Hidden" Costs

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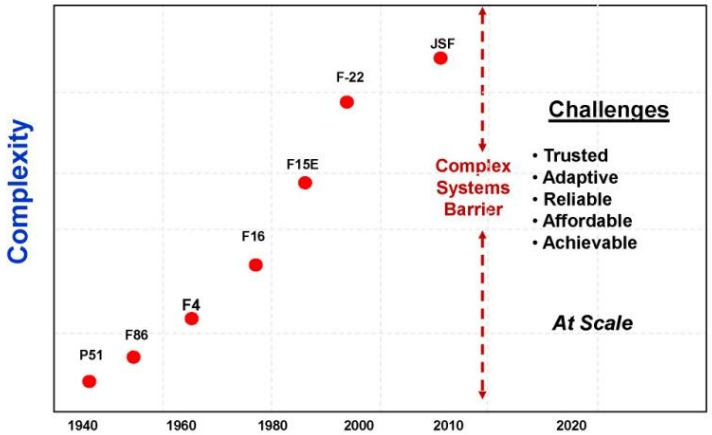
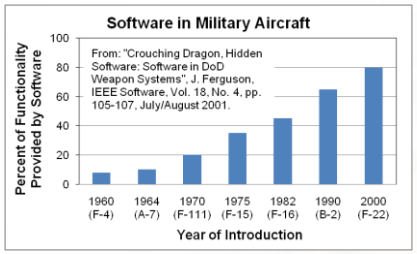
A&D System Complexity Growth

- **Systems larger, more complex, and costly**
  - **Maximum functionality in smallest "package"**
  - **Numerous competing "ilities" to trade-off**
  - **Manufacturing risks becoming more prevalent**
- **Affordability is spiraling out of control**
  - **Inability to understand "risks" common theme**



From Lemnios, Z.J., "Transforming US Defense R&D to Meet 21st Century Challenges", NDIA 11th Annual Science and Engineering Technology Conference, Charleston, South Carolina, April 13, 2010.



Complex Systems Barrier

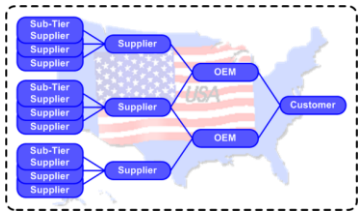
Complexity

System Scale and Complexity Growing...

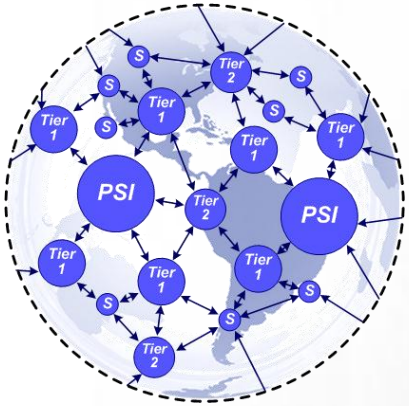
A&D Industrial Landscape Shifts

- **Manufacturing off-shored to low cost regions**
  - **Shift from OEM to system integrator roles**
  - **Suppliers responsible for larger work packages**
  - **Unprecedented levels of "risk" for all tiers**
- **Supply chains became global dynamic entities**
  - **Industrial base evolved into a complex adaptive system**

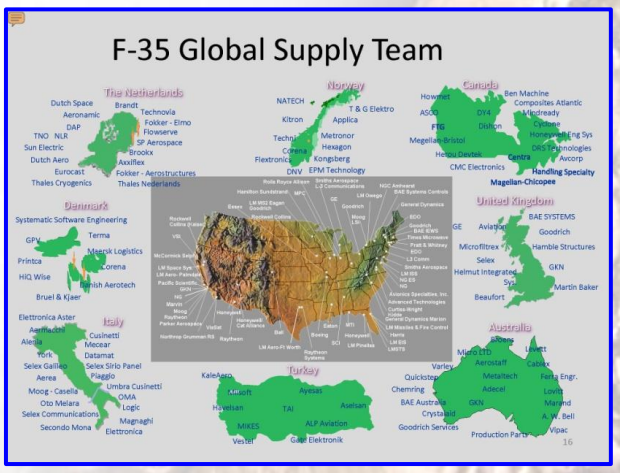
1960-2000
Relatively Static Supply Chains



2000-2010
Global Dynamic Manufacturing Enterprises



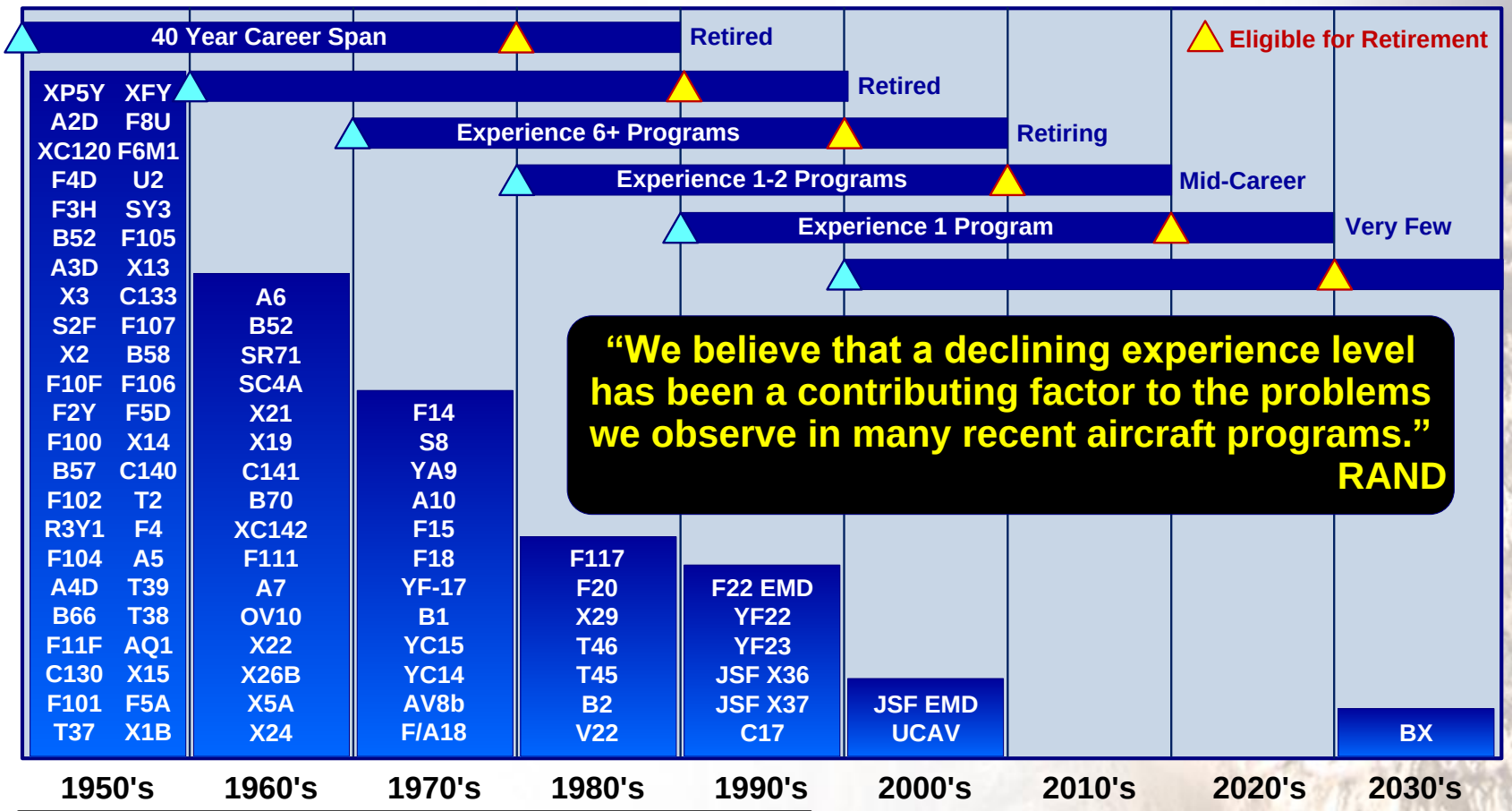
2010 Era Supply Network



Design and Manufacturing Diverging…

A&D Sector Skill Erosion

Vertical Bars: Military Aircraft Program Starts
Horizontal Bars: Typical 40 Year Career Span



"We believe that a declining experience level has been a contributing factor to the problems we observe in many recent aircraft programs."
RAND

Source: RAND Study (chart by Northrop Grumman)

Limited Opportunities to Learn by Doing...

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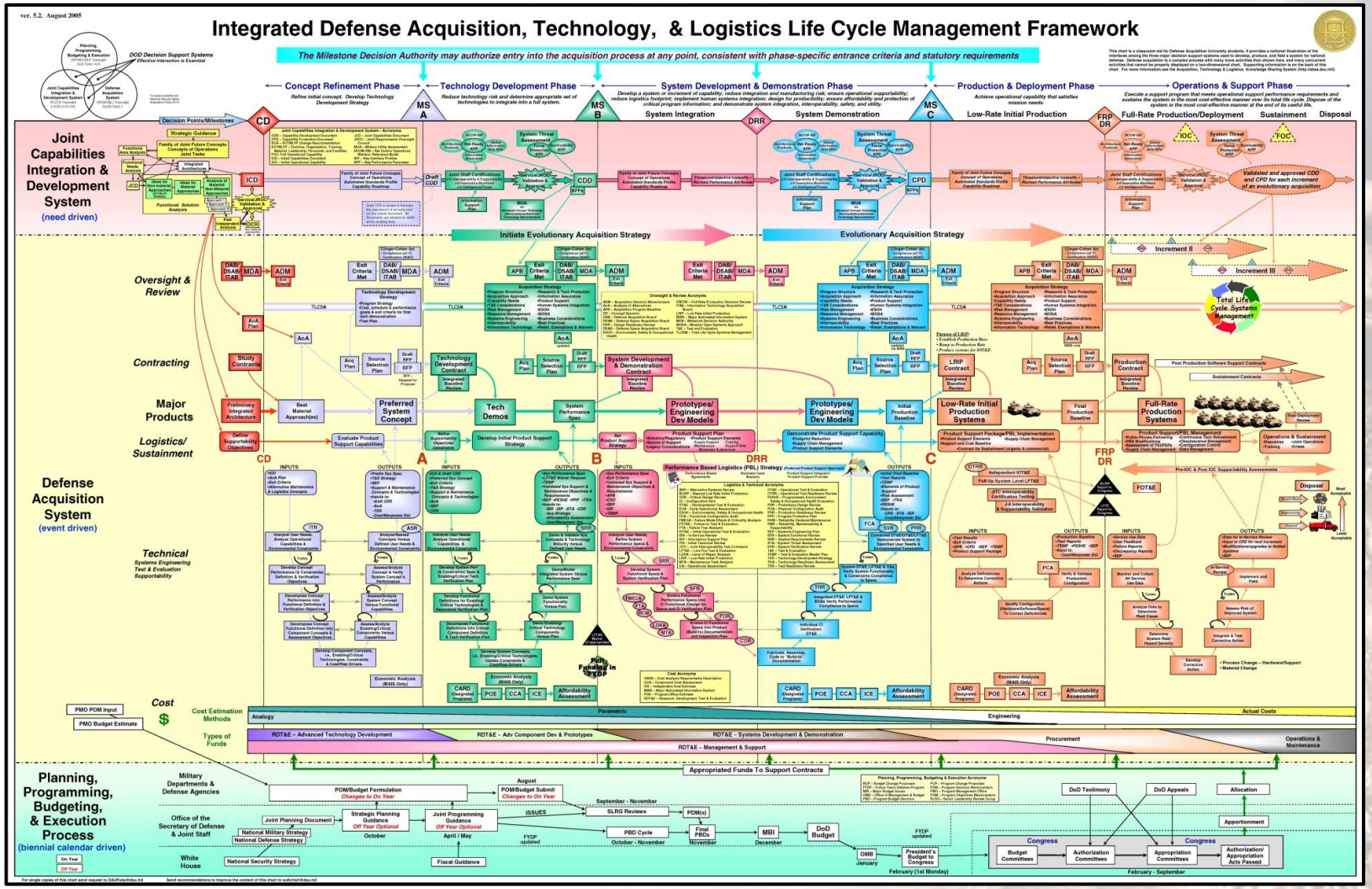
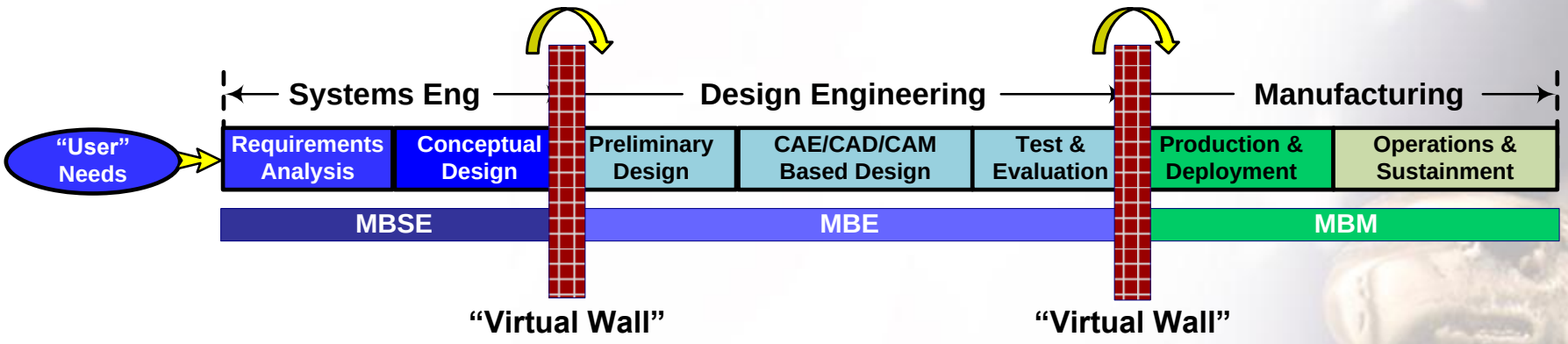
A&D System Development Process

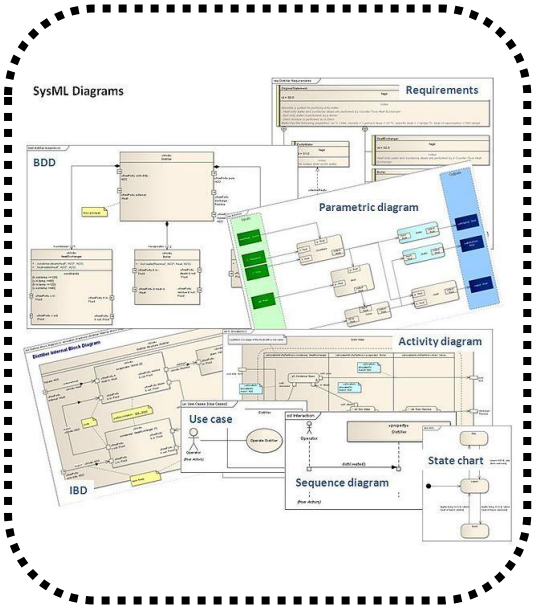


Process Scale and Complexity Growing…

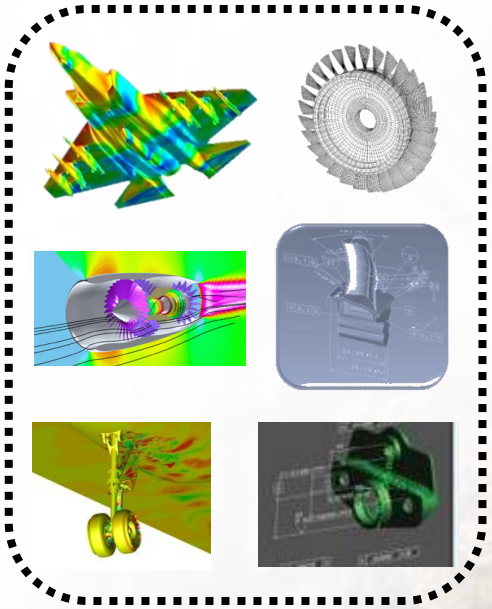
Current Model-Based Approaches



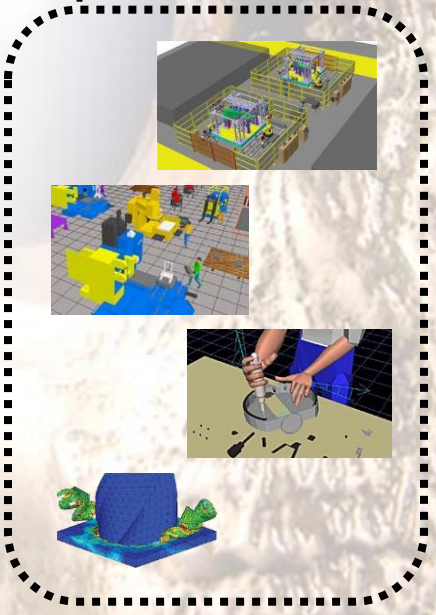
"Function Centric"



"Geometry Centric"



"Operation Centric"



Same Problems now Happen Virtually...

Something to Think About….

"Scientists study the world as it is; Engineers create the world that has never been."

Theodore von Kármán
Pioneer in Aerodynamics

"Long standing definitions and perceptions of engineering and manufacturing are constraining our ability to adapt to the 21st century world; It's time to re-engineer design processes and boundaries between engineering and manufacturing."

Al Sanders
Former Aerodynamicist

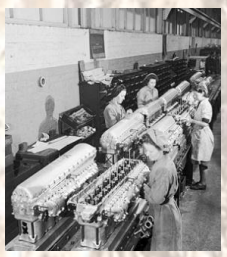
Changing Long-Standing Paradigms

- **Engineering invents and creates….**
  - Rocket scientists and engineers dream up new technologies
  - Mathematical and scientific principles used to solve problems
  - Performance enhancing technologies developed at any cost
- **Manufacturing builds and mass produces….**
  - Semi-skilled labor uses machine tools and jigs to make parts
  - Experience and judgment used to develop/optimize processes
  - Automation and lean used to make processes more efficient





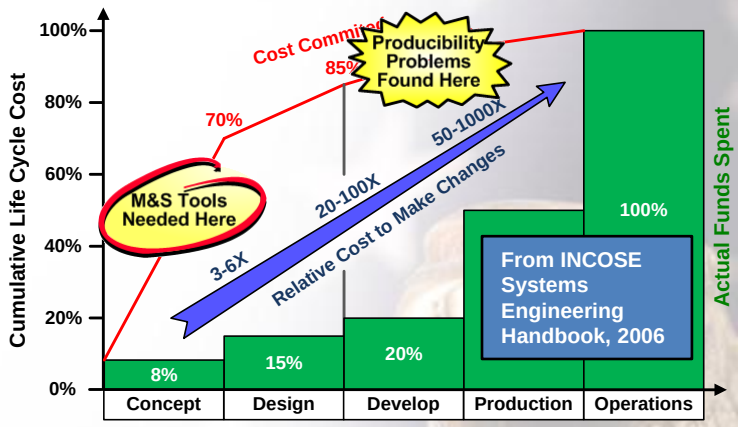




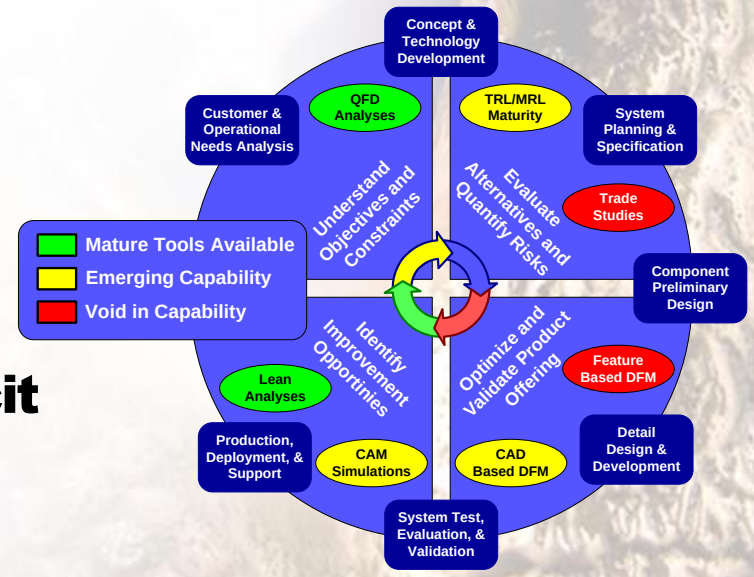
Need to Change a Century of Perceptions

Design-Manuf Interdependence

- **Early design decisions lock-in cost**
  - Trade studies focus on performance
  - Exotic materials used to save weight
  - Design thrown across the "globe"



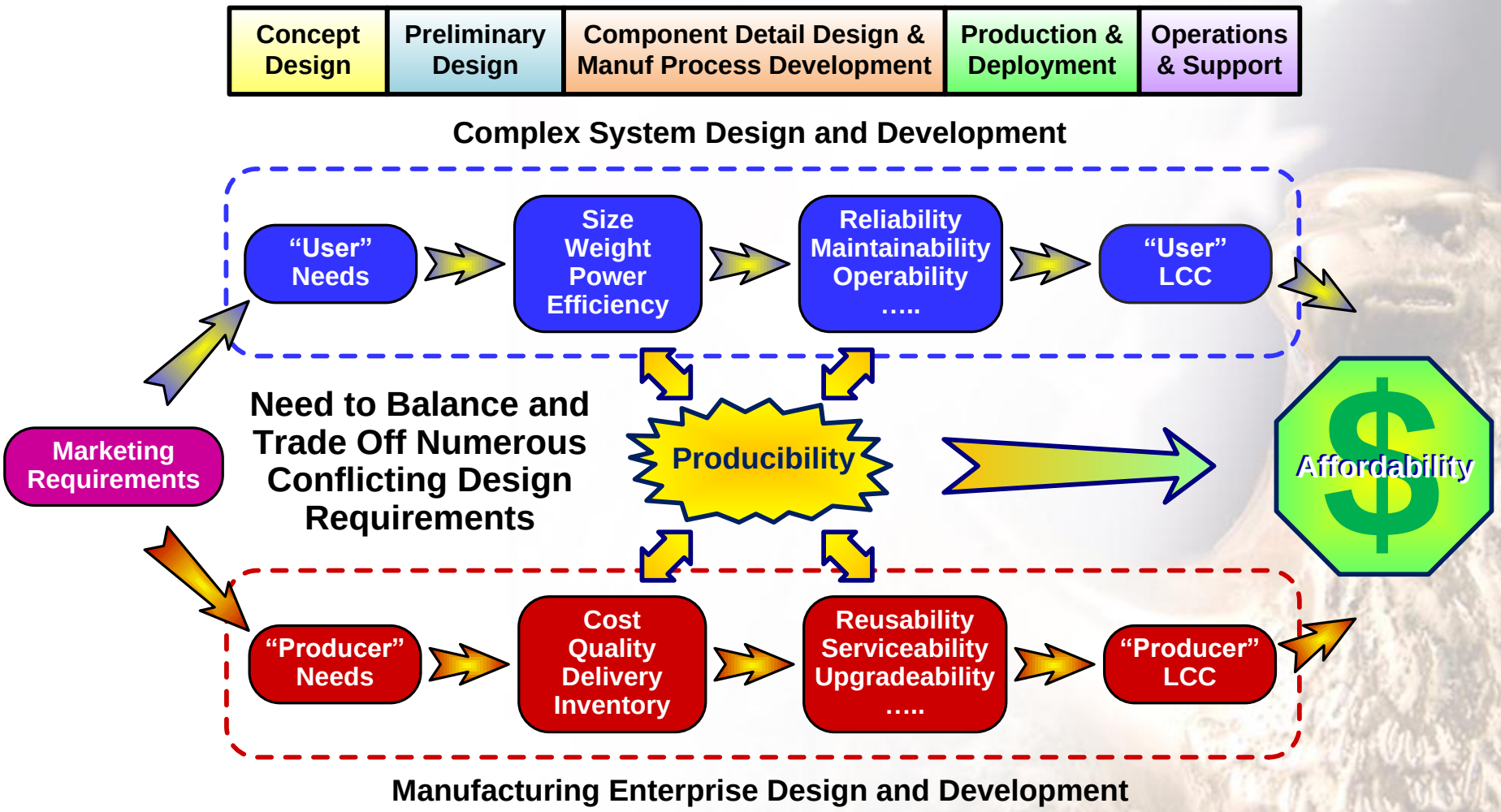
- **Moving manufacturing to the "left"**
  - Concurrent engineering teams
  - Early supplier involvement
  - Design for manufacturing (DFM)



- **Quantitative DFM tools lacking**
  - Manufacturing knowledge mostly tacit
  - High level DFM guidelines/checklists
  - Rule-based CAD/CAM occurs too late

M&S Enabler to Move Manufacturing Left

Role of Producibility in Trade Space



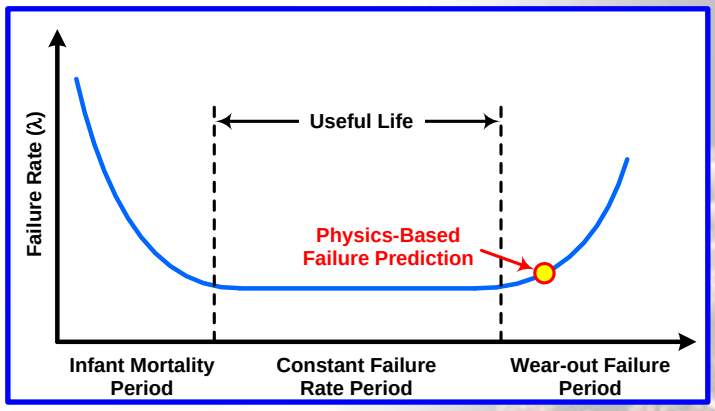
Producibility a Critical "x"
Driving the Big "Y" of Affordability

Reliability Engineering Discipline

Reliability Theory

Reliability: Probability that a device will perform its intended function during a specified period of time under stated conditions.

Physics of Failure Analysis



Analytical Basis

$$MTBF = \frac{1}{\lambda} = \frac{total\ operating\ hours}{number\ of\ failures}$$

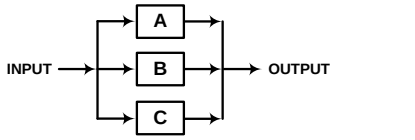
$$R(t) = \int_t^{\infty} f(t)dt = e^{-\lambda t}$$

$$f(t) = \frac{1}{\theta}e^{-t/\theta} \qquad \lambda = \frac{1}{\theta}$$

RAMS

Reliability
Availability
Maintainability
Safety

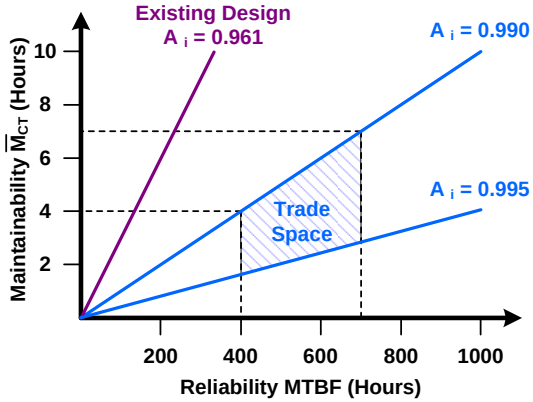
Modeling Relationships



$$R = 1 - (1 - R_A)(1 - R_B)(1 - R_C)$$

$$R = (R_A)(R_B)(R_C)$$

Trade Off Evaluations



Configuration	A_i	MTBF	$\bar{M}_{CT}$
Existing Design	0.961	125	5.0
Alternative 1	0.991	450	4.0
Alternative 2	0.990	375	3.5
Alternative 3	0.991	320	2.8

Focus is Early Detection of Failure Modes

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What About Producibility?

Merriam-Webster.com

pro·duc·ibil·i·ty *noun* \prə,d(y)üsə'bilətē\

Definition of PRODUCIBILITY

: the character, state, or fact of being producible

'pro·duce *verb*

Definition of PRODUCE

5 **a** : to cause to have existence or to happen : BRING ABOUT

b : to give being, form, or shape to : MAKE; *especially* : MANUFACTURE

'man·u·fac·ture \,man-yə-'fak-chər, ,n

Definition of MANUFACTURE

3 : the act or process of producing something

USAF Research Lab

Producibility: A **design characteristic** which allows **economical fabrication, assembly, inspection, and testing** of an item using available manufacturing techniques. The relative ease of manufacture of an item or system.

BusinessDictionary.com

Producibility: Ease of manufacturing an item (or a group of items) in large enough quantities. It depends on the **characteristics and design features of the item** that enable its **economical fabrication, assembly, and inspection or testing** by using existing or available technology.

Defense Acquisition University

Producibility: The measure of relative ease of manufacturing a product. The product should be **easily and economically fabricated, assembled, inspected, and tested** with high quality on the first attempt that meets performance thresholds.

Analytical Basis needed for Producibility

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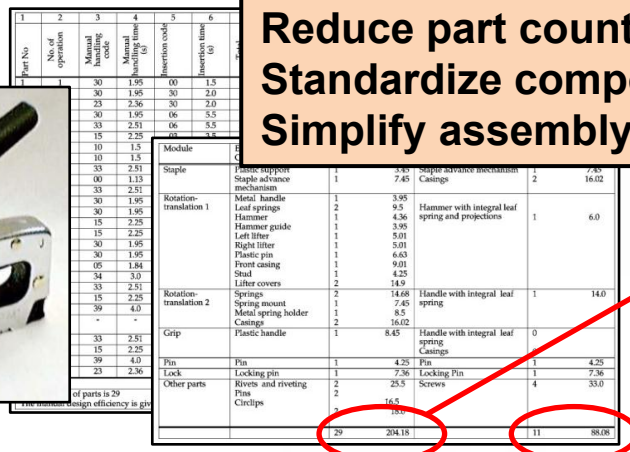
State-of-the-Art DFMA Analysis

Reduce part counts…
Standardize components…
Simplify assembly operations…

Stapler

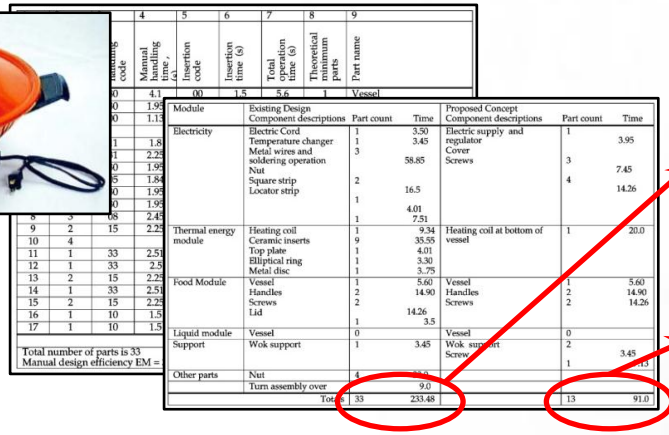


Module	Existing Design Component descriptions	Part count	Time	Proposed Concept Component descriptions	Part count	Time
Staple	Plastic support	1	3.45	Staple advance mechanism	1	7.45
	Staple advance mechanism	1	7.45	Casings	2	16.02
Rotation-translation 1	Metal handle	1	3.95	Hammer with integral leaf spring and projections	1	6.0
	Leaf springs	2	9.5			
	Hammer	1	4.36			
	Hammer guide	1	3.95			
	Left lifter	1	5.01			
	Right lifter	1	5.01			
	Plastic pin	1	6.63			
	Front casing	1	9.01			
	Stud	1	4.25			
	Lifter covers	2	14.9			
Rotation-translation 2	Springs	2	14.68	Handle with integral leaf spring	1	14.0
	Spring mount	1	7.45			
	Metal spring holder	1	8.5			
	Casings	2	16.02			
Grip	Plastic handle	1	8.45	Handle with integral leaf spring	0	
				Casings		
Pin	Pin	1	4.25	Pin	1	4.25
Lock	Locking pin	1	7.36	Locking Pin	1	7.36
Other parts	Rivets and riveting	2	25.5	Screws	4	33.0
	Pins	2				
	Circlips	1	16.5			
			18.0			
		29	204.18		11	88.08

"As Is" Design
- 29 Total Parts
- Assy Time 204 sec

"To Be" Design
- 11 Total Parts
- Assy Time 88 sec

Electric Wok



Module	Existing Design Component descriptions	Part count	Time	Proposed Concept Component descriptions	Part count	Time
Electricity	Electric Cord	1	3.50	Electric supply and regulator	1	3.95
	Temperature changer	1	3.45	Cover		
	Metal wires and soldering operation	3	58.85	Screws	3	7.45
	Nut				4	14.26
	Square strip	2				
	Locator strip	1	16.5			
		1	4.01			
		1	7.51			
Thermal energy module	Heating coil	1	9.34	Heating coil at bottom of vessel	1	20.0
	Ceramic inserts	9	35.55			
	Top plate	1	4.01			
	Elliptical ring	1	3.30			
	Metal disc	1	3.75			
Food Module	Vessel	1	5.60	Vessel	1	5.60
	Handles	2	14.90	Handles	2	14.90
	Screws	2		Screws	2	14.26
	Lid		14.26			
		1	3.5			
Liquid module	Vessel	0		Vessel	0	
Support	Wok support	1	3.45	Wok support	2	
				Screw		3.45
					1	3.43
Other parts	Nut	4	9.0			
	Turn assembly over					
		33	233.48		13	91.0

"As Is" Design
- 33 Total Parts
- Assy Time 233 sec

"To Be" Design
- 13 Total Parts
- Assy Time 91 sec

Source: R.B. Stone et. al, "A Product Architecture-Based Conceptual DFA Technique," Design Studies, Vol. 25, No. 3, pp. 301-325, May 2004.

Simple DFMA Approaches Work for Simple Products

A&D Producibility Analysis Needs

- **Aerospace producibility challenges**
  - Maximum functionality in smallest package
  - Highly 3-D shapes with intricate features
  - Exotic hard to machine/fabricate materials
  - Tightly controlled dimensions & tolerances

- **Producibility is a "design characteristic"**
  - Ease and economy of making item(s) at rate
  - Drives manufacturing inefficiencies and risk
  - F(fit, form, function, complexity, capability,..)

- **Need quantitative analytical design tools**
  - Make "hidden factory" costs & risks visible
  - Shape design vs. verify rule adherence

M&S Enabler for Producibility Prediction

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Manufacturing Paradigm Shifts

- **Manufacturing is more than a constraint on design**
  - Need to define, allocate, and flow down producibility rqmts
  - Conflicting "user" vs. "producer" needs require trade-offs
  - Producibility the "kingpin" of system affordability and cost

- **Design for manufacturing needs to become a science**
  - Analytical basis needed for producibility similar to reliability
  - Design attributes drive manufacturing complexity & yield fallout
  - Methods needed to balance assembly vs. part complexity

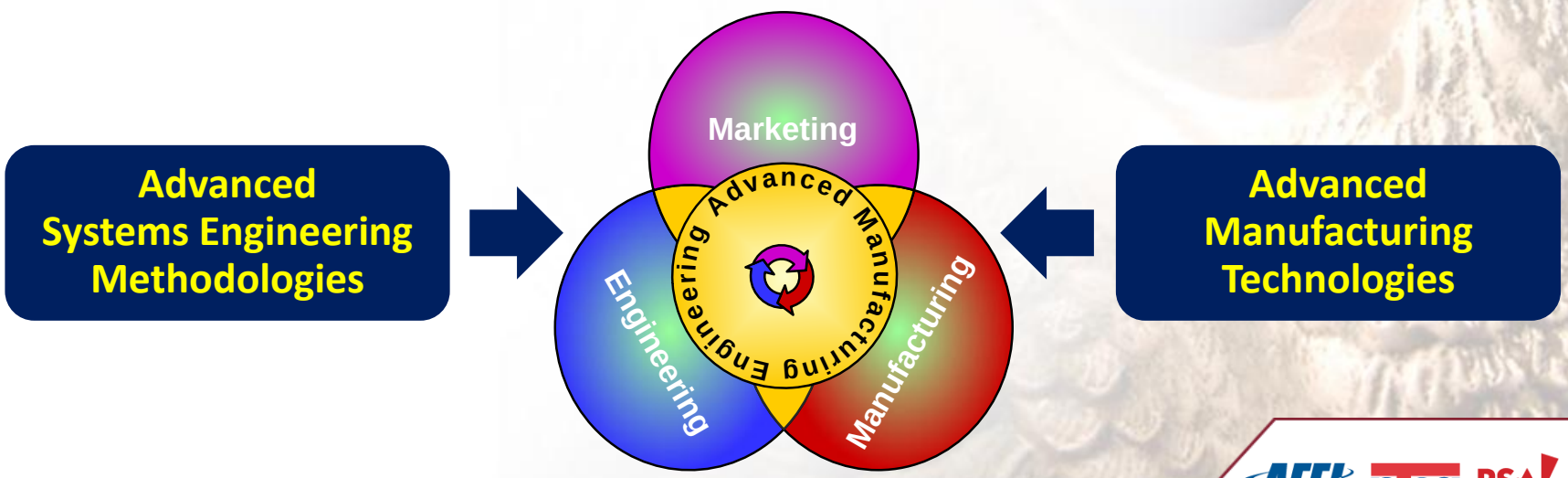
- **System integration and test are now part of manufacturing**
  - Encompasses mechanical, electrical, and software disciplines
  - Extensive testing currently used to detect and contain defects
  - Bulk of component producibility problems discovered here….

Scope of Manufacturing has Changed

AFEI nTsa PSA WID

Birth of Advanced Manufacturing

- **Fundamentally more expansive than just factory operations**
  - **Above shop floor activities across the manufacturing enterprise**
  - **Use of robotics, automation, sensing, information technology, …**
  - **Model-based methods enabled by high performance computing**
- **Fusion of engineering, manufacturing, and marketing**
  - **High value-add activities including new business & org models**
  - **Holistic "systems" view of rqmts-driven product development**
  - **"Smart design", "smart materials", "smart processes"**



Summary and Key Take Aways

- **Producibility issues drive significant "hidden factory" costs**
  - **Neglected "ility" due to lack of analytical predictive tools**
  - **M&S capabilities needed to move manufacturing to the left**
  - **Primary lever to attack affordability during early design**

- **Advanced manufacturing M&S a critical research area**
  - **Quantitative product-centric analyses to guide design decisions**
  - **Supply chain analysis tools to predict industrial base behavior**
  - **Design methods that integrate manufacturing into trade space**

- **Vision is to create a "virtual manufacturing" environment**
  - **Design methods integrate manufacturing into SE trade space**
  - **Manufacturing enterprises designed in parallel to the product**
  - **Producibility predicted, quantified, and traded as design evolves**

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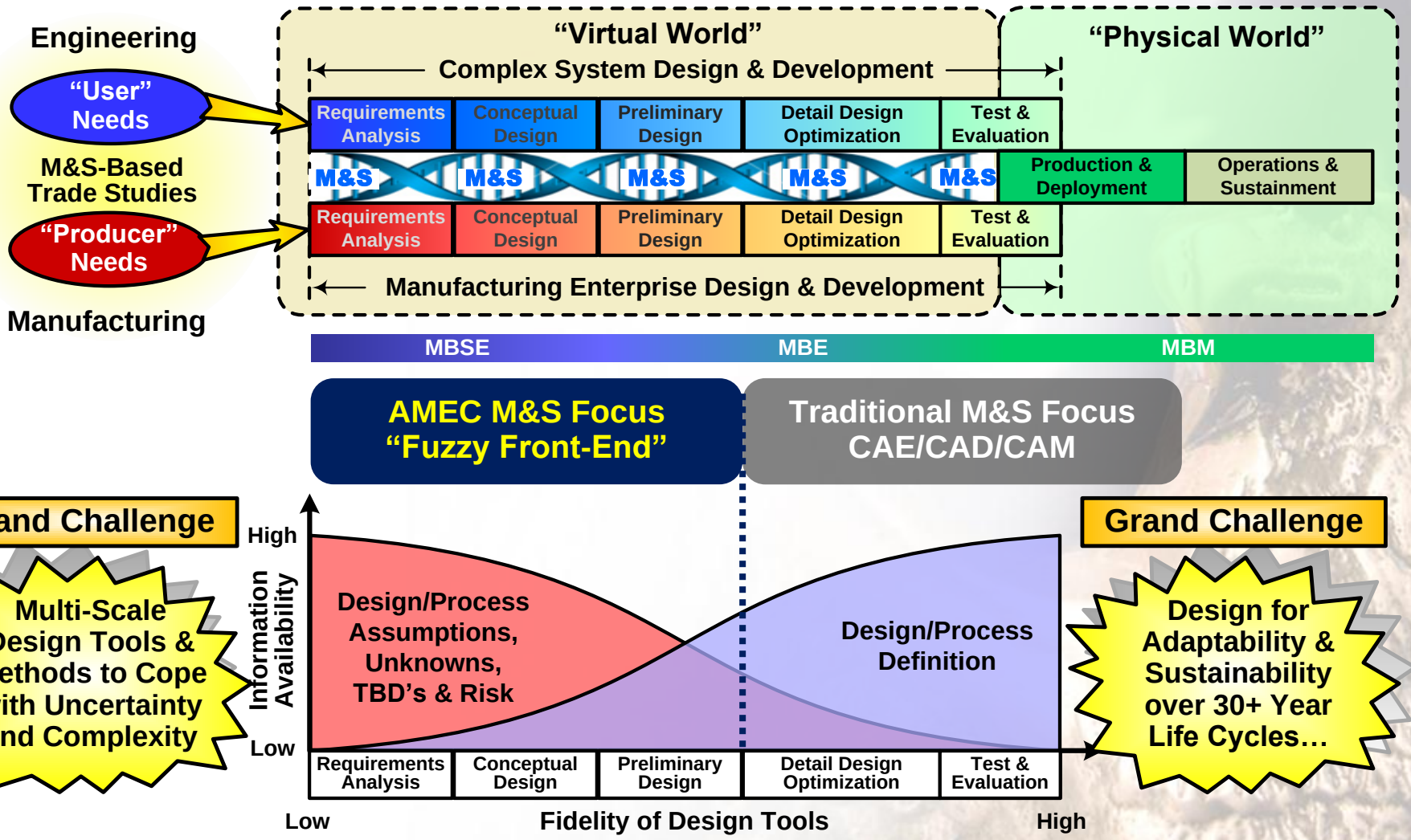
"Virtual Manufacturing" Vision



Time to "Re-Engineer" the Design Process

Breakout Questions

- **Job creation….**
  - How can virtual manufacturing M&S be used to create jobs?
  - How can M&S tools make upgrades/retrofits more affordable?
  - How much of the A&D "bleeding" can manufacturing M&S stop?

- **Workforce development….**
  - Foundational "manufacturing-systems-engineering" skills?
  - Virtual learning and development strategies for manufacturing?
  - Developing "systems thinkers" through learning by simulation?

- **Research gaps….**
  - Transformation of manufacturing from a constraint to a rqmt?
  - Potential complex system "fuzzy front-end" research topics?
  - Non-traditional engineering trans-disciplinary research topics?

Thank You
Questions?