



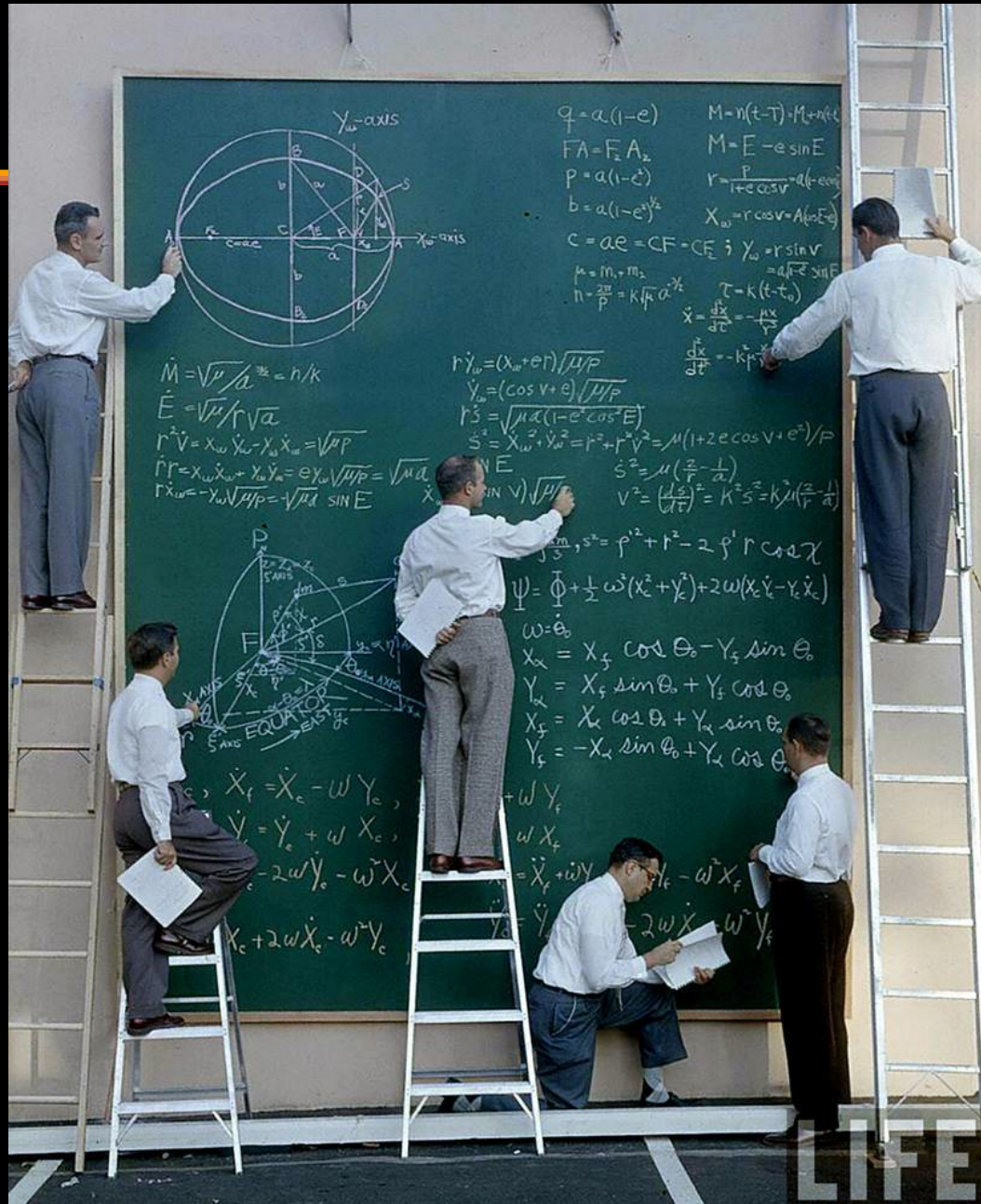
GSFC MBE Workshop:

Moving Toward Model Based Systems Engineering

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marshall





$q = a(1 - e)$ $M = n(t - T) + M_0 + n(t - T)$
 $FA = F_2 A_2$ $M = E - e \sin E$
 $P = a(1 - e^2)$ $r = \frac{P}{1 + e \cos v} = a(1 - e^2)$
 $b = a(1 - e^2)^{1/2}$ $X_w = r \cos v = A(\cos E - e)$
 $c = ae = CF - CE$; $Y_w = r \sin v = a\sqrt{1 - e^2} \sin E$
 $\mu = m_1 + m_2$ $T = k(t - t_0)$
 $n = \frac{2\pi}{P} = k\sqrt{\mu} a^{-3/2}$ $\dot{x} = \frac{dx}{dt} = -\frac{\mu x}{r^2}$
 $\dot{y} = \frac{dy}{dt} = -\frac{\mu y}{r^2}$
 $\dot{M} = \sqrt{\mu/a} = n/k$
 $\dot{E} = \sqrt{\mu}/r\sqrt{a}$
 $r^2 \dot{v} = X_w \dot{Y}_w - Y_w \dot{X}_w = \sqrt{\mu P}$
 $r \dot{r} = X_w \dot{X}_w + Y_w \dot{Y}_w = e Y_w \sqrt{\mu/P} = \sqrt{\mu a} \sin E$
 $r \dot{X}_w = -Y_w \sqrt{\mu/P} = -\sqrt{\mu a} \sin E$
 $r \dot{Y}_w = (X_w + e) \sqrt{\mu/P}$
 $Y_w = (\cos v + e) \sqrt{\mu/P}$
 $r^3 = \sqrt{\mu a(1 - e^2 \cos^2 E)}$
 $S^2 = X_w^2 + Y_w^2 = r^2 + r^2 v^2 = \mu(1 + 2e \cos v + e^2)/P$
 $S^2 = \mu(\frac{r}{a} - \frac{1}{a})$
 $v^2 = (\frac{dr}{dt})^2 = k^2 S^2 = k^2 \mu (\frac{r}{a} - \frac{1}{a})$
 $\frac{dr}{dt} = \frac{dr}{d\chi} \frac{d\chi}{dt}$, $s^2 = r^2 + r^2 - 2r^2 \cos 2\chi$
 $\Psi = \Phi + \frac{1}{2} \omega^2 (X_c^2 + Y_c^2) + 2\omega(X_c \dot{Y}_c - Y_c \dot{X}_c)$
 $\omega = \dot{\theta}_0$
 $X_c = X_s \cos \theta_0 - Y_s \sin \theta_0$
 $Y_c = X_s \sin \theta_0 + Y_s \cos \theta_0$
 $X_s = X_c \cos \theta_0 + Y_c \sin \theta_0$
 $Y_s = -X_c \sin \theta_0 + Y_c \cos \theta_0$
 $\dot{X}_c = \dot{X}_s - \omega Y_c$
 $\dot{Y}_c = \dot{Y}_s + \omega X_c$
 $\dot{X}_c = \dot{X}_s - \omega Y_c$
 $\dot{Y}_c = \dot{Y}_s + \omega X_c$
 $\dot{X}_c + 2\omega \dot{X}_c - \omega^2 Y_c$
 $\dot{Y}_c + 2\omega \dot{Y}_c - \omega^2 X_c$

NASA Before PowerPoint

The physics are the same, how we can communicate has changed.

What's MBSE to us?

- **Modeling Information Relationships (to produce the products we need)**
 - Federated Information Model that is the central model in which all authoritative data resides and from which all Views are created
 - The Data is developed and managed by disparate organizations (within & across Centers & Contractors) in disparate data sources
- **Creating and using various types of models to improve how we do SE or evaluate the system (helping get the best system)**
 - Taking a look at how we can mathematically model the system
 - Using models to replace traditional approaches to SE (like requirements)
 - Using Models to plan or conduct lifecycle reviews

Our Vision

- Reducing the effort and time in producing our SE products
- Enabling the effective management of the system's information as it changes over the lifecycle
- Reusing data and models across projects and organizations
- Reducing the effort necessary to prepare for and conduct lifecycle reviews
- Improving how the system's knowledge is shared and communicated
- Improving our ability to evaluate the system (new techniques)

Our Challenges

- Infrastructure/architecture - Model Based Enterprise
- Systems Engineering & Integration vs. Modeling
- Project Life Cycle and Life Cycle Reviews
- Accommodating a Broad Portfolio of projects
- Distributed Systems Engineering Organization
- Workforce
- Influencing change – adapting while executing, dealing with our culture

MSFC's Portfolio



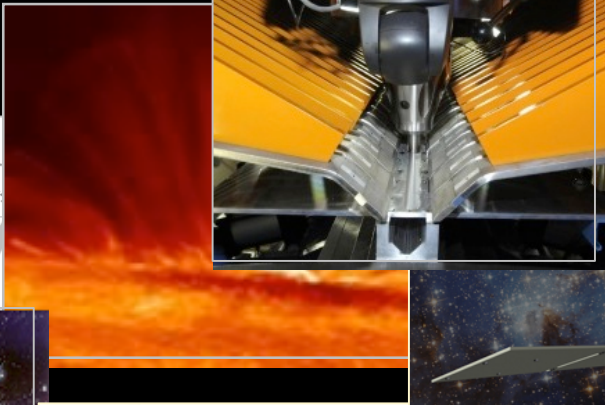
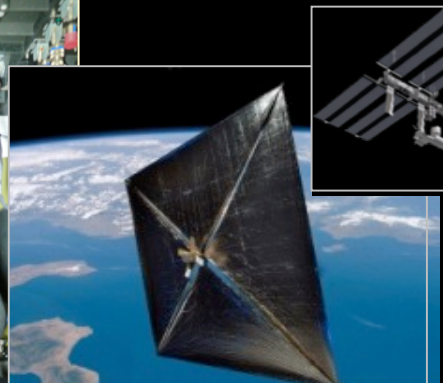
SLS



SPARTAN



ISERV



R&T



Lunar Prospector –
Discovery Program



JWST Mirror Testing

Strategies and Initiatives

- Practice/implement Model-Based approaches on a small scale
 - Using models in lieu of traditional requirements (SLS)
 - Interface modeling for Command & Data Handling (SLS)
 - Europa Clipper – SLS interface modeling
- Develop knowledge and skills in our workforce
 - Infusing MBSE related projects into our Systems Engineering Leadership Development Program
 - Developing a community that can share experiences and lessons
 - Participating in Pilot Projects and Agency Activities
- Examining different approaches and tools to develop a better understanding of what we need (smart-buyers)
 - ISEF (Integrated Systems Engineering Framework)
 - JPL's open MBEE
 - Cradle/SysML
 - Enterprise Architect
 - Magicdraw

Strategies and Initiatives

- Exploring our policy and processes
 - Finding where our policy may limit implementation
 - Examining how we could model policy ourselves in a way to help the implementers (Planning our SE approaches and Reviews)
 - Creating model libraries, capturing lessons and communicating approaches
- Developing relationships with our Agency and Local CIO
 - Discussing fundamental architecture needs and capabilities
 - Improving our relationship with Institutional IT planning and engineering needs
 - Developing use cases to drive out functional requirements
- Research and collaboration
 - Systems Engineering Research Consortium (Exergy, Value Models, State Modeling....)
 - Digital Thread Cooperative Agreement

SLS Model-Based Requirements

- Goal - Define a process to employ on SLS to minimize requirements and attendant verification using engineering models.
- Why?
 - Reduce the verification effort necessary for the Elements to satisfy vehicle-level requirements specifying the details of the system design
 - Reduce the verification effort necessary at the integrated vehicle level to track and roll up verification of all the detailed requirements
 - Allow the Elements the flexibility to adjust the detailed subsystem values to Element benefit without requesting approval for each detailed change
 - Use of a single model for a system guarantees that the system-level impacts of changes will be visible, whereas specifying the detailed individual values does not. The model is needed anyway; the requirements are not.
 - Avoids the experience of having a system design that works, models that accurately show its behavior, but having to negotiate what the detailed requirements should be and how to verify them.
 - e.g. TVC model works, but in standard approach would negotiate detailed TVC requirements.
 - Reduces resulting conservatism

Inertial Navigation System Example

Traditional Requirements for INS System could result in 230 Shall Statements

- Requirements for anti-aliasing portion:
 - The inertial measurements shall be anti-aliased
 - Anti-alias filter shall have a bandwidth of 29.5 Hz
 - Anti-alias filter shall execute at a minimum sample frequency of 250 Hz
 - Anti-alias filter shall have a maximum phase lag of 5 degrees at 1 Hz.
 - Anti-alias filter shall have a maximum gain of +/- 2e-3 dB at 1 Hz
 - Anti-alias filter shall have a minimum attenuation of 6 dB at 20 Hz

• Anti-Aliasing Filter Implementation Model in Code

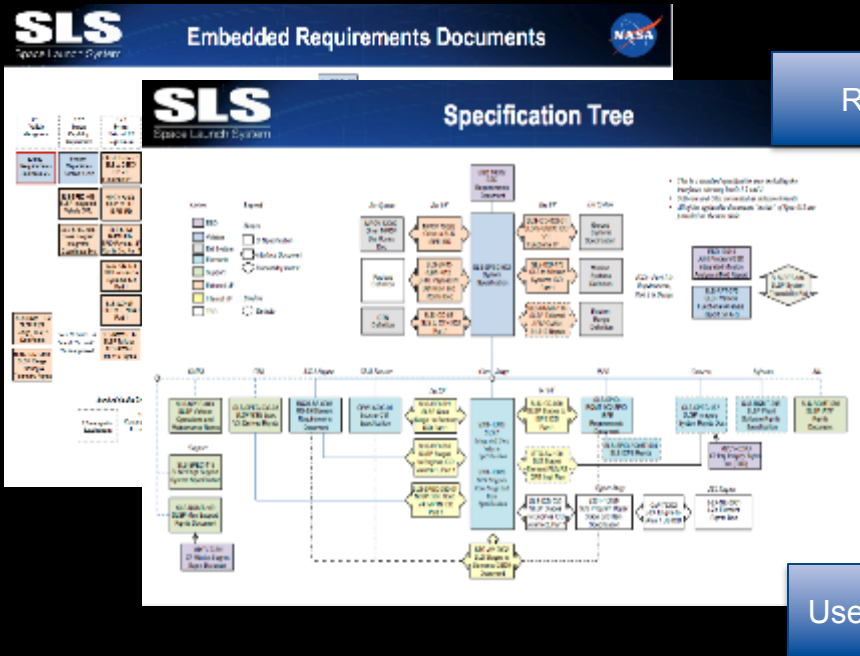
Model Input Data:

```
TF_method      3      # 2nd order TF method:
                # 1) continuous with Euler integration,
                # 2) continuous using MAVERIC integration,
                # 3) discrete with Tustin transform
enableTFdyn_w  1      # enable 2nd order transfer function
omega_w_hz     29.5   # Gyro bandwidth frequency (Hz)
zeta_w         0.6    # second order damping factor
TF_T_w_hz     250.0  # Sampling freq for discrete filter (Hz)
enableTFdyn_a  1      # enable 2nd order transfer function
omega_a_hz     26.5   # Accel bandwidth frequency (Hz)
zeta_a         0.6    # second order damping factor
TF_T_a_hz     250.0  # sampling frequency for discrete filter (Hz)
```

- ◆ Implementation in Code – little ambiguity in intent or assumptions
- ◆ Alternate implementations are available. If coefficients are specified, they would be dependent upon a fixed execution rate, and therefore could be constrained.
- ◆ Alternate designs are possible. As long as the vehicle-level needs are satisfied, these can be explored without detailed requirements revision.
- ◆ Customer works directly with the subsystem folks to agree on the model that meets the integrated vehicle needs and works best for the Element

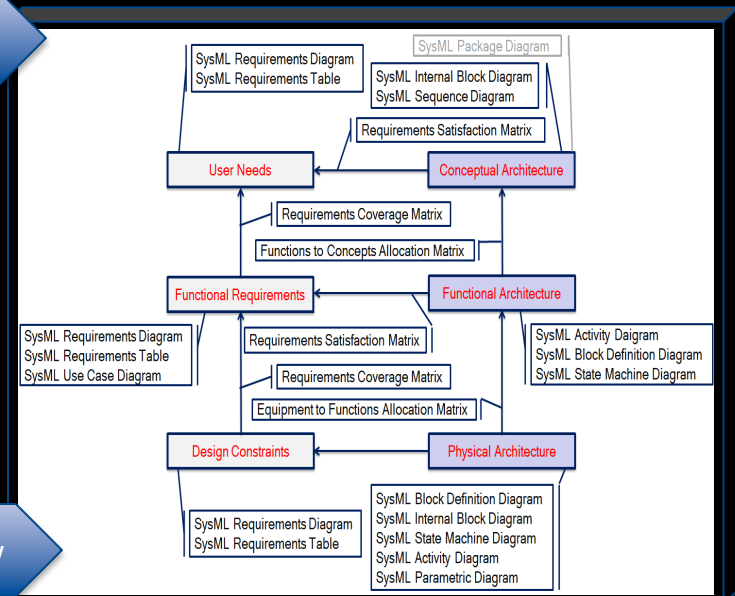
SLS – Europa Clipper Pilot

- Develop and demonstrate the Model Based Systems Engineering (MBSE) approach for SLS/Europa Interface Requirements Model (IRM) for systems engineering functions in the Model Based Engineering Environment (MBEE)
- Update IRM content using available data and latest version of the Mission Planner's Guide (MPG)
- Use the SLS Block 1 Configuration Documentation for this activity.



Replaced By

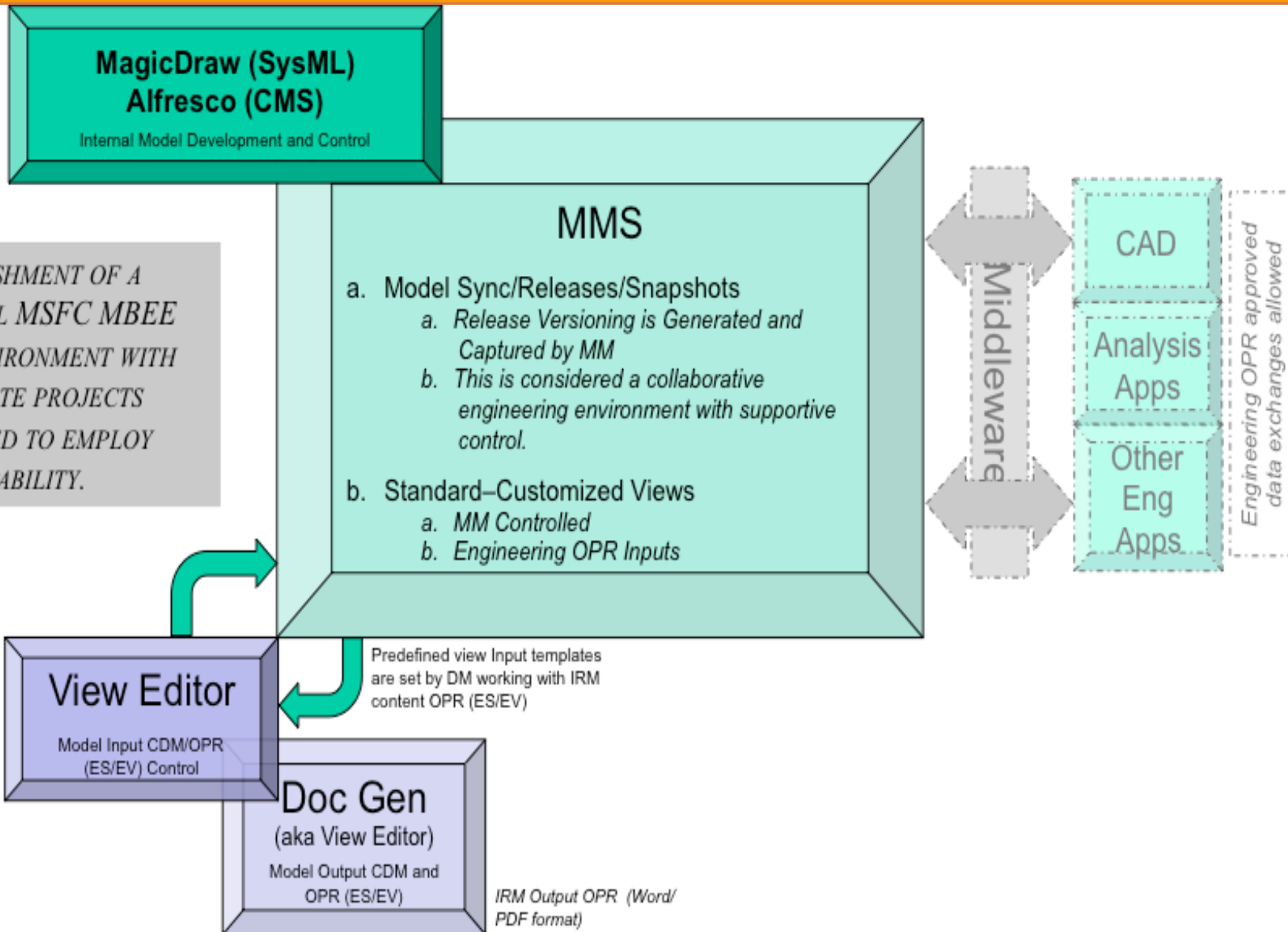
SysML Mission Model



User Defined View

MODEL BASED CONCEPTUAL AND FUNCTIONAL REQUIREMENTS, ICD'S, CONSTRAINTS, & SPECIFICATION INFORMATION, BECOMES INTEGRATED RELATIONAL, AND INTUITIVELY ACCESSIBLE THROUGH DIAGRAMMATIC AND DOCUMENT-BASED VIEWS

SLS – Europa Clipper Pilot



Systems Engineering Research Consortium

- The SE Research Consortium is providing some additional areas/ideas where models could be used to improve the effectiveness of our Systems Engineering Effort
 - Exergy Models
 - The work available from an energy source, more specifically, it is useful work
 - A synthesis of First Law of Thermodynamics (Energy) and Second Law (Entropy) analyses
 - Provides a meaningful system characteristic to understand system interactions across multiple disciplines, subsystems and scales
 - Goal-Function Tree (GFT) Model
 - A top-down, formal, hierarchical representation of stakeholder intentions for the system
 - System State Machine Model
 - State machine representations consist of many simple models of the state transitions of individual components, which can be triggered by the state transitions of other components, with relevant time delays as appropriate

Research Results are provided to the Systems Engineering TDT and should be available to your Center SE Rep

Digital Thread for Advanced Concepts

What's Next? A 21st Century Analytical Capability

NASA Life-Cycle Phases

Formulation

Approval

Implementation

Initiation

Acquisition & Development

Implementation

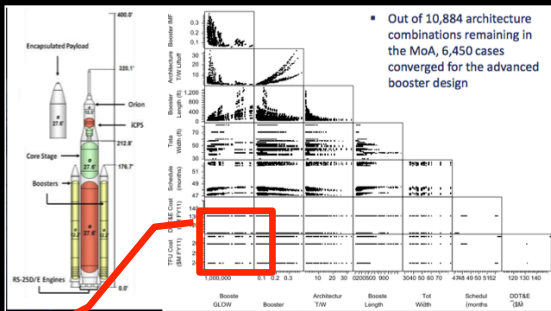
Operations

Sunset

**Parametric Based Models
EDO4**

Surrogate Models

Advanced Concepts has invested well over millions of dollars modernizing our analytical capabilities

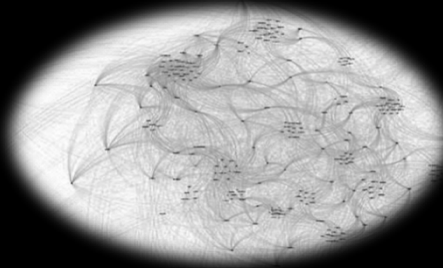


ACO needs are centered on access to data and tools to build surrogate models. The ability to assess study coverage and foster knowledge transfer

**Data Relationships
IT/CIO**

Digital Thread & Communication

Provide an ability for different types of models (Parametric Geometry Physics) to access information across a data architecture that provides autonomous associations

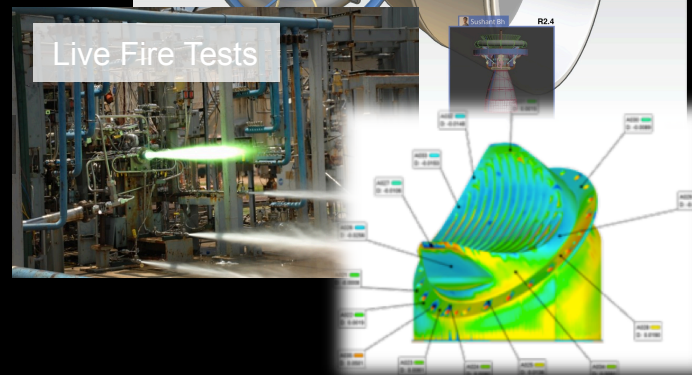
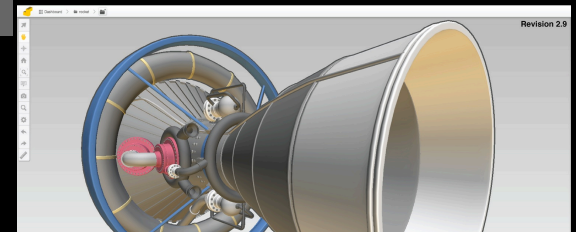


Relationship Mining

Cost Estimating Relationships
Mass Estimating Relationships
Manufacturability Factors
Reliability Factors
Technology Assessment

**Geometry and Process Based Models
EM, ER & ES
Design and Manufacturing:
Rocket Engines**

Digital Manufacturing
Additive Manufacturing

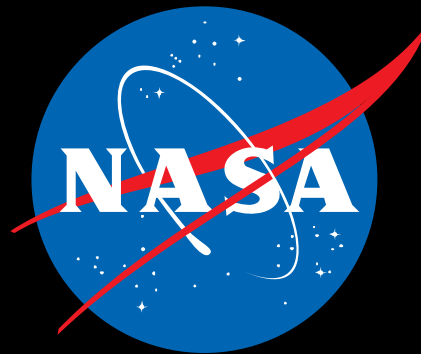


Propulsion Systems Objectives using Digital Thread

- ER Liquid Engine design/analysis:
 - Develop and manage engine designs in a 100% digital manner
 - Improve design integration especially design traceability internal and external to ER in a value added way
 - Improve workflow and design and modeling efficiency
 - Integrate engine design analysis with other levels of digital thread for more efficient, and effective (robust and affordable) design analysis
 - ER (engine design/analysis) \Leftrightarrow ED04 (transportation architecture)
 - ER (engine design/analysis) \Leftrightarrow EM41 (advanced manufacturing)
 - Characterize the benefit of utilizing advanced manufacturing (additive manufacturing) on a candidate part at the engine level and communicate across domains
 - Provide capability to generate surrogate models for candidate liquid engine – surrogate models will facilitate flow of information in digital thread
 - Demonstrate that a product, either released or in work, can be moved to manufacturing and all configuration control and traceability remains intact
 - Digitally assess producibility of candidate part
 - Characterize the benefits of advanced manufacturing for a candidate engine part

Questions?

- **Contacts:**
 - SLS use of Models – John Hanson (john.m.hanson@nasa.gov)
 - Europa Clipper – SLS – Paul Gill (paul.gill@nasa.gov)
 - Digital Threat – Mark Rogers (mark.rogers@nasa.gov)
 - Propulsion Digital Design/Manufacturing – Dave Whitten (dave.whitten@nasa.gov)
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 - MBSE tools and frameworks - Bobby Powell (bobby.powell@nasa.gov)
 - CIO Architectures and Use Cases, MBSE Community of Interest – Joe Hale (joe.hale@nasa.gov)
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