

An Implementation of Automated Structural Design-To-Cost in a Model Based Engineering Environment

Christopher Price
Nate Sirirojvisuth

PRICE Systems



Leonor Hagberg
Brig Bjorn
Daphne Biddle

Lockheed Martin
Missiles and Fire Control



PRICE
COST ESTIMATION SOLUTIONS

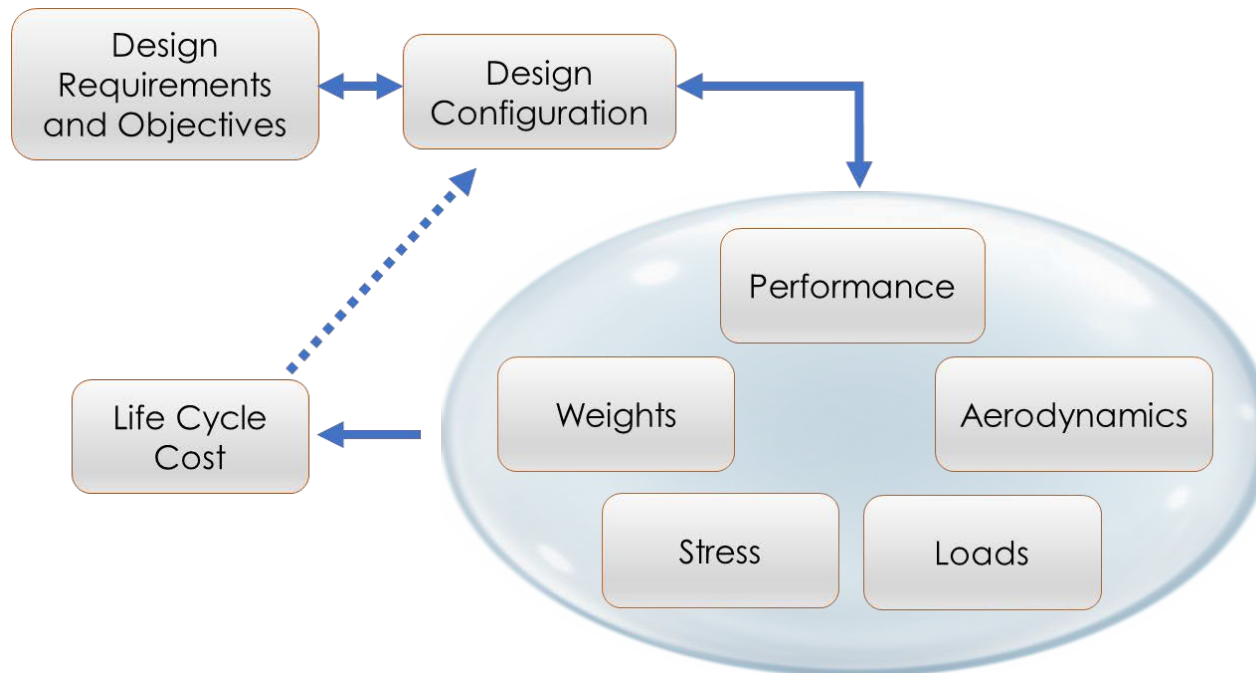
LOCKHEED MARTIN

Agenda

- **The Problem with Conventional Design Processes**
 - Current State
- **Current process**
 - CAD Model
 - Performance Model
 - Cost Model
 - System Effectiveness
- **The Desired Future State**
- **The New Paradigm**
 - A Case Study of an Integration of Structural Design and Affordability in a Model Based Engineering Environment
- **Conclusion**

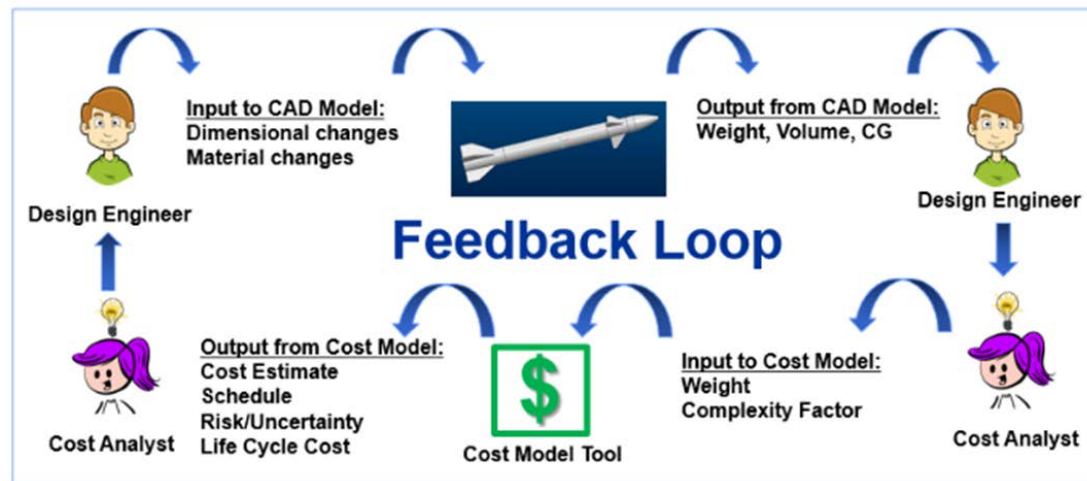
The Problem with Conventional Design Processes

- Performance, schedule, and risk often take precedence over affordability
 - Engineers and program managers operate under pressure to adhere to performance, schedule, and risk
 - Cost assessment is a by-product of committed design
 - Affordability issues influence design decisions too late in the process

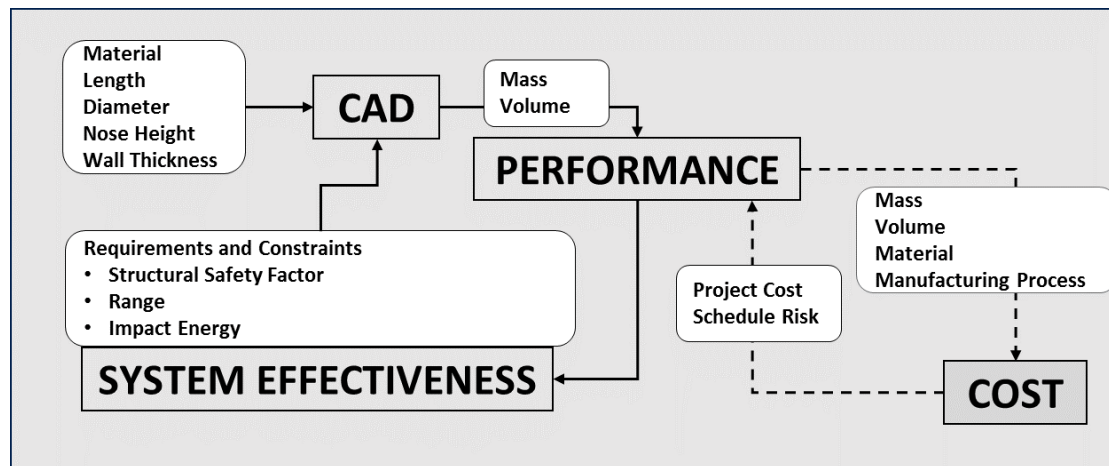


Our Current State

Process Flow



Data Flow



Current State Design Data

- The first step is in understanding the data that is needed to support a model as well as the output needed to feed other tools and design decisions
- This data flow must be understood to integrate all of the tools needed to capture data to achieve a balanced decision based upon performance, schedule, cost and risk
- The case study examined integrating:
 - CAD Model
 - Performance Model
 - Cost Model

CAD Model

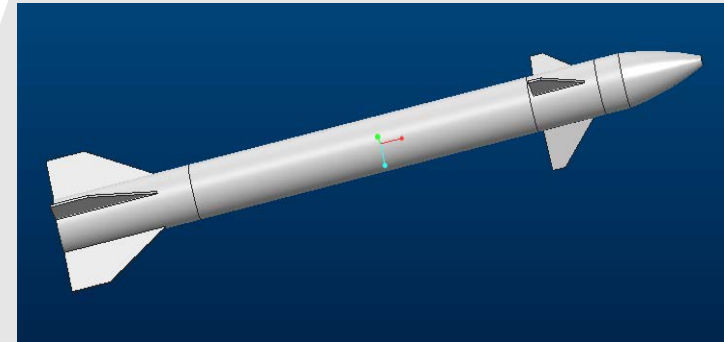
- Defines basic geometry and determines mass and volume

■ INPUTS:

- Length
- Diameter
- Wall Thickness*
- Nose Height
- Material

■ OUTPUTS:

- Component Weights
- Internal Volume



	Item	Material 1	Material 2	Material 3
Material Description		Aluminum 6061-T6511	S31266 Stainless Steel	Titanium Ti- 6Al-4V
Yield Strength (GPA)		276	470	570
Density (lb/in ³)		0.097	0.296	0.160
*Relative Wall Thickness for same safety factor		1	0.587	0.484

Performance Model

- Calculates flight trajectory and performance

Force Equations

$$\sum \hat{F} = \hat{T} + \hat{D} + \hat{W},$$

$$\hat{T} = \hat{A}_e(p_e - p_0) + \frac{dm}{dt} \hat{u}_e \cong \frac{dm}{dt} \cdot Isp \cdot \hat{g}_0,$$

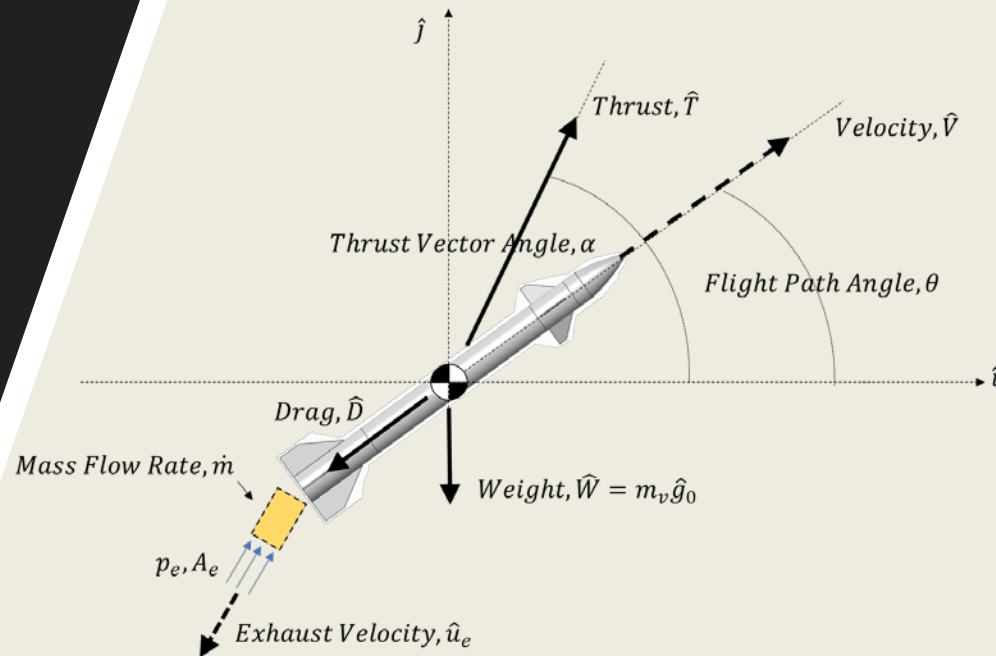
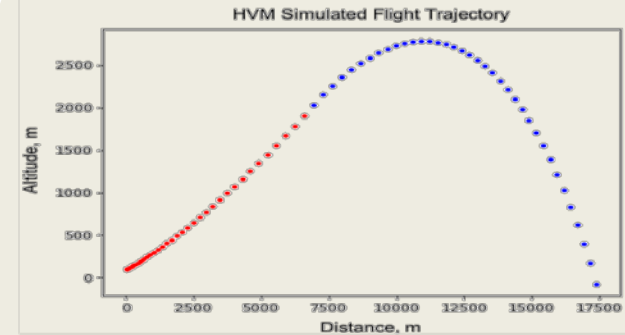
$$\hat{D} = \frac{\rho \hat{V}^2 C_D A}{2}, \quad \text{and} \quad \hat{W} = m_v \hat{g}_0$$

Simulation Routine

$$S = \begin{bmatrix} m_v \\ m_p \\ u \\ v \\ \theta \\ alt \\ dis \end{bmatrix},$$

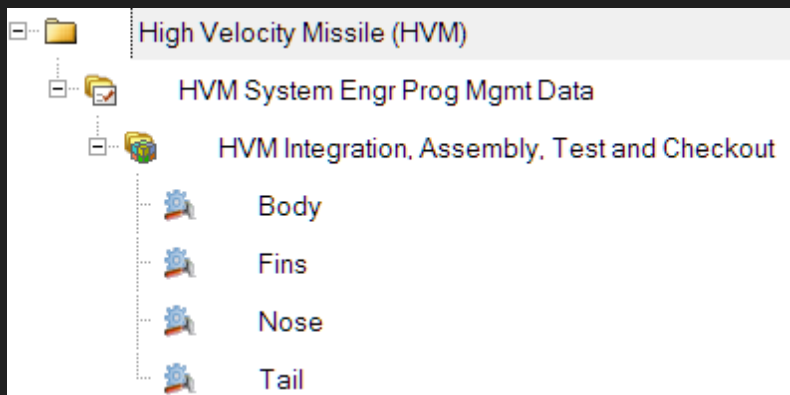
$$\hat{a} = \frac{\hat{T} + \hat{D} + \hat{W}}{m_v}, \quad \Delta \hat{V} = \hat{a} \Delta t,$$

$$\dot{m} = \frac{T}{Isp}, \quad S^* = \begin{bmatrix} m_v - \dot{m} \\ m_p - \dot{m} \\ u + a_i \Delta t \\ v + a_j \Delta t \\ \arctan\left(\frac{v + a_j \Delta t}{u + a_i \Delta t}\right) \\ alt + V_j \Delta t \\ dis + V_i \Delta t \end{bmatrix},$$



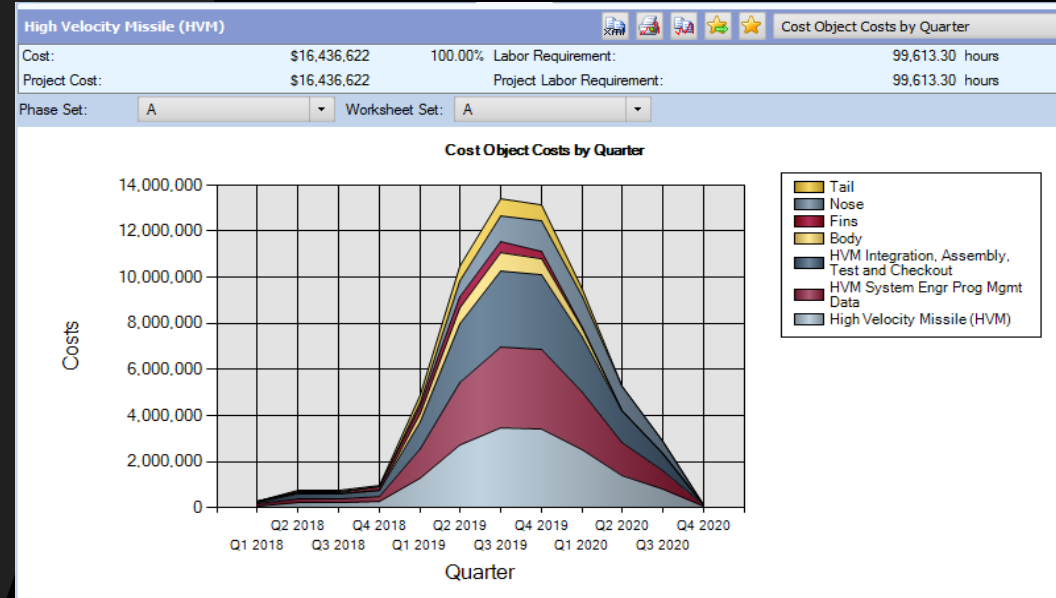
Cost Model

- Analyzes total project cost and schedule based on material (weight) and processes (manufacturing complexity)



High Velocity Missile (HVM)				
Cost:	\$16,436,622	100.00%	Labor Requirement:	99,613.30 hours
Project Cost:	\$16,436,622		Project Labor Requirement:	99,613.30 hours
Phase Set:	A		Worksheet Set:	A
Costs : High Velocity Missile (HVM) - [System Folder] Currency in USD (\$) (as spent)	Total	Development	Production	
1 High Velocity Missile (HVM)	16,436,622	691,148	15,745,474	
2 HVM System Engr Prog Mgmt Data	16,436,622	691,148	15,745,474	
3 HVM Integration, Assembly, Test and Checkout	15,539,121	622,883	14,916,238	
4 Body	3,009,923	125,150	2,884,773	
5 Fins	1,799,009	72,541	1,726,468	
6 Nose	6,446,633	210,089	6,236,544	
7 Tail	2,788,453	112,197	2,676,256	

Item	Material 1	Material 2	Material 3
Material Description	Aluminum 6061-T6511	S31266 Stainless Steel	Titanium Ti-6Al-4V
Casting Process Complexity	5.890	6.050	6.130
Machining Process Complexity	6.140	6.300	6.380
Precision Machining Complexity	6.490	6.670	6.750



System Effectiveness Model

- Amalgamates all engineering metrics in a single number
 - Objective is to increase system effectiveness while meeting all requirements

Missile System Effectiveness

$$= \frac{\text{Total Utility}}{\text{Total Project Cost}}$$

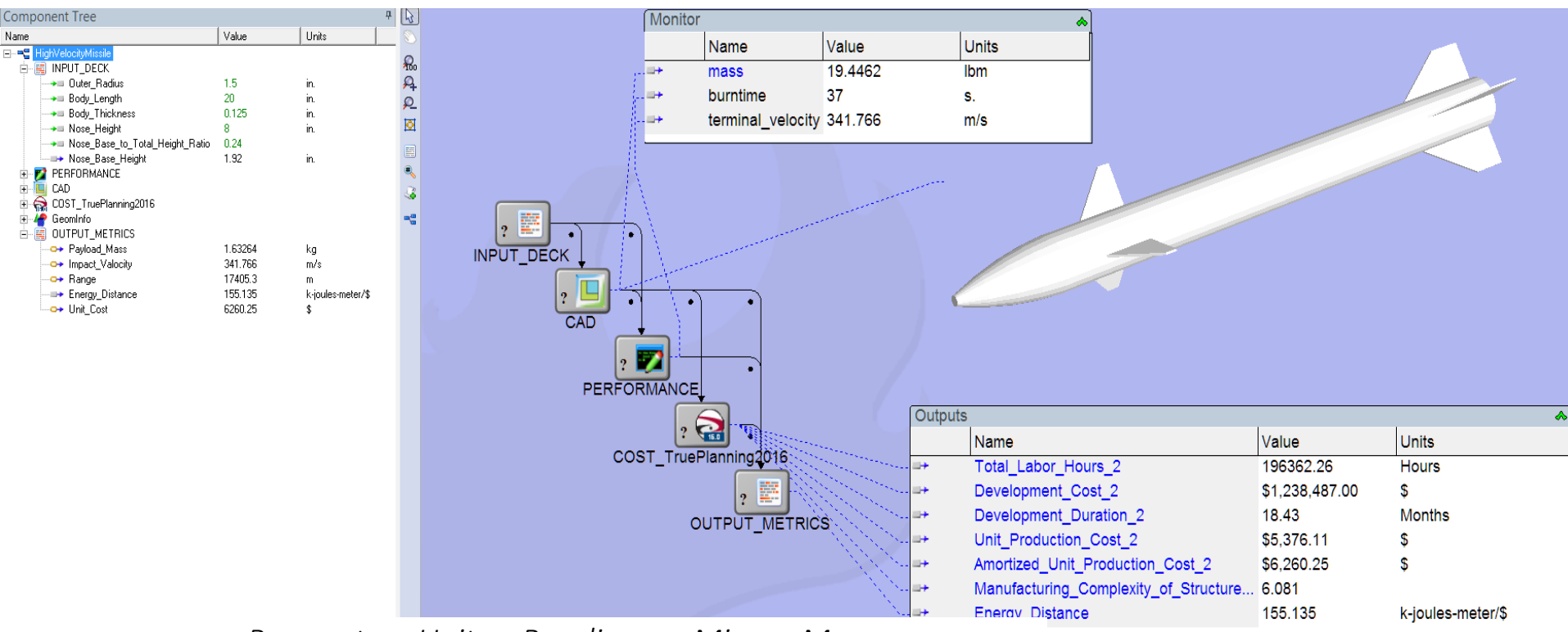
$$= \frac{\text{Impact Energy} * \text{Range} * \text{Production Quantity}}{\text{Total Development and Production Cost}}$$

$$= \frac{(1/2 \cdot m_v \cdot V^2) * \text{Range}}{\text{Amortized Unit Cost}}, \quad \frac{\text{kJ} \cdot \text{m}}{\$}$$

Desired Future State

- Model-based design
- Integrated data flow
- Integrated process flow
- Faster iteration

Model Based Engineering (MBE) Implementation



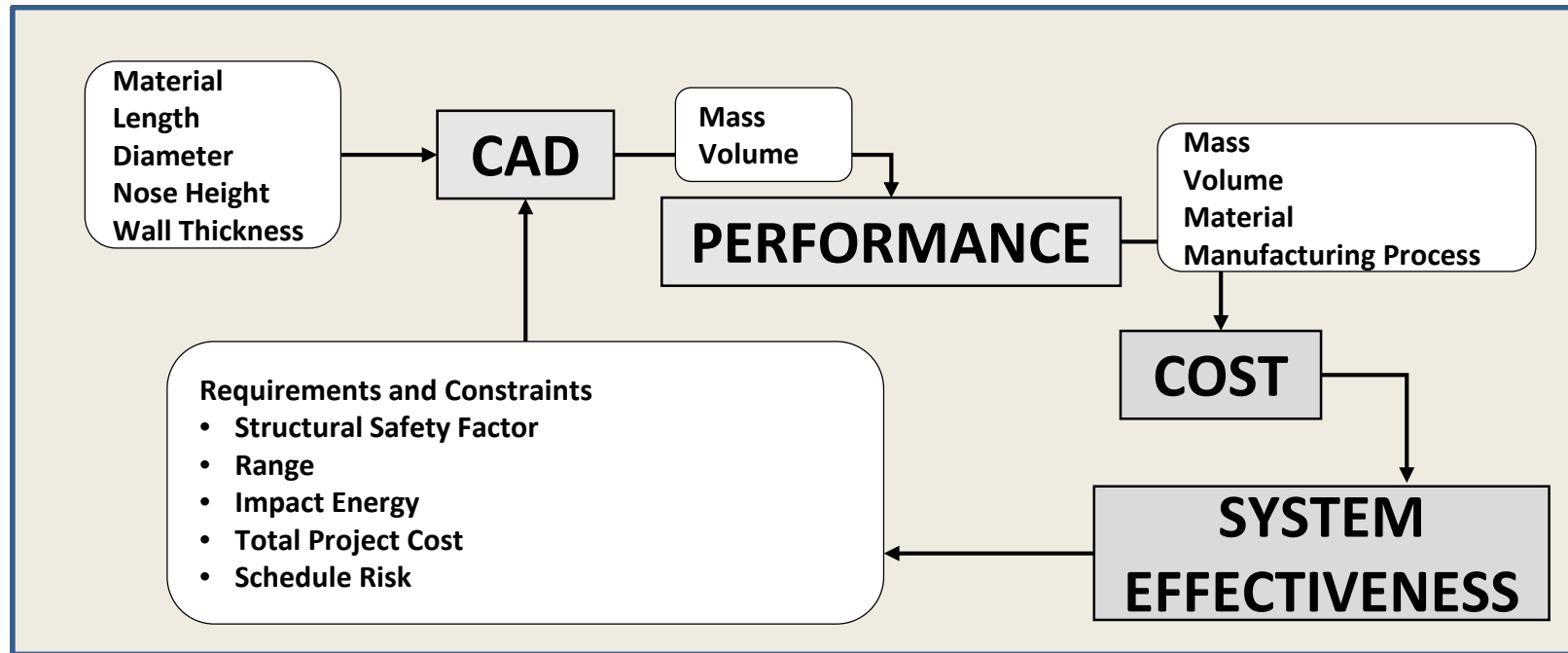
Parameter	Unit	Baseline	Min	Max
Body Length	inch	15	10	20
Body Diameter	inch	3	1	5
Wall Thickness	inch	1.5	1	3
Nose Height	inch	6	5	10
Production Unit	unit	1000	100	5000
Material	--	Aluminum, Steel, Titanium		
Manufacturing Process	--	Casting, Hi/Low Precision Machining		

The New Paradigm

Automation and Design Space Exploration

The New Paradigm Process

- Streamlined process – shorten development time
- SMEs are virtually co-located
- Decisions are made in a timely manner

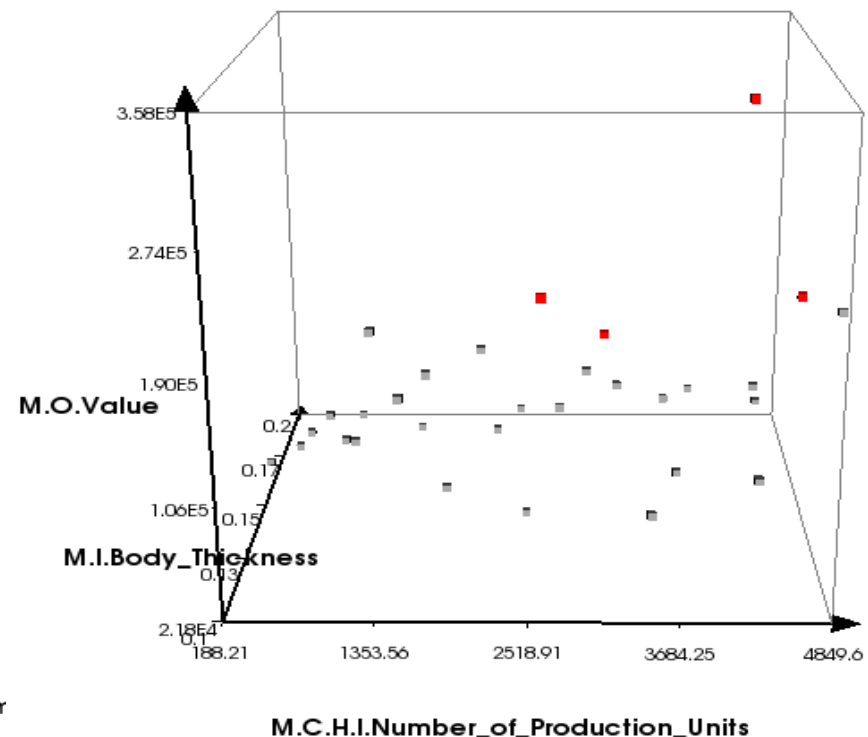
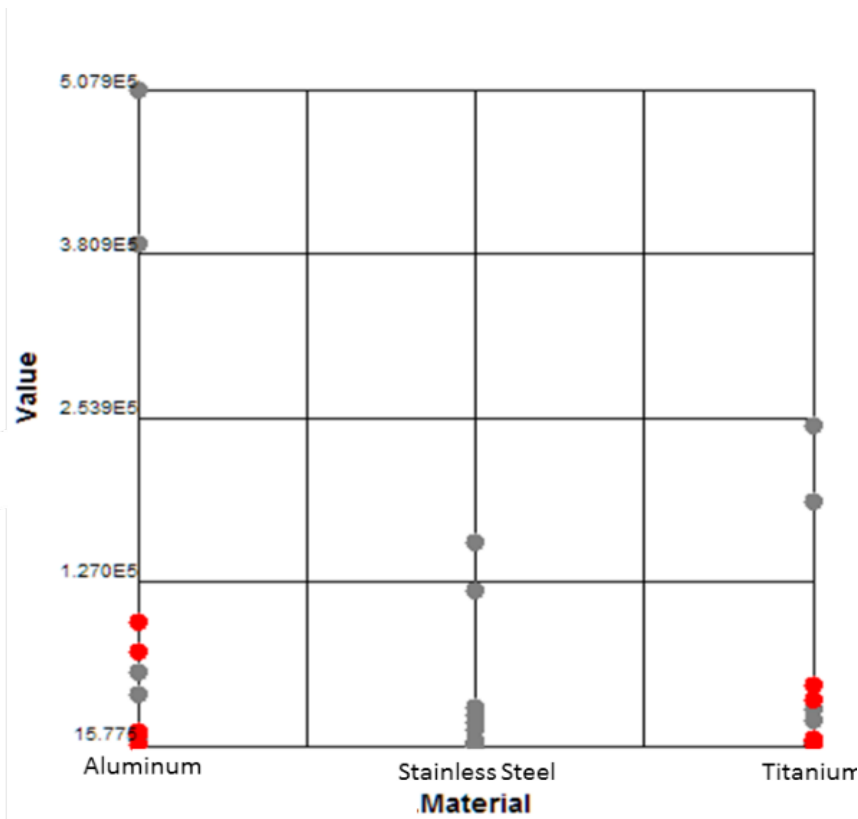


MBE-Driven Agile Process

- MBE-driven analyses - design of experiment (DOE) methodology
 - Parameter Scan
 - Sensitivity Analyses
 - Design Variable Interactions
 - Design Space Exploration
 - Risk-Based Alternative Selection
- The result is an efficient process to discover best-value solutions based upon performance, schedule, cost and risk

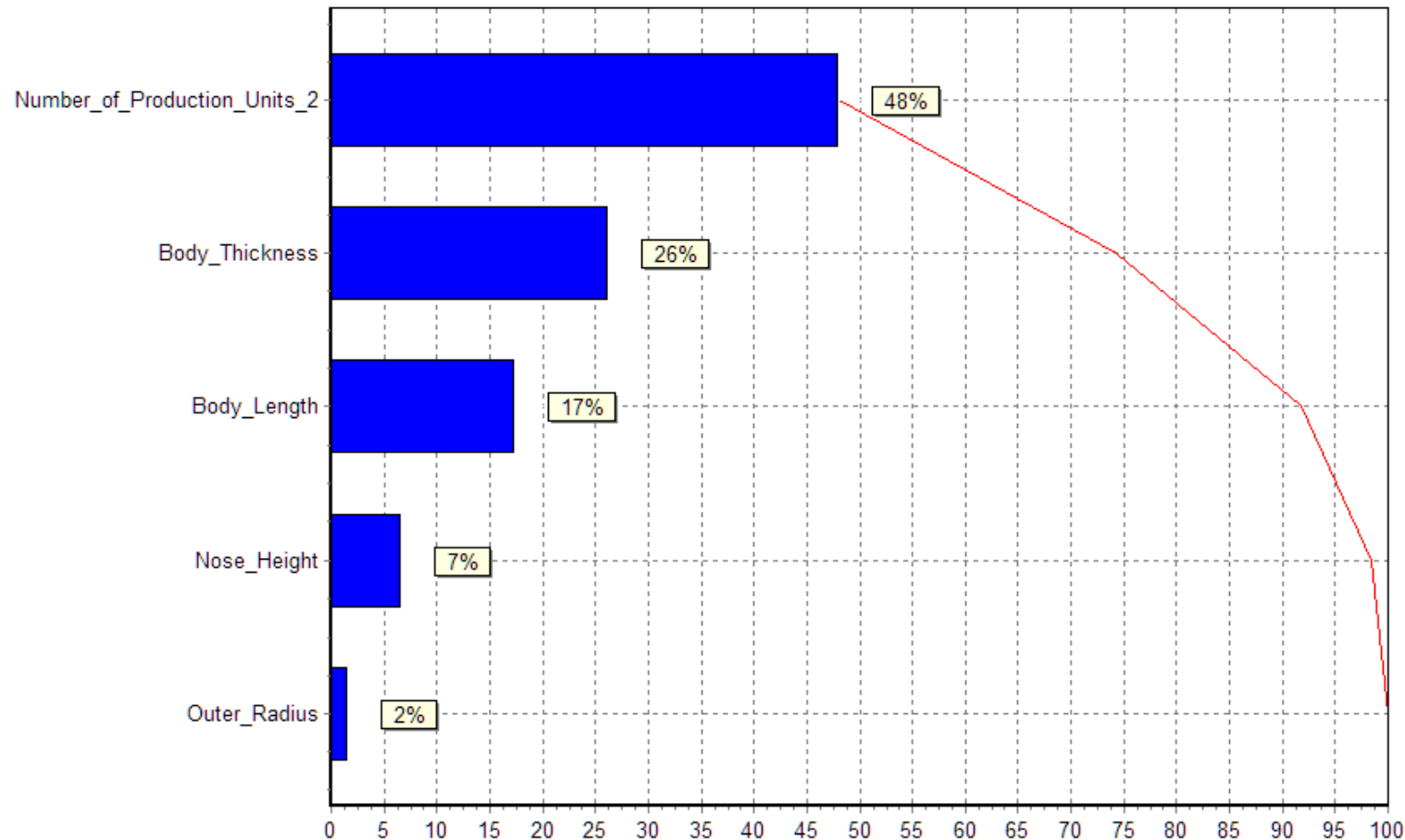
Parameter Scan

- Quickly runs through every combination of extreme values
 - Both discrete and continuous independent variables
- Allows early screening of infeasible region of design space
 - Reduce overall run time



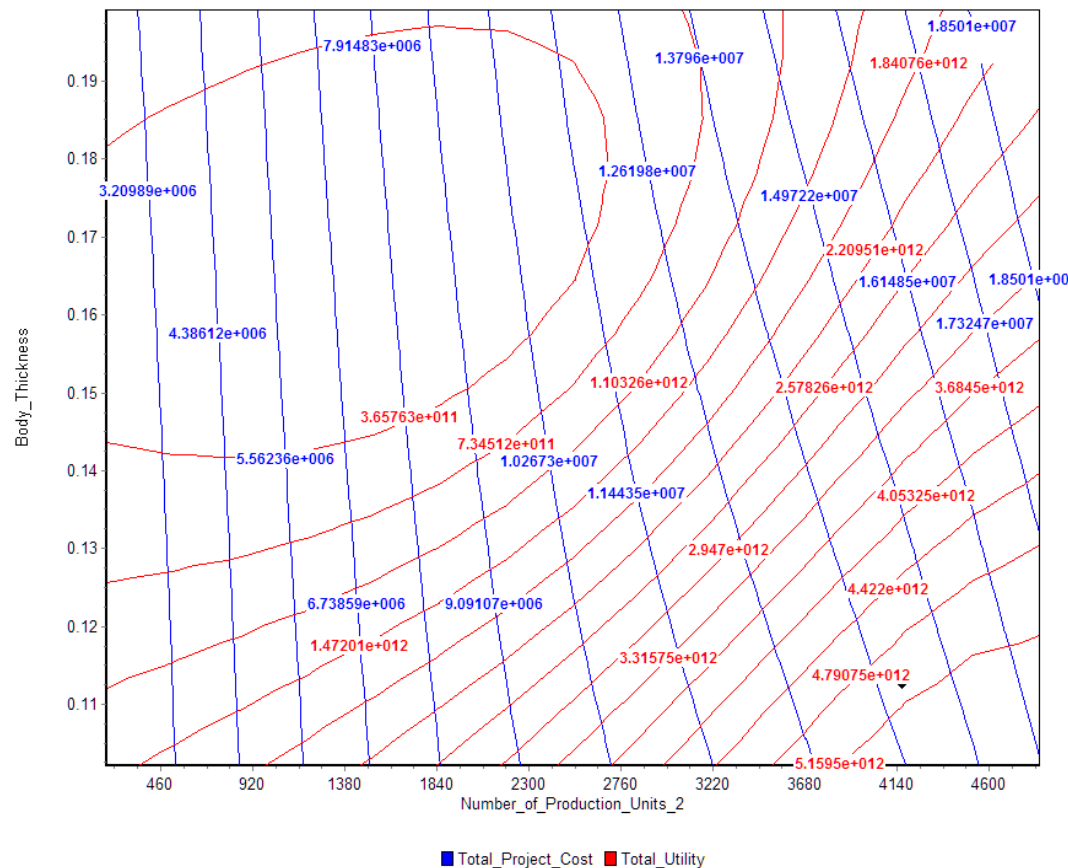
Sensitivity

- Pareto Plot shows how important each input is to the output, e.g., system effectiveness



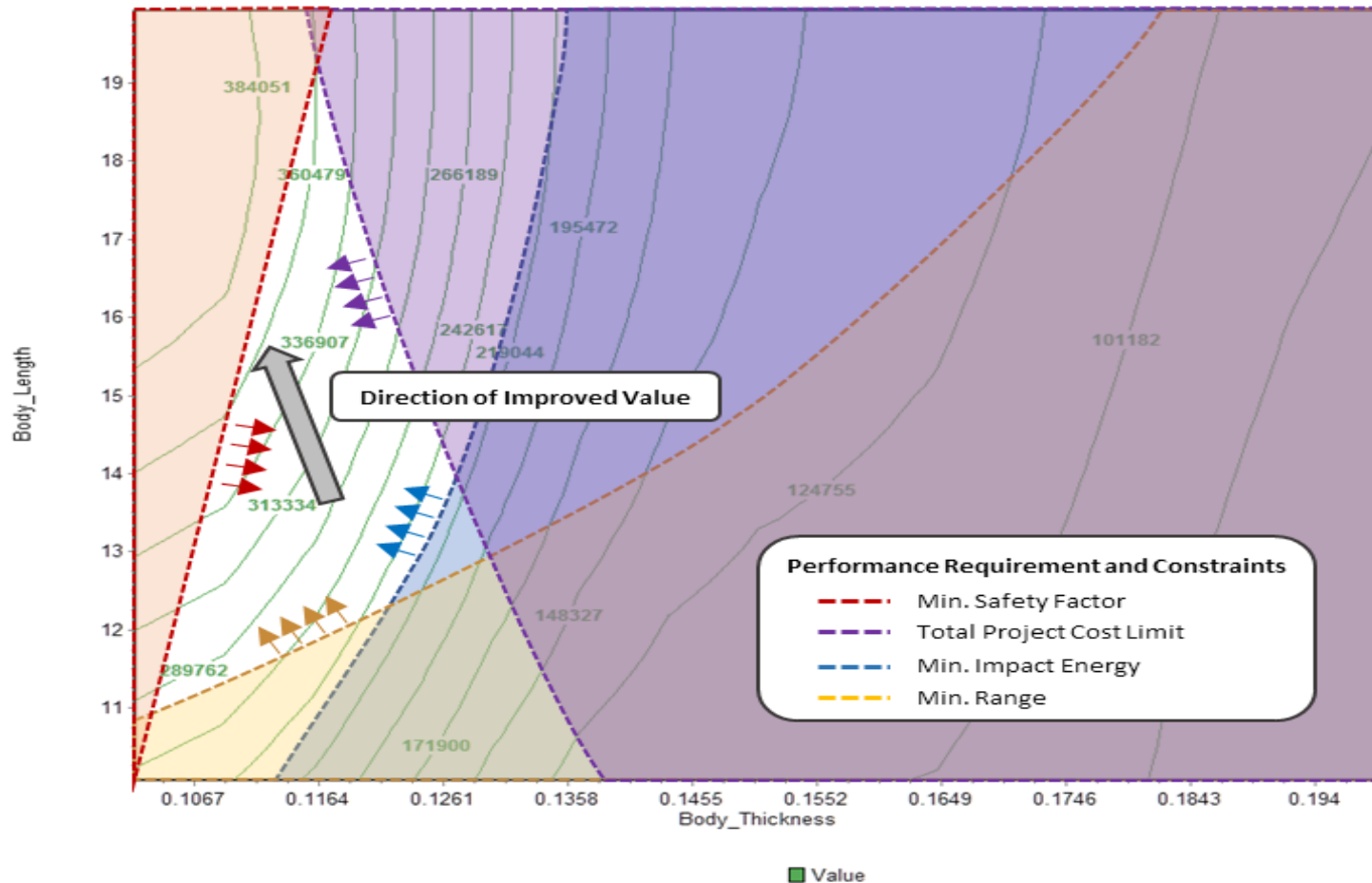
Interaction

- Carpet plots can provide the sense of interaction between different inputs and outputs
 - Example: wall thickness/production quantity vs total utility/project cost



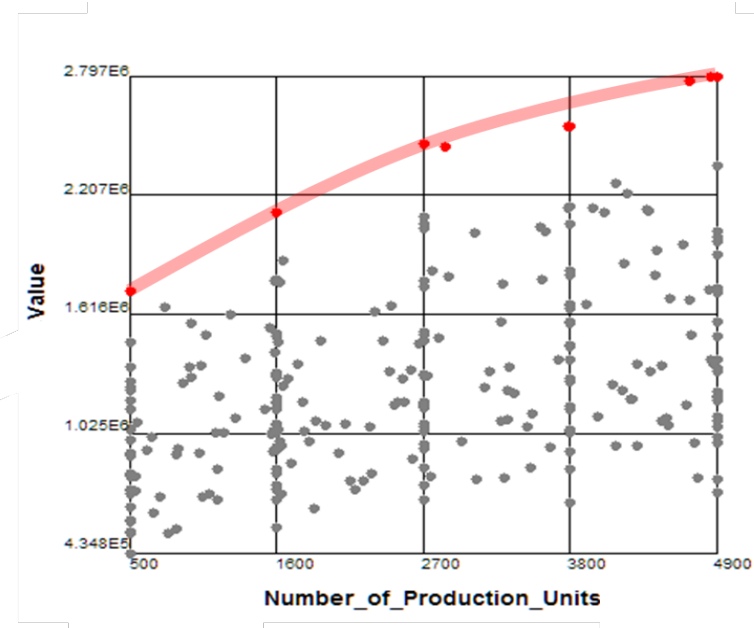
Design Space Exploration

- Establishes feasible design space considering design constraints
- Provides guidance on the locations of desirable alternatives

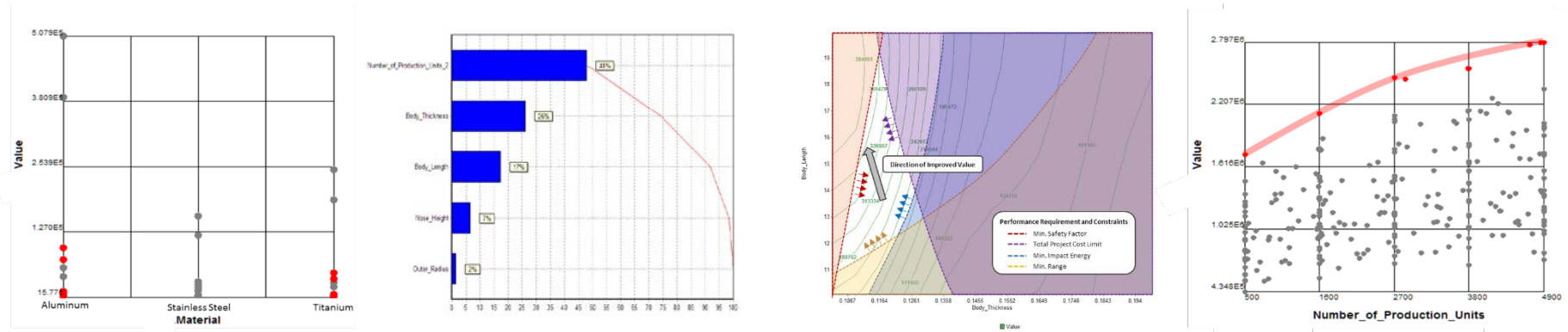


Risk-Based Alternative Selection

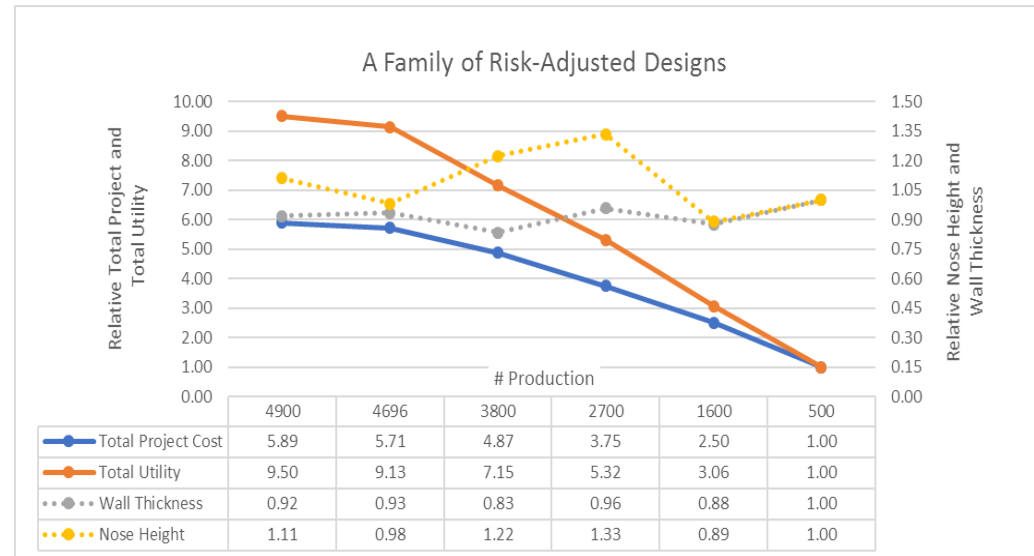
- A family of solutions can be studied as opposed to point designs
- Incorporate risk and uncertainty to study their impacts, e.g. funding level and production volume uncertainties.
- Can be used as communication tool to
 - Make good design decisions
 - Negotiate better requirements
 - Provide management visibility and traceability
 - Support GAO Best Practices



Summary of a MBE-Driven Agile Process



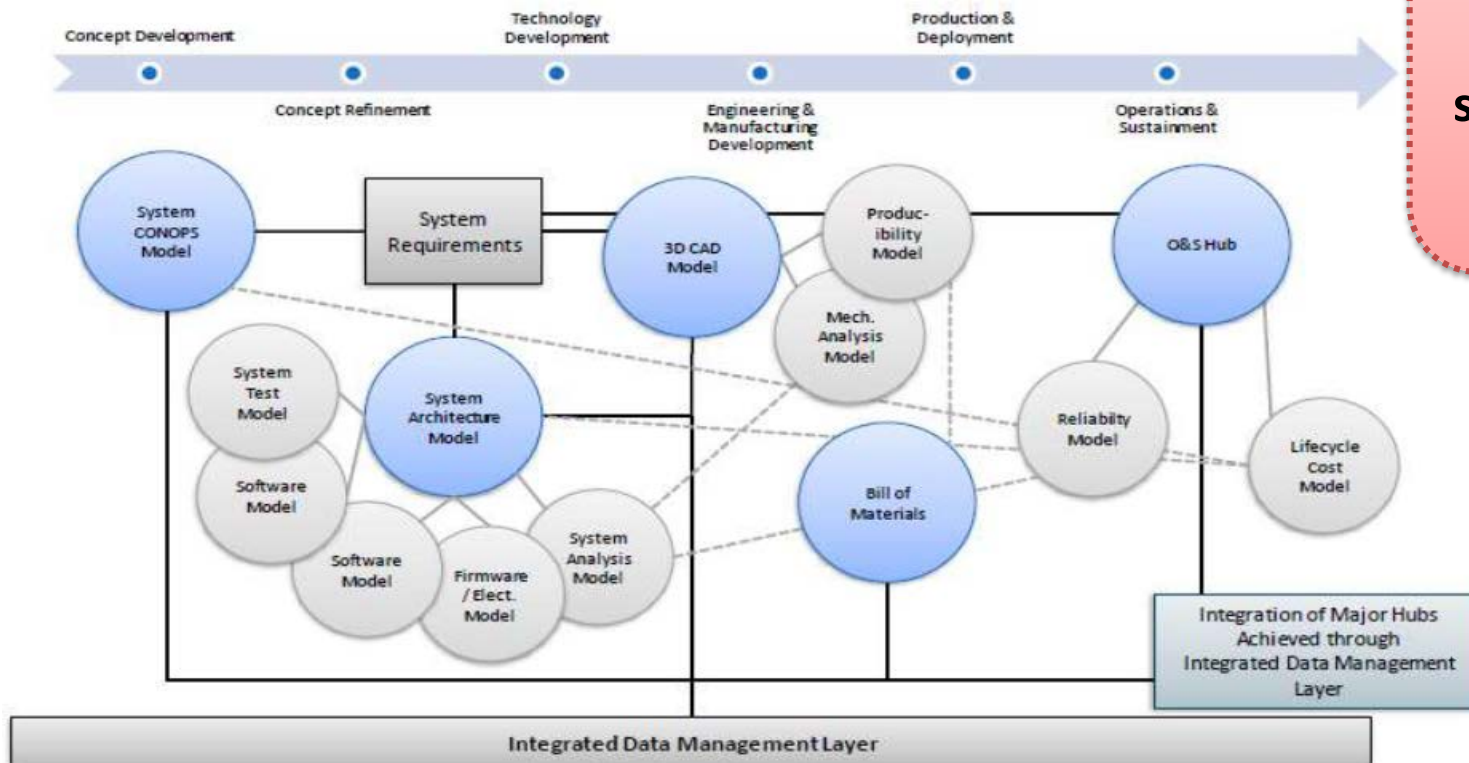
- Makes use of existing MBE technology
- Eliminates brute force
- Improves traceability
- Affords more point designs to be “carried over” to next iteration



New Paradigm Environment

- A highly integrated and collaborative environment
 - Allows on-demand management visibility
 - Traceability to requirement sources
 - Improvement to design/cost feedback loop
 - High quality and up-to-date design data
 - Delivers best value product

An MBE environment streamlines the design process resulting in a broader solution space and greater efficiency



Conclusion

Model Based Engineering:

- Reduces development cycle time through improved efficiency
- Is a key enabler for finding optimal solution
- Enables value-driven decision, i.e., affordability concerns are equally important as performance requirements
- Provides synergy with GAO best practices

Questions?

