Tool Development for NIRPS Industrial Base Analysis
PropSIMA
(Propulsion Supplier Integrated Modeling and Analysis)

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Agenda and Outline

• Time Management
  – *Presentation:* 25 min.
  – *Database demonstration:* 20 min
  – *Questions:* 5 min

• Task Overview

• Supply Chain Model and Analysis Approach

• Results Summary

• Database Visualization Demonstration
PropSIMA (Propulsion Supplier Integrated Modeling and Analysis)

- The Aerospace Corporation is assisting NIRPS with the development of rocket engine and solid motor supply chain database analytical capabilities
  - Conduct a **bottom-up** analyses of how launch vehicle and engine procurement selections affect rocket engine industrial base (suppliers and engine manufacturers)
  - *Prototype Tool developed with following analytical capabilities*
    - Visualize data for a detailed supplier level database
    - Identify supplier interdependencies, critical & high risk suppliers, etc.
    - Conduct industry related trade studies for engine demand scenarios
- NIRPS collaborated with NASA’s Space Launch System (SLS) Program on a pilot project to guide capability development
  - Evaluate potential impacts of SLS Exploration Upper Stage (EUS) engine options on propulsion industrial base
  - Compare to the J-2X baseline
PropSIMA (Propulsion Supplier Integrated Modeling and Analysis)

**What the Tool Does**

- Models Propulsion Industry-Wide Participation for Launch Vehicle Demand
- Allows High-Level Trade Studies between Different Engine Demand Scenarios
- Tracks Suppliers and Prime Involvement in rocket engine production
- Accounts for Engine Demand Uncertainty using Discrete Event Simulation tool
- Book-keeps Suppliers and How They are Shared Across the Industrial Base
- Book-keeps Relative Part Value for what Supplier Provides to Primes
- Stores metadata associated suppliers: parts produced, location, estimated financial health and dependency of prime
- Allows Several Types of Visualization for Industry-Wide Supply Chains

**What the Tool Does NOT Do**

- Model Business Metrics on a Supplier Scale
- Model Process Flow for Engine Production
  - Currently does not identify bottlenecks but could be incorporated
- Track Every Sub-Tier Supplier
  - Trade high level accuracy (complexity/time) for ease of performing demand scenario trade studies
- Model Supplier Uncertainty or Future Diversification
PropSIMA (Propulsion Supplier Integrated Modeling and Analysis)

Launch Vehicle Scenario
- Launch vehicle demand driven by assumed procurement scenario and determines engine and motor demand

Engine and Motor Demand
- One supplier may make several parts on an engine
- Each part supplied creates a single supplier “touch”
- Metadata stored in database tracks the value of each “touch” (Described later)
- Allows tracking of the value of hardware provided by each supplier

Prime and Supplier Involvement
- The value of the prime contractors integration and manufacturing is tracked as well

Value of Touches per Engine

Relative Value of Touches Compared to baseline scenario
- Engine relative cost is incorporated to adjust the value of the supplier and prime “touches”
- “Valuized” touches are booked in terms of “cumulative benefit” with a value of 1 equating to the value of 1% of subtier supplier hardware used on the baseline

Trade Results for Launch Vehicle Scenarios
PropSIMA Supplier Data

- Major suppliers for engines and motors used for US expendable launch vehicles have been identified and the parts they supply to major subsystems
- Metadata recorded for the supplier include the best estimate
  - Supplied Commodity
  - Alternative Suppliers
  - Financial health
  - Dependency on engine prime contractor
  - Relative value of parts supplied
  - Location (City, State, Country)
Supply Chain Details

- Fraction of engine cost between prime contractor and suppliers is estimated:

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<tr>
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<th>Development</th>
<th>Production</th>
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<tbody>
<tr>
<td>Prime</td>
<td>60%</td>
<td>67%</td>
</tr>
<tr>
<td>Suppliers</td>
<td>30%</td>
<td>25%</td>
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- Initial analysis using this tool focused on prime and first-tier suppliers, but the database and discrete event simulation tools are highly scalable.

- Top 15-20 suppliers make up 80% of the material cost for an engine.

- Supplier “touches” (single unit purchase) do not represent every touch needed to produce a single engine – focus on big ticket items.

- Some suppliers provide multiple parts and others just one.

- A value of “importancy” has been assigned to the suppliers.

\[
Importancy = \frac{Percentage\ of\ Hardware\ Cost\ for\ Engine}{Number\ of\ supplier’s\ touches\ in\ our\ database}
\]

- Multiplying the number of “touches” for a supplier by the importance allows the analysis to recover the percentage of hardware cost.

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Demo Liquid Engine Model Database

- Database Type: JavaScript Object Notation (JSON) Datafile
- Scripts generate large Möbius Descrete Event Models from JSON databases
Launch Vehicle Scenarios: Engine Demand

• Baseline engine demand constructed from current launch manifests that impact the U.S. industrial base, combined with projections for future
  – *EELV*
    • DoD
    • NASA LSP
    • Commercial EELV
  – *NASA Human Spaceflight*
    • Commercial Crew Launch
    • SLS (booster, core, and EUS options)

• Variation in engine demand included to reflect uncertainty in future years
  – *Uncertainty captures events such as launch date slips or mission cancellation*

• Alternative Scenarios represent a fundamental change to launch vehicle demand due to higher level decisions
  – *Payloads moving from one existing launch vehicle to another*
  – *New launch vehicle enters market*
  – *New propulsion system developed for an existing launch vehicle*
Baseline Demand Model

- Launch vehicle demand model determines production rates for all engines
  - *Vehicle demand and propulsion configuration are inputs to kick-off engine level supply chain model (Möbius)*
- Monte Carlo method used to sample a production rate for all engines for each year considered for analysis
  - *Triangular distribution applied in the Monte Carlo simulation*
Möbius Overview

- Möbius: Model-Based Environment for Validation of System Reliability, Availability, Security, and Performance
  - Software tool for modeling the behavior of complex systems
  - Developed by the University of Illinois

- **Distributed discrete-event simulation**: Evaluates the custom measures using efficient simulation algorithms to repeatedly execute the system, either on the local machine or in a distributed fashion across a cluster of machines, and gather statistical results of the measures.*
  - Current models execute on a 30-core cluster; several hours to complete simulation

- The Aerospace Reliability and Statistics Department (RSD) has applied Möbius to a number of programs:
  - Audit of a commercial satellite constellation reliability model
  - Augmentation of replenishment modeling capabilities
  - Process/Schedule analysis

*https://www.mobius.illinois.edu/
Trade Study Analysis for Competing Scenarios

- A “composed” Möbius model ties together engine models and identifies shared suppliers
- Monte Carlo simulation performed for each alternative scenario
- Results of each alternative scenario traded
- Cumulative supplier benefit (mean value and distribution)

Figure courtesy of https://www.mobius.illinois.edu/
Supplier Disruption Alternative Scenario Analysis

Tracks all Suppliers including Primes

Baseline vs. Alternative Scenario A

Year

Supplier A
Supplier B
Supplier C
Supplier X
Supplier Y
Supplier Z

Cumulative Benefit of Scenarios Compared

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<thead>
<tr>
<th>Scenario</th>
<th>Engine A</th>
<th>Engine B</th>
<th>Engine C</th>
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<tr>
<td>Baseline</td>
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<td>Scenario A</td>
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<td>Scenario E</td>
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Summary and Future Work

• Prototype tool developed (PropSIMA) to perform industrial base analysis including
  – Baseline launch vehicle demand scenario including variability in launch manifest
  – Trade Studies featuring alternative scenarios for launch vehicle options based on potential future developments in the market

• PropSIMA Tool Structure
  – Launch Vehicle Demand Model
  – Flexible Engine/Motor supplier databases with user-specified metadata tagging
  – Engine Hardware & Supplier Network Visualization
  – Discrete Event Simulation Tool
  – Analysis Tools for Extracting Significant Findings of Industrial Base Impact

• Future Work
  – Expand capabilities and information in Engine/Motor Database
  – Develop additional visualization capabilities
  – Further develop trade study analysis/visualization methodology

• Propose JANNAF PIB to develop industry panel to provide guidance on how to define PropSIMA inputs and metrics