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

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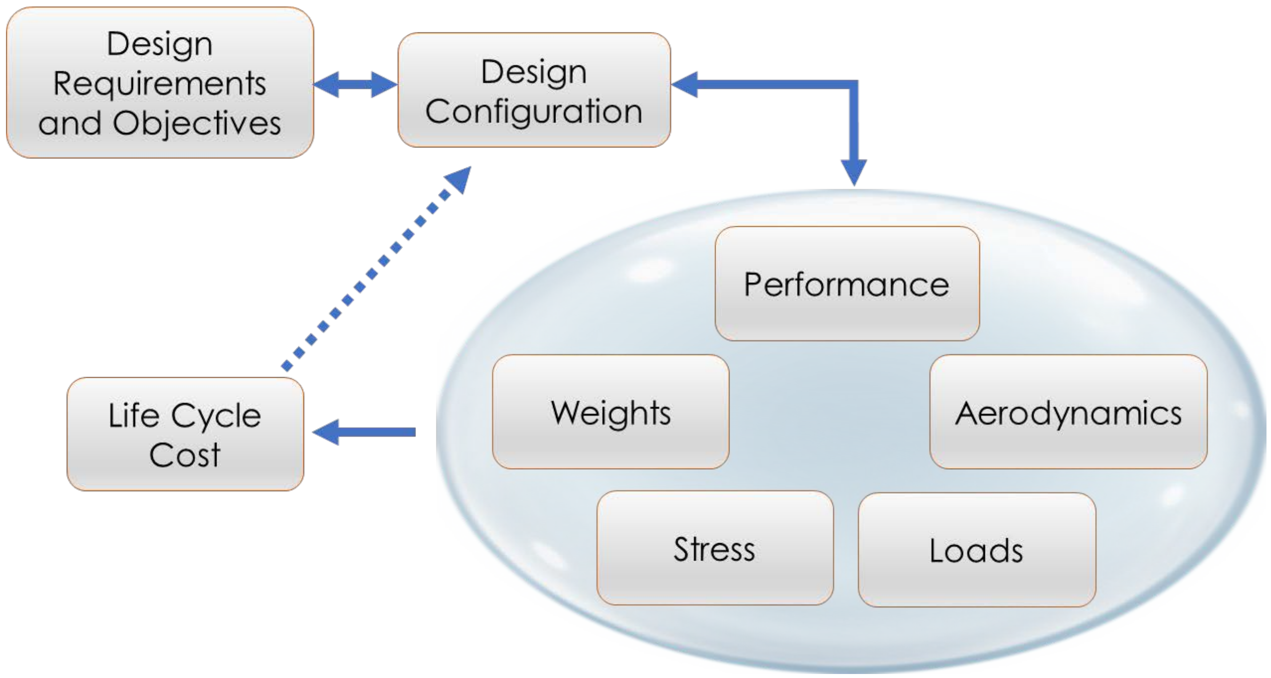
Agenda

- **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



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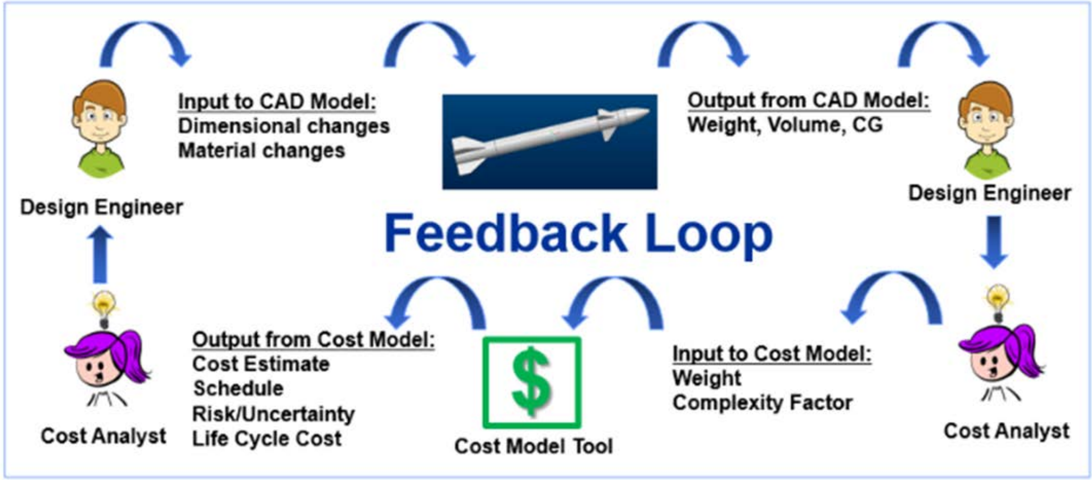
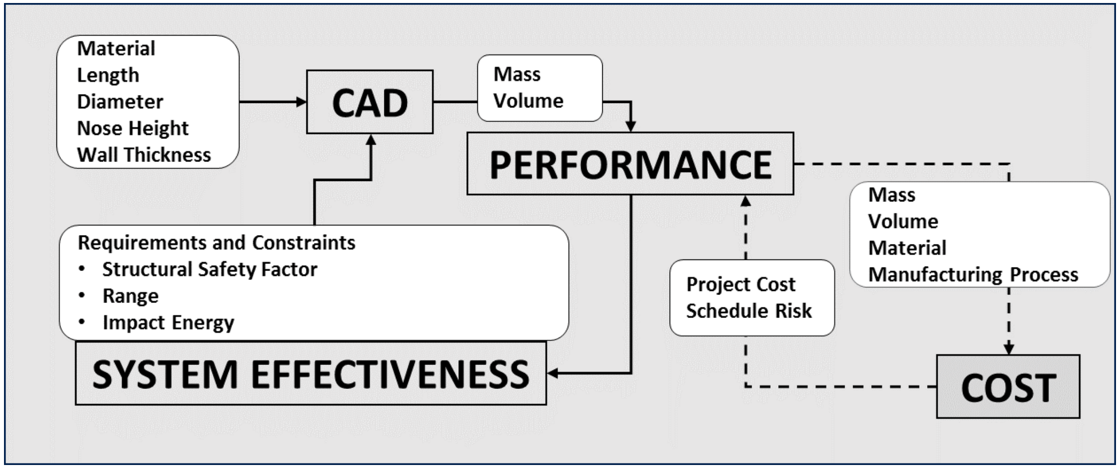
Our Current State

Process Flow



Data Flow



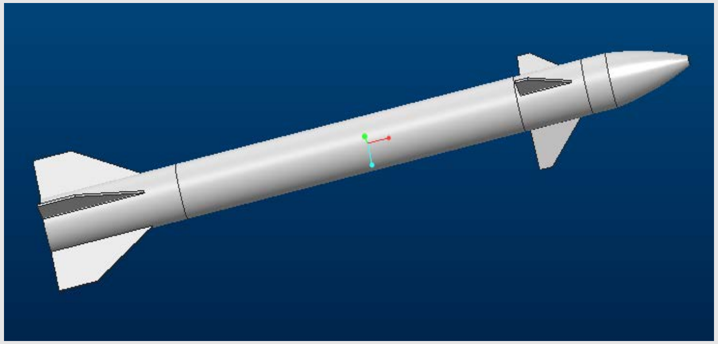
Current State Design Data

- 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

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

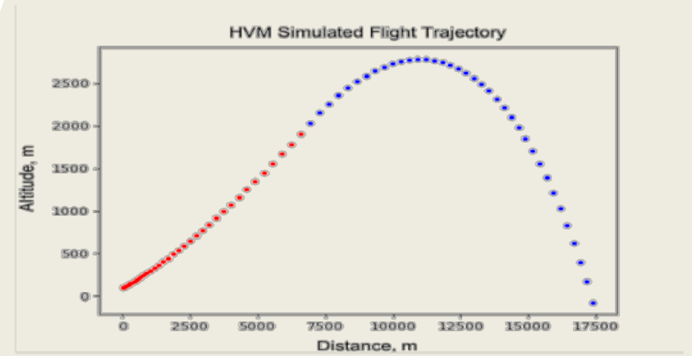
$$\hat{T} = \hat{A}_e(p_e - p_0) + \frac{dm}{dt}\hat{u}_e \quad \cong \frac{dm}{dt} \cdot Isp \cdot \hat{g}_0,$$

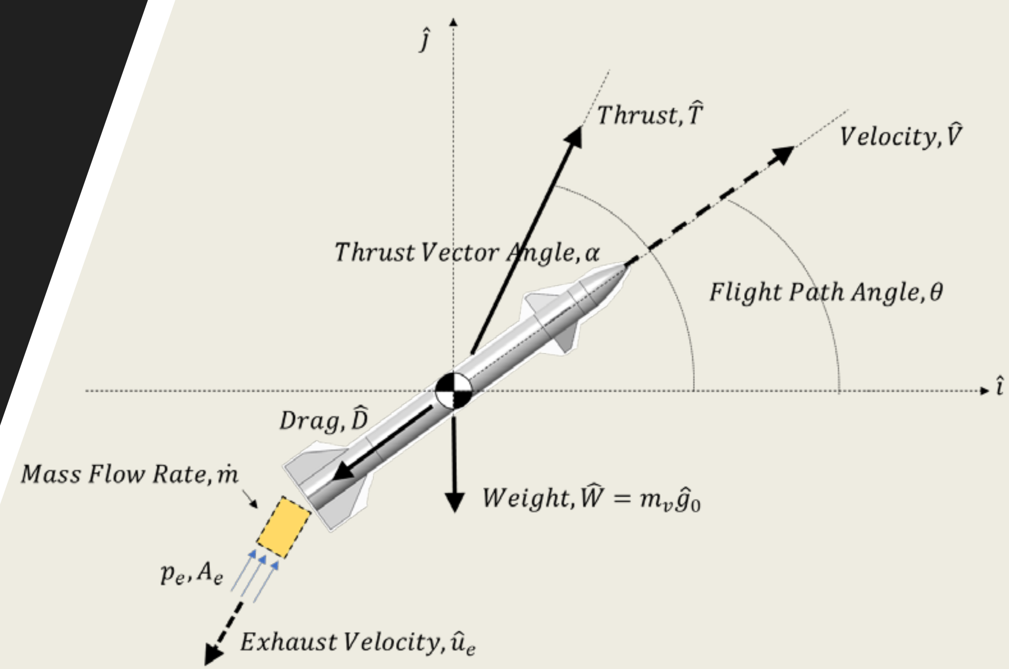
$$\hat{D} = \frac{\rho \hat{V}^2 C_D A}{2}, \qquad and \quad \hat{W} = m_v \hat{g}_0$$

Simulation Routine

$$S = \begin{bmatrix} m_v \\ m_p \\ u \\ v \\ \theta \\ alt \\ dis \end{bmatrix}, \qquad \hat{a} = \frac{\hat{T} + \hat{D} + \hat{W}}{m_v}, \qquad \Delta\hat{V} = \hat{a}\Delta t,$$

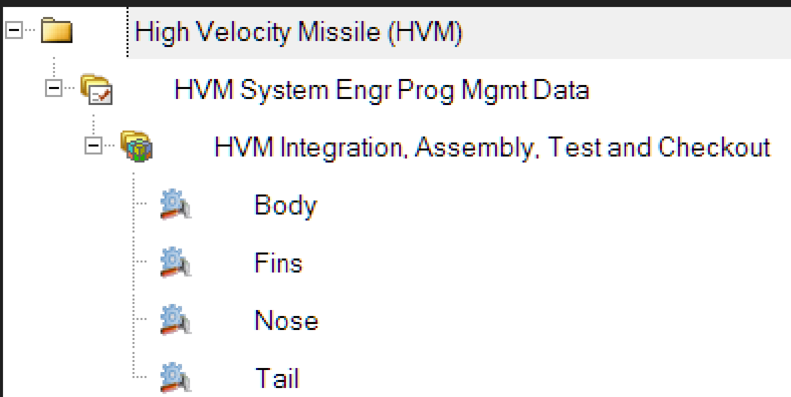
$$\dot{m} = \frac{T}{Isp}, \qquad S^* = \begin{bmatrix} m_v - \dot{m} \\ m_p - \dot{m} \\ u + a_i \Delta t \\ v + a_j \Delta t \\ \mathrm{atan}\left(\frac{v + a_j \Delta t}{u + a_i \Delta t}\right) \\ alt + V_j \Delta t \\ dis + + V_i \Delta t \end{bmatrix},$$





Cost Model

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

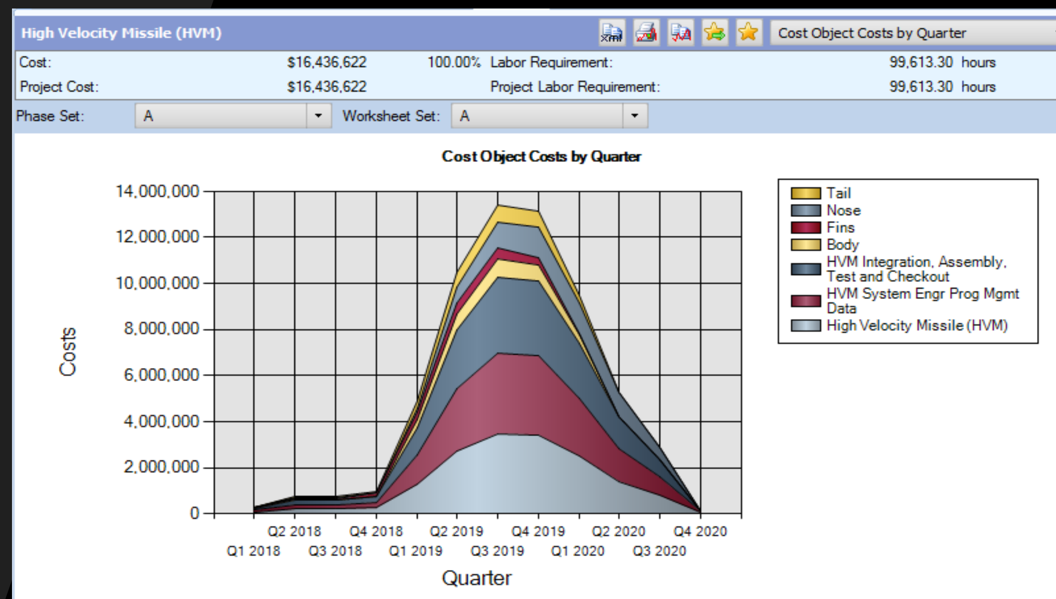


Item	Material 1	Material 2	Material 3
Material Description	*Aluminum 6061-T6511*	*S31266 Stainless Steel*	*Titanium Ti-6Al-4V*
Casting Process Complexity	*5.890*	*6.050*	*6.130*
Machining Process Complexity	*6.140*	*6.300*	*6.380*
Precision Machining Complexity	*6.490*	*6.670*	*6.750*

High Velocity Missile (HVM) — Cost Object Costs by Phase

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



System Effectiveness Model

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

$$Missile\ System\ Effectiveness$$

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

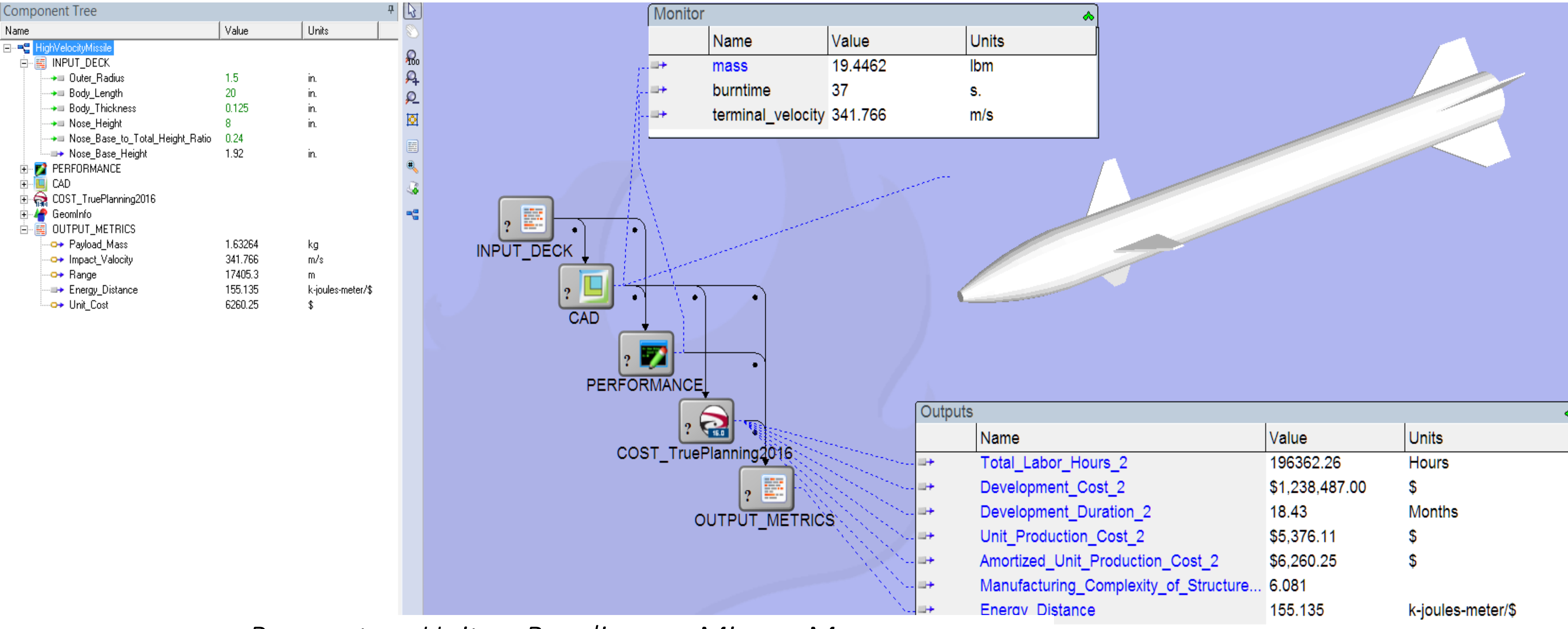
$$= \frac{Impact\ Energy * Range * Production\ Quantity}{Total\ Development\ and\ Production\ Cost}$$

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

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		

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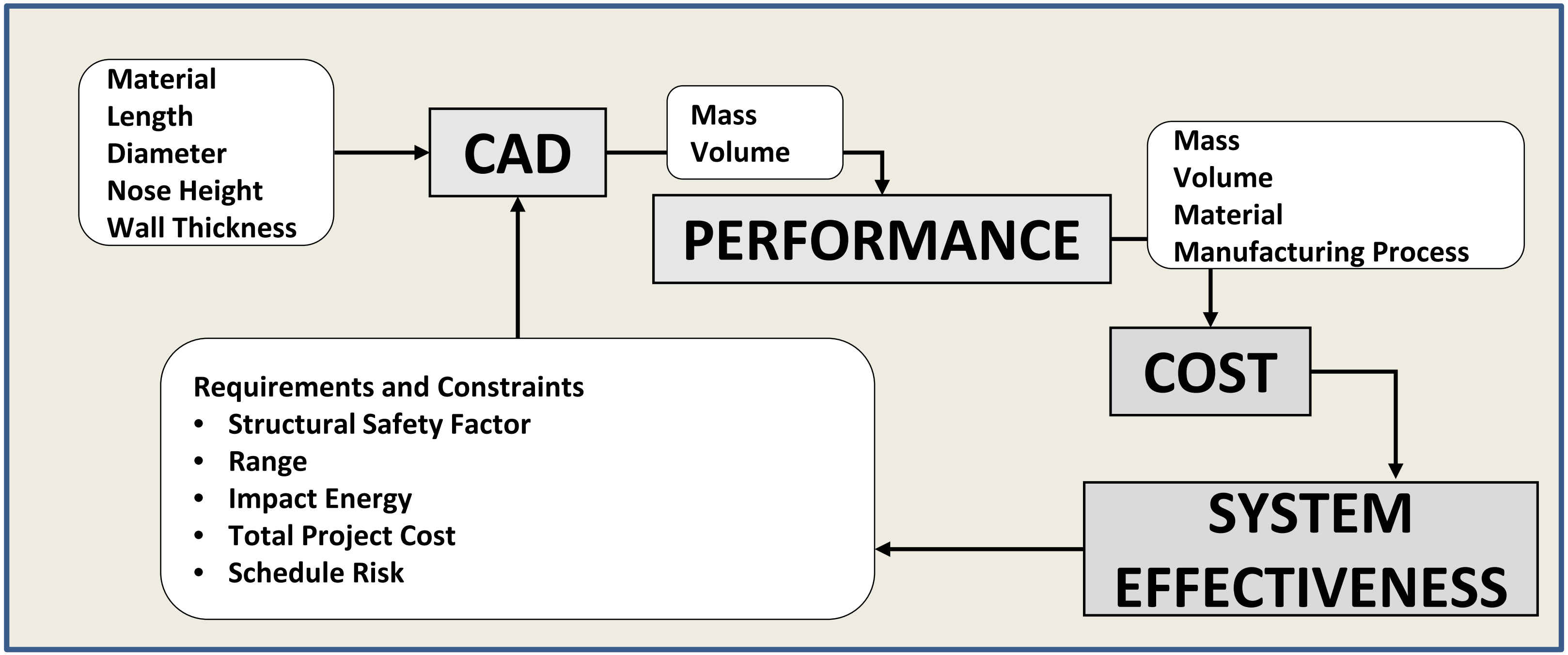
The New Paradigm

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

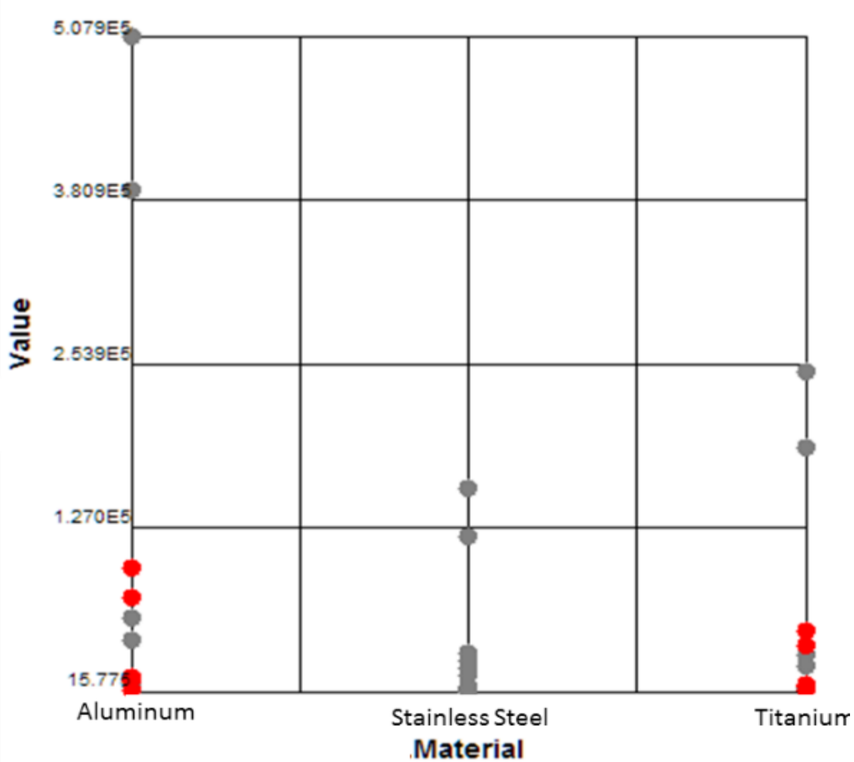


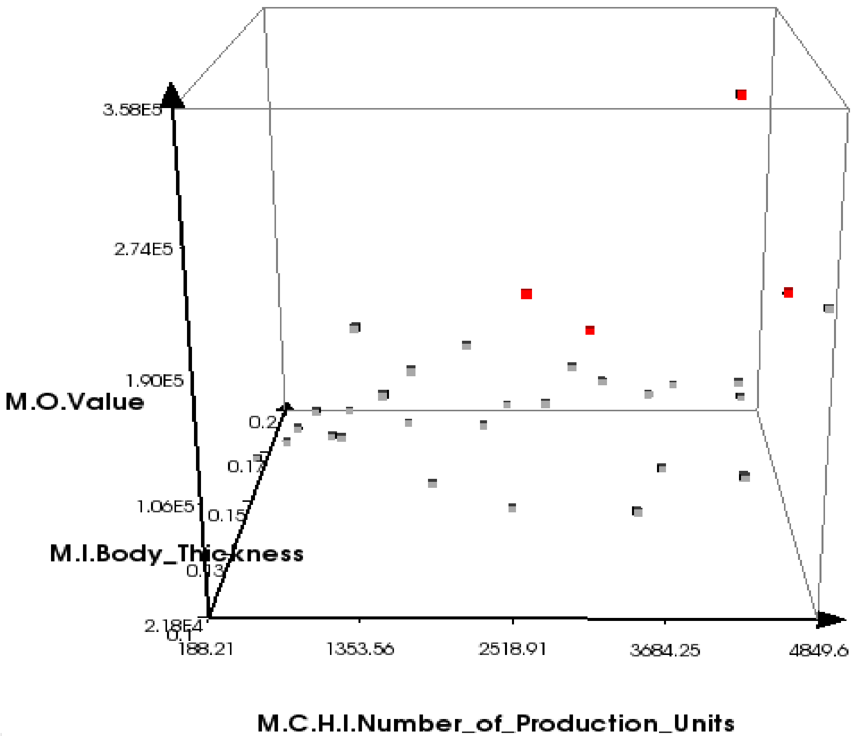
MBE-Driven Agile Process

- 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

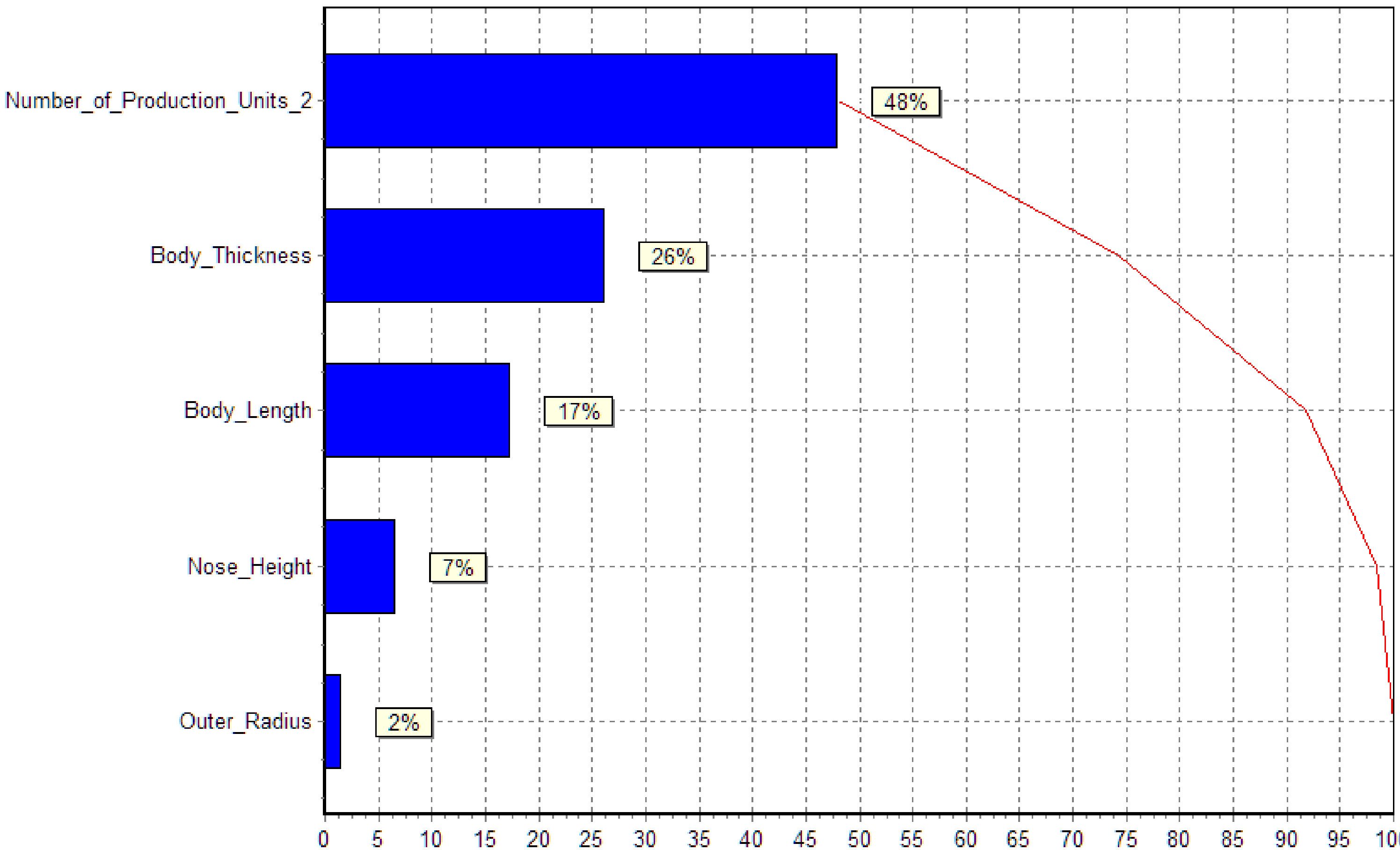
- Quickly runs though every combination of extreme values
  - Both discrete and continuous independent variables
- Allows early screening of infeasible region of design space
  - Reduce overall run time





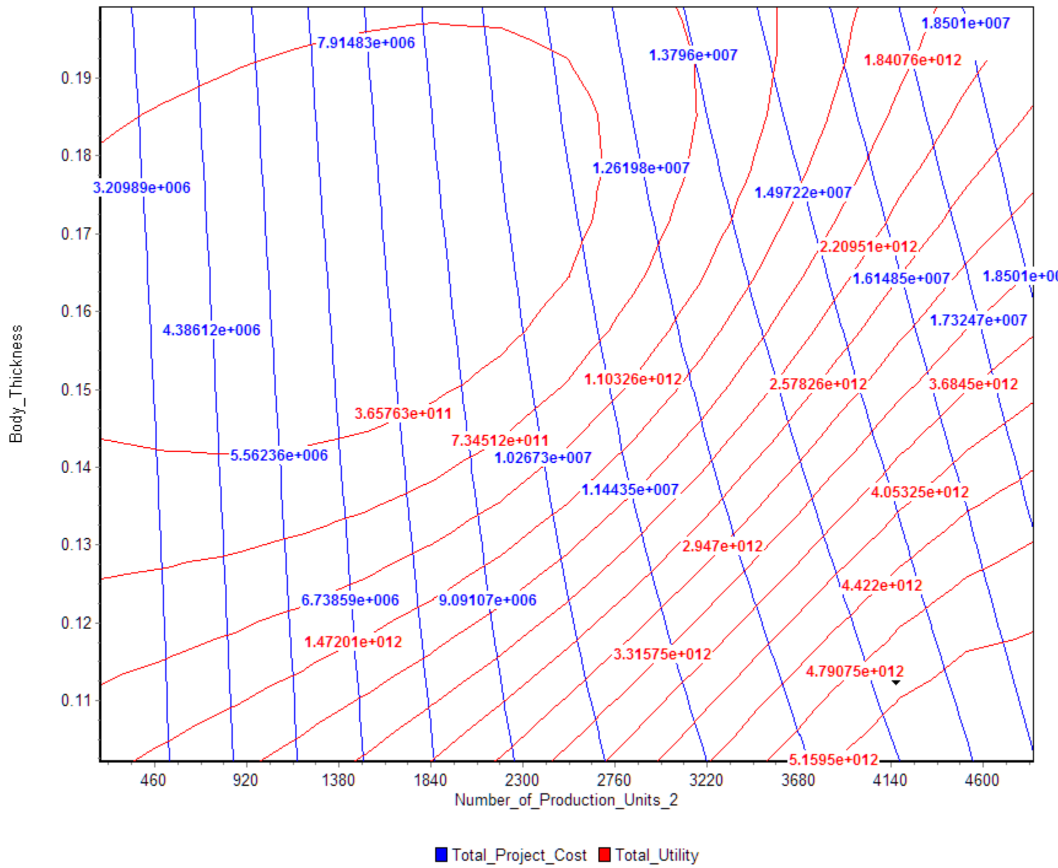
Sensitivity

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



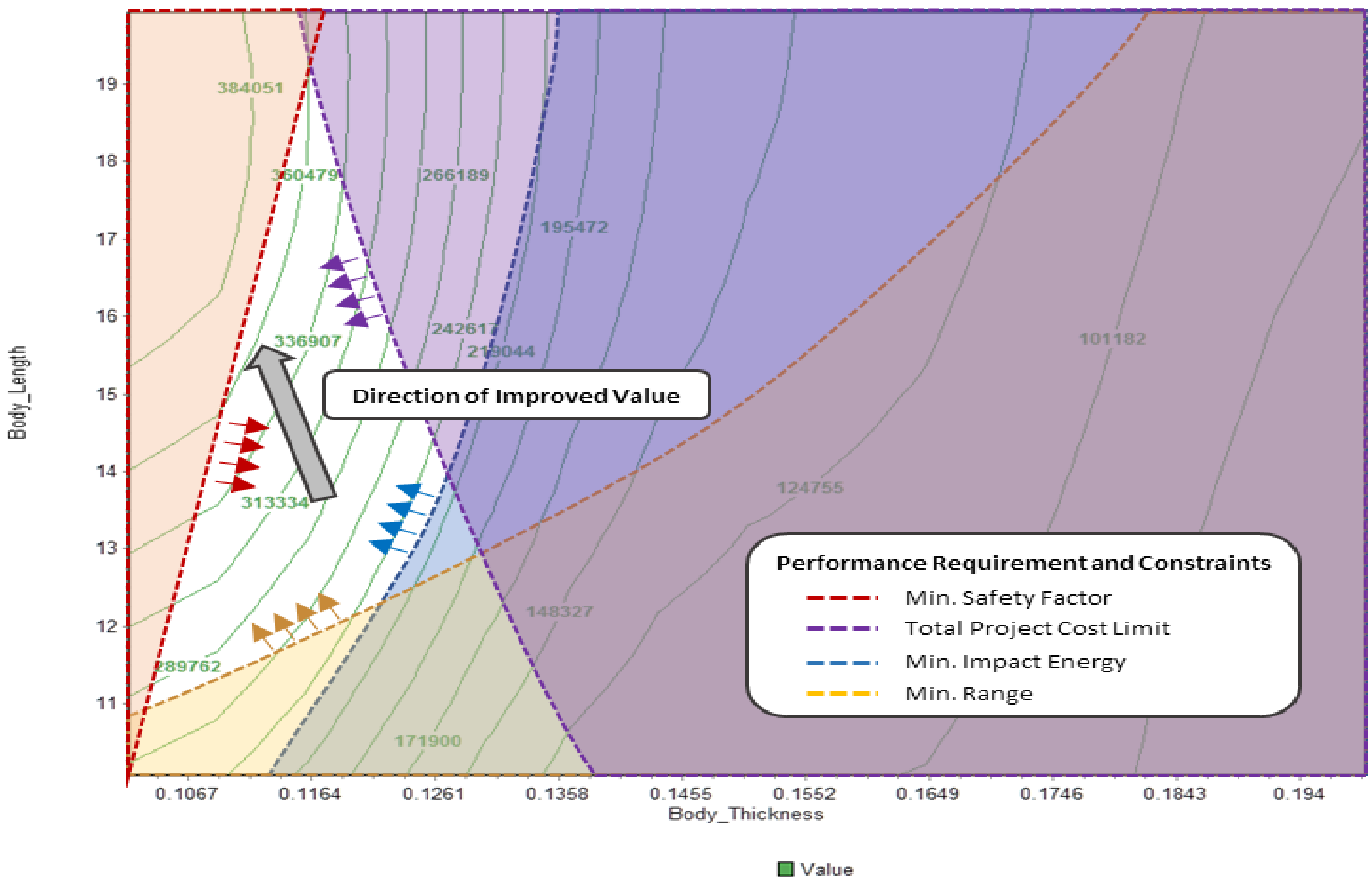
Interaction

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



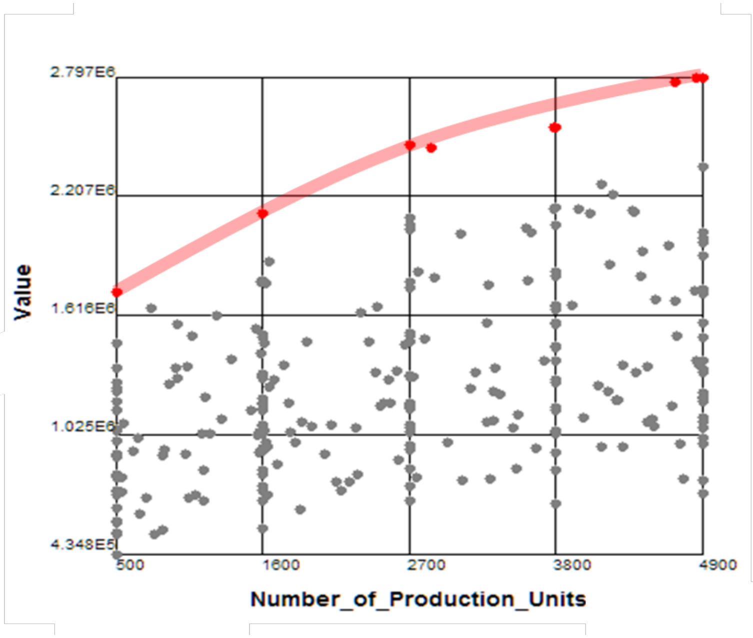
Design Space Exploration

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

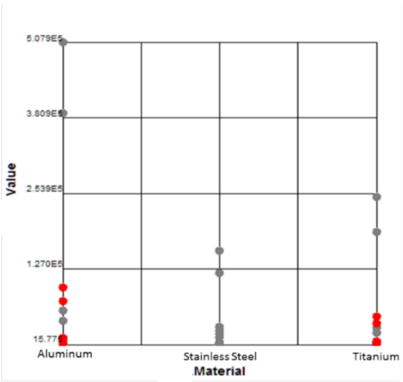


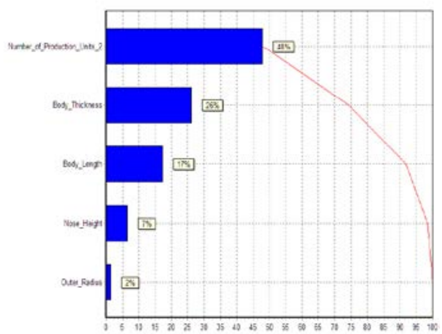
Risk-Based Alternative Selection

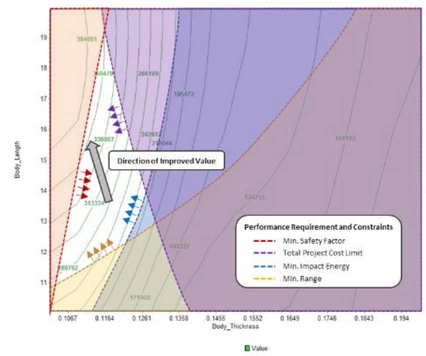
- A family of solutions can be studied as opposed to point designs
- Incorporate risk and uncertainty to study their impacts, e.g. funding level and production volume uncertainties.
- Can be used as communication tool to
  - Make good design decisions
  - Negotiate better requirements
  - Provide management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

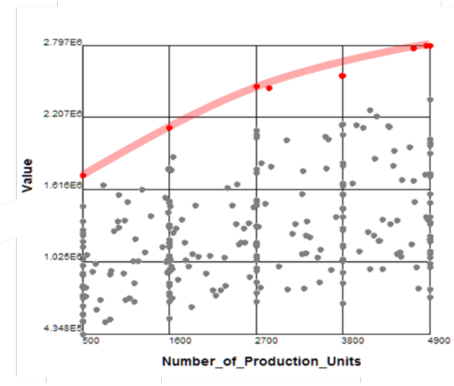


Summary of a MBE-Driven Agile Process

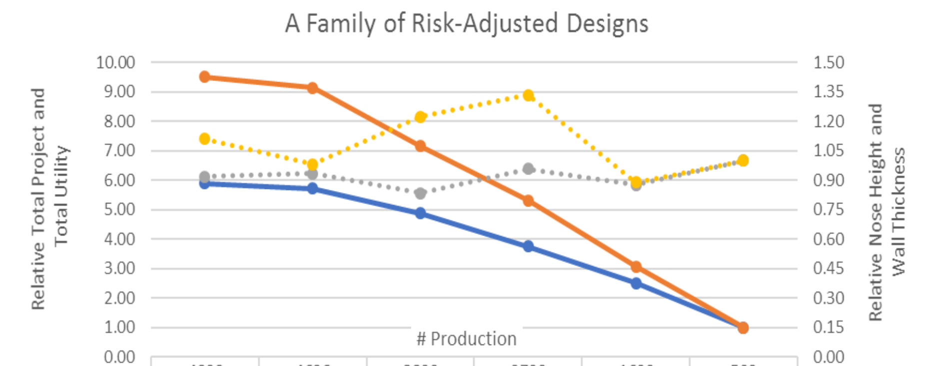








- Makes use of existing MBE technology
- Eliminates brute force
- Improves traceability
- Affords more point designs to be “carried over” to next iteration

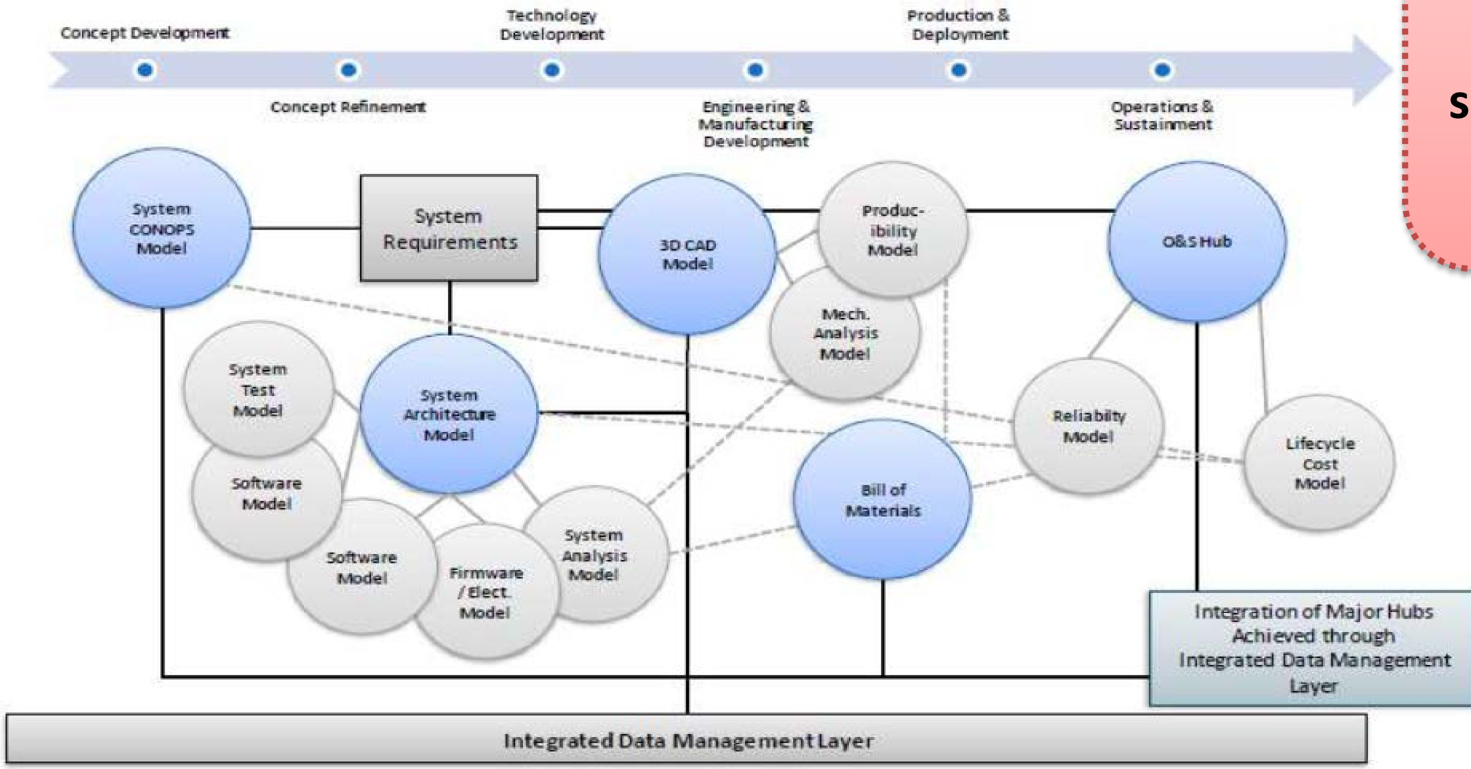


	4900	4696	3800	2700	1600	500
Total Project Cost	5.89	5.71	4.87	3.75	2.50	1.00
Total Utility	9.50	9.13	7.15	5.32	3.06	1.00
Wall Thickness	0.92	0.93	0.83	0.96	0.88	1.00
Nose Height	1.11	0.98	1.22	1.33	0.89	1.00

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?