

**Pi Blue Software, Inc.**

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## Non-Gradient Based Optimization Using ModelCenter and ProbWorks

April 2003



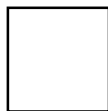
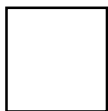
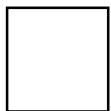
**Introduction to the Firm**

**Overview of ProbWorks: ModelCenter**

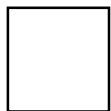
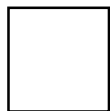
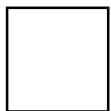
**ProbWorks: ModelCenter Case Studies**

**ProbWorks: ModelCenter Demonstration**

**Summary**



# Agenda

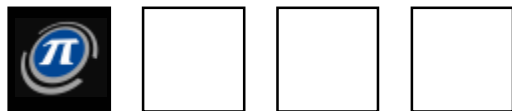


# Introduction to the Firm

# About



Pi Blue Software, Inc. (Pi Blue) specializes in developing easy-to-use software products for advanced numerical analysis, risk/uncertainty assessment, and optimization. Our flagship products are OptWorks: ModelCenter<sup>®</sup> and ProbWorks: ModelCenter<sup>®</sup>. Pi Blue's products provide powerful numerical simulation and probabilistic design capabilities for users of all skill levels, from professionals to students.



# Overview of ProbWorks: ModelCenter

# ModelCenter<sup>®</sup> Collaborative Environment

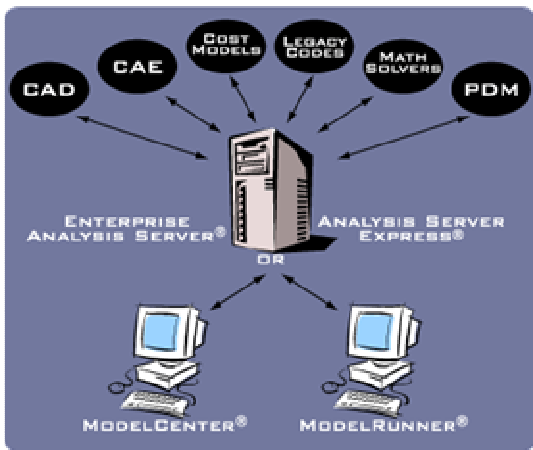
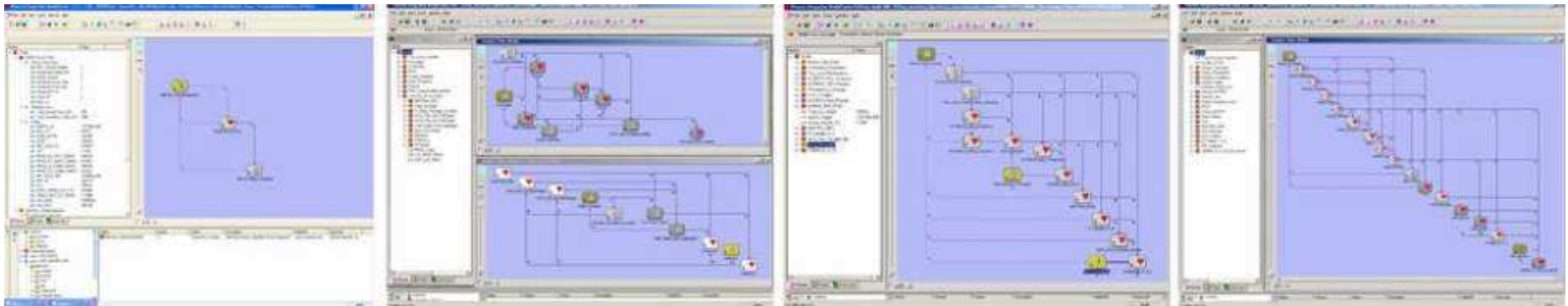


Image Source: Phoenix Integration Inc.  
<http://www.phoenix-int.com/products/index.html>

“Phoenix Integration allows manufacturing companies to integrate and automate numerous software tools, remote locations, and different computing platforms into a cohesive environment for systems design...

...Our client software and back-end server software products help you build an integrated process for your engineering design team.”

Phoenix Integration Inc.  
<http://www.phoenix-int.com>



## The Need for Robust Design

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- ▶ A prudent decision maker can use **Robust Design** to calculate the 80% or 90% confidence value for a program metric to assure themselves that they will **meet or exceed the desired metric 80% or 90% of the time**
- ▶ **Robust design** is concerned with the objective and the variance in the objective
- ▶ Program "risk" is generally a measure of the standard deviation of some output distribution about a mean value
- ▶ Robust Design can be implemented by **Monte Carlo techniques** based on a variety of numerical methods that use sequences of **random numbers** to perform statistical simulations
- ▶ Alternative methods coupled and in addition to Monte Carlo can **reduce computational and temporal expense**
- ▶ Design tools and robust design drivers can be coupled in a collaborative design environment such as Phoenix Integration's ModelCenter<sup>®</sup> for **Probabilistic Data Assessment (PDA)**



Pi Blue Software, Inc. introduces a new suite of uncertainty and sensitivity analysis tools for use with Phoenix Integration's ModelCenter<sup>®</sup> collaborative design environment.

Entitled ProbWorks: ModelCenter<sup>®</sup>, this suite consists of four tools to help employ uncertainty analysis techniques, each implemented as a Java-based component which can function on any platform running Phoenix Integration's ModelCenter<sup>®</sup> and Analysis Server<sup>®</sup>.



## ProbWorks: ModelCenter



**ProbWorks: ModelCenter**  
version: 1.1

ProbWorks ModelCenter is a suite of probabilistic analysis tools for use with Pharoa Integration Optimizer™ probabilistic optimization framework. Each main component has a unique feature or offers a different view of problems. The probabilistic capabilities in the ProbWorks suite component are listed in the table below. The suite is used when trying to maximize the computational expense for Monte Carlo simulation. The suite enables the better DPOMD model inference as well as linear model approximation through Regression surface approximation. Each of the components in the suite is used as a main component and can be triggered through only a function call by the user in a main driver program.

COMPONENT NAME	CAPABILITY
ProbWorks_ModelCenter	Provides Monte Carlo analysis capabilities using random numbers for creating distributions (normal, Weibull, lognormal, etc.) on input parameters. Supports model simulation for the linear surface (average, mean, variance, level, etc.) over to simulation results.
ProbWorks_DPOMD	Implements the Efficient Probability Output Method (EPOMD) technique that serves as an alternative to Monte Carlo simulation for certain classes of problems. Monte Carlo simulation is used to generate a small number of runs.
ProbWorks_Regression	Determines the correlation or deviation of each model input with respect to each selected output with regression analysis of continuous. Outputs of regression results in MS Excel.
ProbWorks_Integration	Provides probabilistic regression solutions to support Monte Carlo simulation of time-varying systems. Supports basic solution of probabilistic techniques such as Monte Carlo, Regression-based analysis on goodness of fit in selected data. Provides subsequent analysis of regression results.

**SYSTEM REQUIREMENTS:**  
ProbWorks ModelCenter™ does not require any hardware that supports Pharoa Integration Optimizer™ or a PC or tablet.

**ORDERING AND PRICING:**  
Pharoa Integration, Inc. serves as the primary supplier for Pi Blue Software, ModelCenter™ and ProbWorks ModelCenter™ products. For sales and pricing info, please contact sales@piblue.com or call Pharoa Integration at 1-800-353-1144. Individual and departmental pricing rates (quantity discounts) are available. Individual user licenses are priced at \$1,995 (US) including charge.

**OTHER PI BLUE SOFTWARE PRODUCTS:**  
Pi Blue Software, Inc. develops software products targeted at professionals and students in the engineering, financial, accounting, logistics, materials, mathematics, and physical fields. Our current product portfolio includes the iQOMD suite of domain spanning optimization algorithms and the ProbWorks suite of tools for risk based analysis.

**TRAINING AND CONSULTING:**  
Pi Blue Software, Inc. offers specialized training related to ModelCenter™ and suite of the suite of components as well as consulting services for subsequent application to business or engineering environments.

**TECHNICAL SUPPORT:**  
Pi Blue Software, Inc. offers customer service technical support for all products. Please include PABN, serial number, and an initial support request.

ProbWorks is a trademark of Pi Blue Software, Inc. and ModelCenter™ and ProbWorks ModelCenter™ are registered trademarks of Pharoa Integration, Inc. © 2004 Pharoa Integration, Inc. All other trademarks represent their respective owners. © 2004 Pi Blue Software, Inc.

**PiBlue**  
Pi Blue Software, Inc.  
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www.piblue.com | www.piblue.com

The ProbWorks: ModelCenter®, suite is aimed at users who must treat **uncertainty and risk** in their product designs. The direct Monte Carlo driver and the faster DPOMD approximation driver propagate uncertainty in input parameters to assess statistical parameters such as mean, standard deviation, certainty level, and skewness. Supporting tools allow for the generation of fast-acting polynomial response surface equations (RSEs) and Pareto sensitivity analysis.

This package is currently available for purchase through **individual/group site licenses**. The full product suite includes optimizers in Java byte code, documentation with case study examples, and selected online support.



# ProbWorks: ModelCenter Capabilities

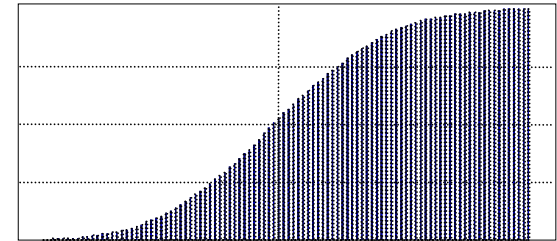
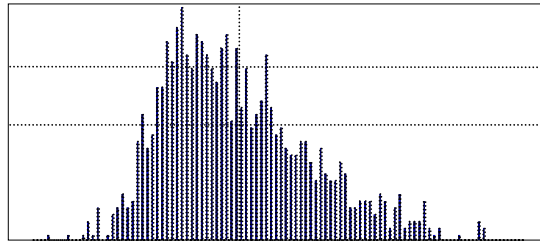
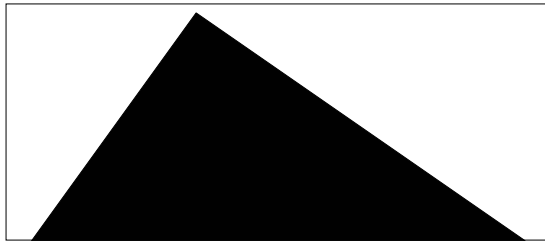
**Uncertainty in design models and simulations**

**Prioritize impact of inputs into model**

**Approximate models and simulations**

**Reduce Monte Carlo computational and temporal expense**

**Visualize output results from Monte Carlo**



**Why ProbWorks?**

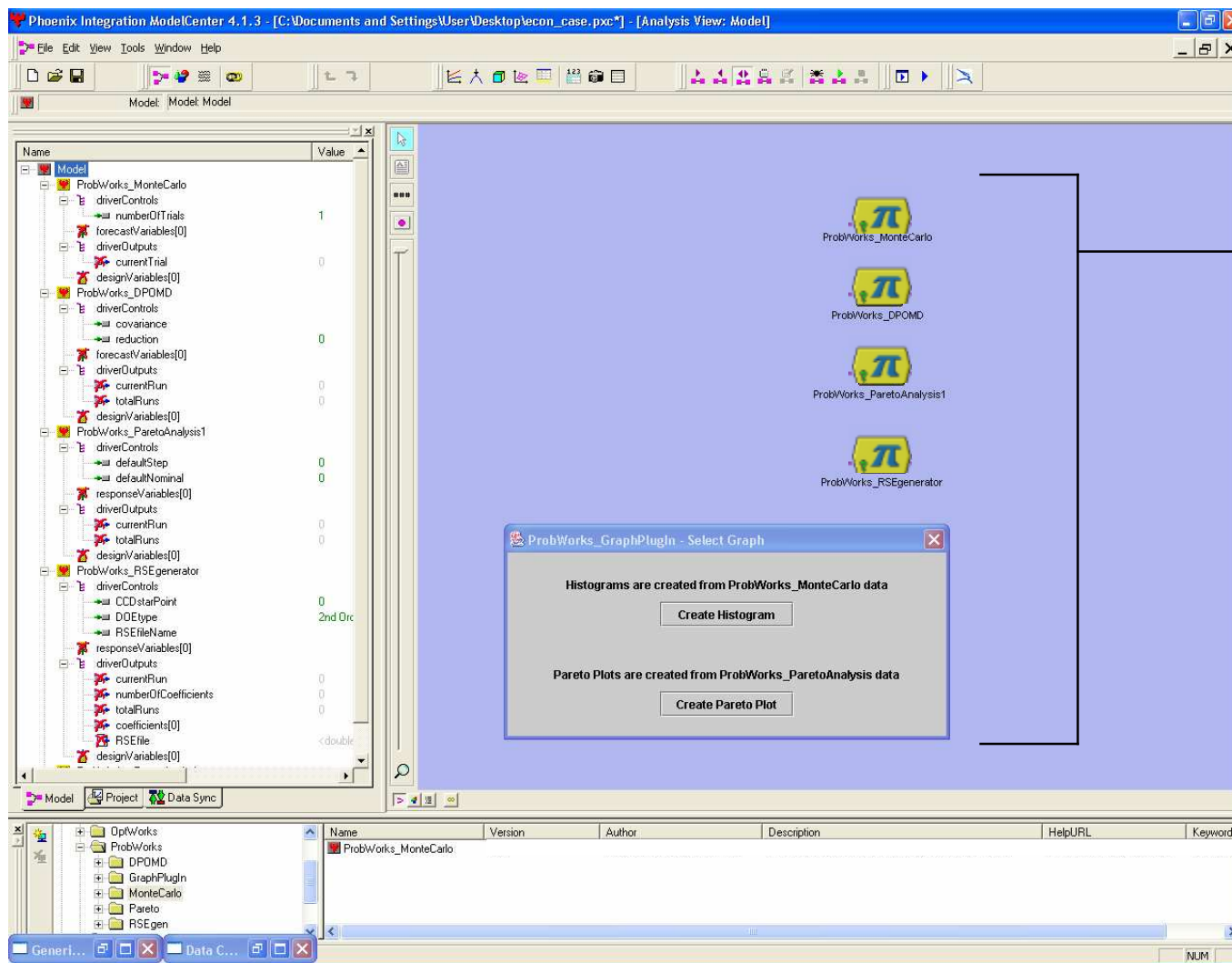
# Basic Functionality of a ProbWorks Component Within ModelCenter®

The screenshot displays the ModelCenter software interface with several key components labeled:

- Component Tree:** Located on the left, it shows a hierarchical structure of model components. The 'ProbWorks\_MonteCarlo' component is highlighted.
- Analysis View:** The central workspace where components are placed. It shows a 'ProbWorks\_MonteCarlo' component (represented by a Pi logo) and a 'CABAM\_A\_v1\_02' component. A dashed box indicates a relationship between them.
- ProbWorks "Driver" Component:** An arrow points to the Pi logo icon in the Analysis View.
- Model:** An arrow points to the 'CABAM\_A\_v1\_02' component in the Analysis View.
- Drag and Drop Components Into Model:** A large green arrow points from the Component Tree to the Analysis View.
- Driver Tool Window:** A window titled 'Generic Driver Tool' is open, showing a table of variables and parameters.
- Server Browser:** Located at the bottom left, it shows a file tree for the project.

Variable	Cert. Level	Cert. Direc...	Average	Std. Dev.	Cert. Value	Skewne
REQ_IR	0.85	Greater_Than	0	0	0	0
designVar...						
Model C...						
Model C...						
Model C...						
Model C...						

# ProbWorks Components Available from Pi Blue Software, Inc.



**ProbWorks Suite**

- Monte Carlo
- DPOMD
- Pareto Sensitivity
- RSE Generator
- Graph Plug-In

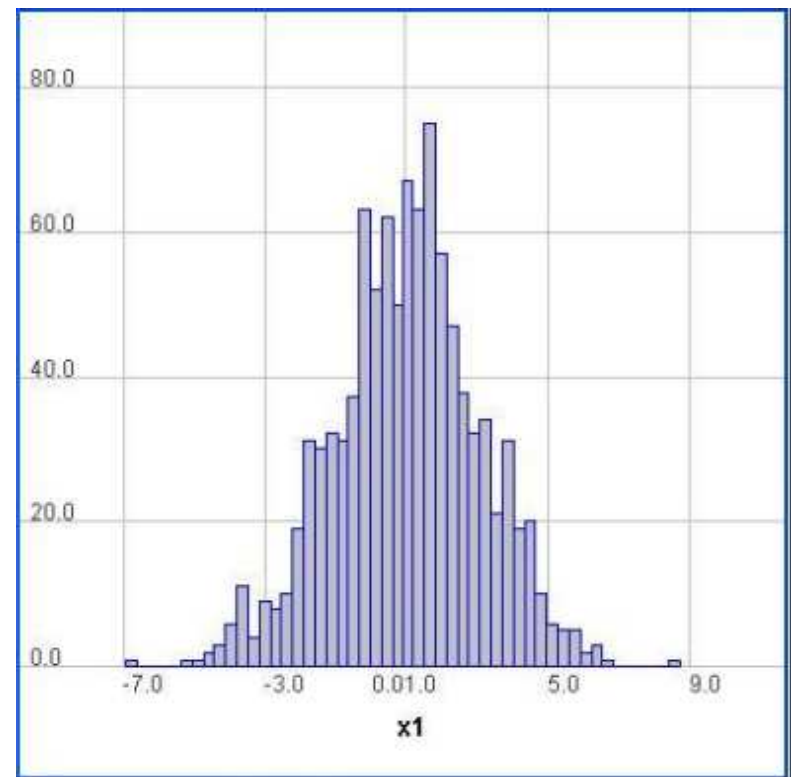
<b>Monte Carlo</b>	Performs Monte Carlo uncertainty simulation using random variables by placing distributions (normal, triangular, Weibull, etc.) on inputs. Generates output statistics for the forecast variables (average, mean, certainty level, etc.) even as simulation is running.
<b>DPOMD</b>	Implements the Discrete Probability Optimal Matching Distribution (DPOMD) technique that serves as an efficient alternative to direct Monte Carlo simulation for certain classes of problems. Allows estimation of a probabilistic output distribution with a small number of runs.
<b>Pareto Sensitivity</b>	Determines the contribution or sensitivity of each selected input with respect to each selected output with appropriate ranking of contribution.
<b>RSE Generator</b>	Produces polynomial regression equations to approximate more complex or time-consuming components enabling faster execution of probabilistic techniques such as Monte Carlo. Generates output statistics on goodness of fit to selected data. Enables subsequent use of regression coefficients.
<b>Graph Plug-In</b>	ModelCenter® plug-in which generates histograms and Pareto plots from other ProbWorks component outputs.



## ProbWorks Suite of Components

## Monte Carlo

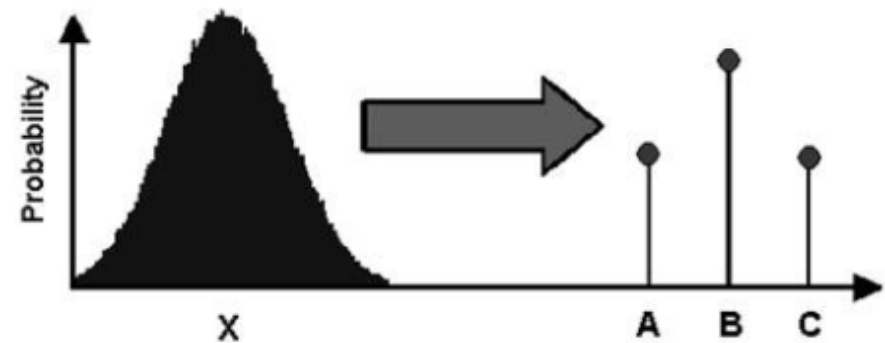
- ▶ Monte Carlo techniques based on variety of numerical methods that use sequences of random numbers to perform statistical simulations
- ▶ For each trial, design variables set to random values based on selected input distributions
- ▶ Value of each forecast variable recorded and certain key output statistics calculated
- ▶ For large number of trials, design variables approximate selected distributions and forecast variables show effect of design variables' variation
- ▶ Monte Carlo analyses performed on selected forecast variables by varying design variables
- ▶ User specifies both the design variables along with the associated distributions, distributions include: normal, uniform, triangular, exponential, Weibull, lognormal, and Beta
- ▶ Driver component collects data from forecast variables and maintains running calculations of mean, standard deviation, certainty values, skewness, and kurtosis for given certainty levels



Example Monte Carlo Output Frequency Distribution

## DPOMD

- ▶ **Discrete Probability Optimal Matching Distribution (DPOMD) is new method that uses limited samples from input distributions**
- ▶ **Compares favorably to traditional Monte Carlo with respect to computing time and accuracy**
- ▶ **Effectiveness of DPOMD is enabled by reducing continuous multivariate input distribution to discrete distribution**
- ▶ **Two-level fractional factorial design of experiments produces discrete distribution with zero mean vector and identity covariance matrix in standardized normal space**
- ▶ **Using values for the mean and covariance matrix from input distribution, inverse Hasofer-Lind transform maps discrete distribution to problem**
- ▶ **Simplified discrete distribution in problem space maintains same first moment (mean) and second moment (standard deviation) as continuous input**
- ▶ **Simulation then executed at these discrete points to produce output distributions**

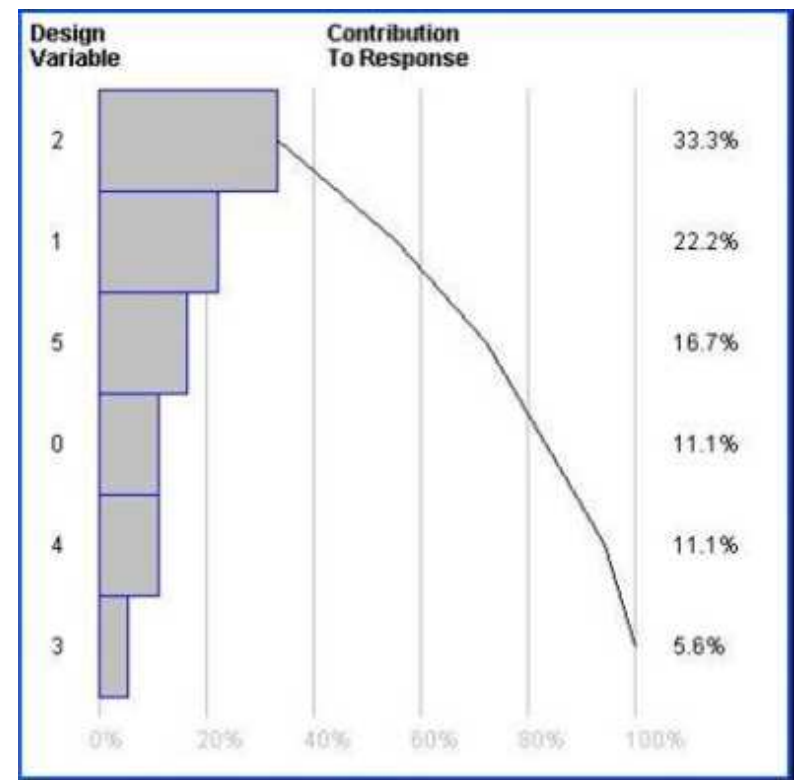


**Illustration of Discrete Distribution Derived from Continuous Distribution**

Based upon work performed by Dr. David McCormick, Space Systems Design Lab (SSDL), School of Aerospace Engineering, Georgia Institute of Technology, Atlanta, GA, For more information see: McCormick, D., Olds, J., "Approximation of Probabilistic Distributions Using Selected Discrete Simulations," AIAA 2000-4863, 8th AIAA/USAF/NASA/ISSMO Symposium on Multidisciplinary Analysis and Optimization, Long Beach, CA, September 6-8, 2000.

## Pareto Sensitivity

- ▶ **Determines most important design variables**
- ▶ **Quickly and easily assess which variables will provide most improvement or which should be included in later analyses, such as creating response surface approximation or executing Monte Carlo**
- ▶ **Each design variable varied and change in response recorded**
- ▶ **Variables then ranked in importance according to how much each contributes to variance about the mean of an output variable**
- ▶ **Set of design variables ranked and their contribution to the response graphically displayed**



Pareto Sensitivity Chart

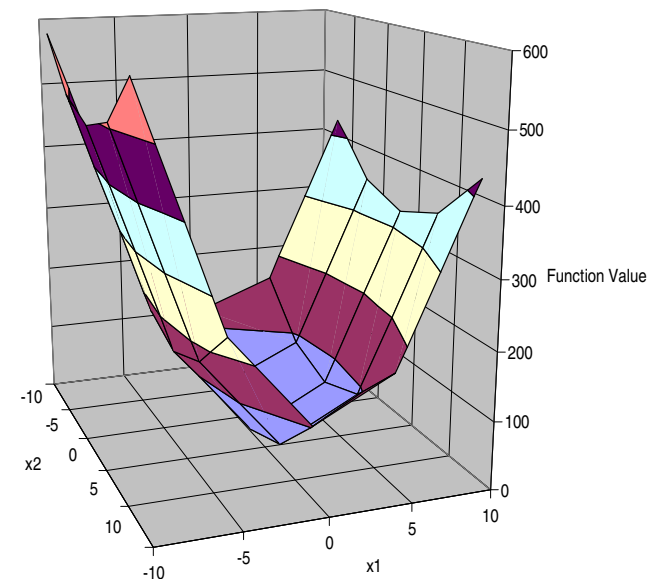


## Response Surface Equation (RSE) Generator

- ▶ Creates Response Surface Equation (RSE) quadratic approximation to substitute slower executing computational codes with analytical approximations
- ▶ Resulting RSE in ModelCenter®-runnable script used in current model file or placed in another
- ▶ Performs specific set of runs based upon Design of Experiments (DOE) methodologies, each design variable set to specific value and all response variables are recorded
- ▶ DOE includes: Central Composite Design (CCD) for second order terms, a D-Optimal design for second order (max 15 design variables), or Fractional Factorial (FF) design for all linear and mixed cross terms (but not pure quadratic terms)
- ▶ Least squares quadratic equation of form:

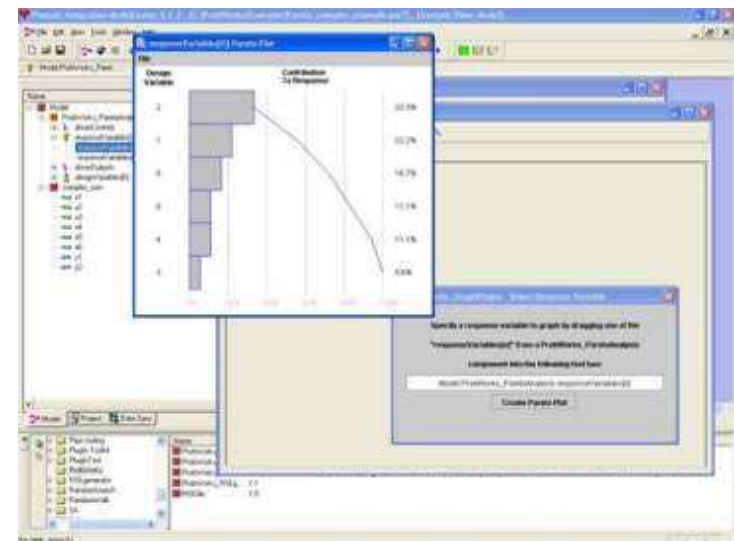
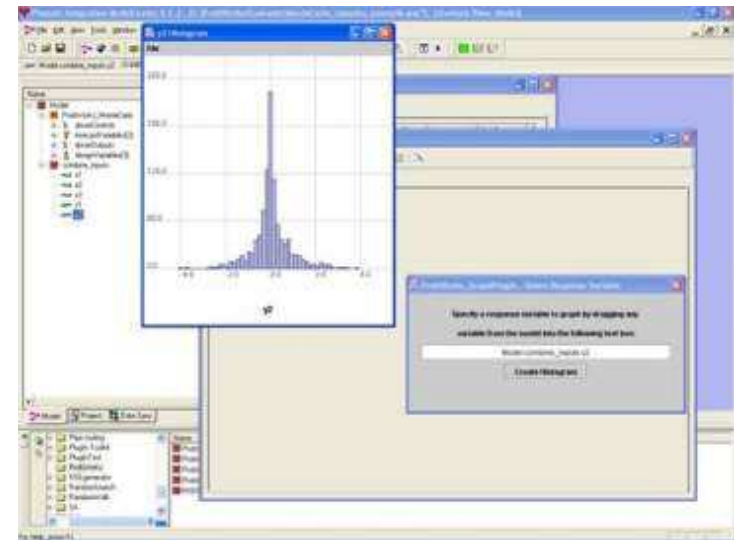
$$\sum_{i=1}^n a_i x_i^2 + \sum_{i=1}^{n-1} \sum_{j=i+1}^n b_{ij} x_i x_j + \sum_{i=1}^n c_i$$

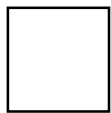
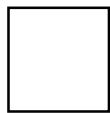
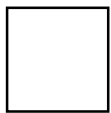
where n is number of design variables,  $x_i$  and  $x_j$  are design variables,  $a_i$  and  $a_j$  are quadratic coefficients,  $b_{ij}$  are cross term coefficients, and  $c_i$  are constant coefficients



## Graph Plug-In

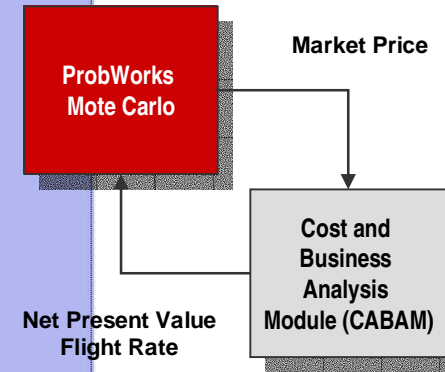
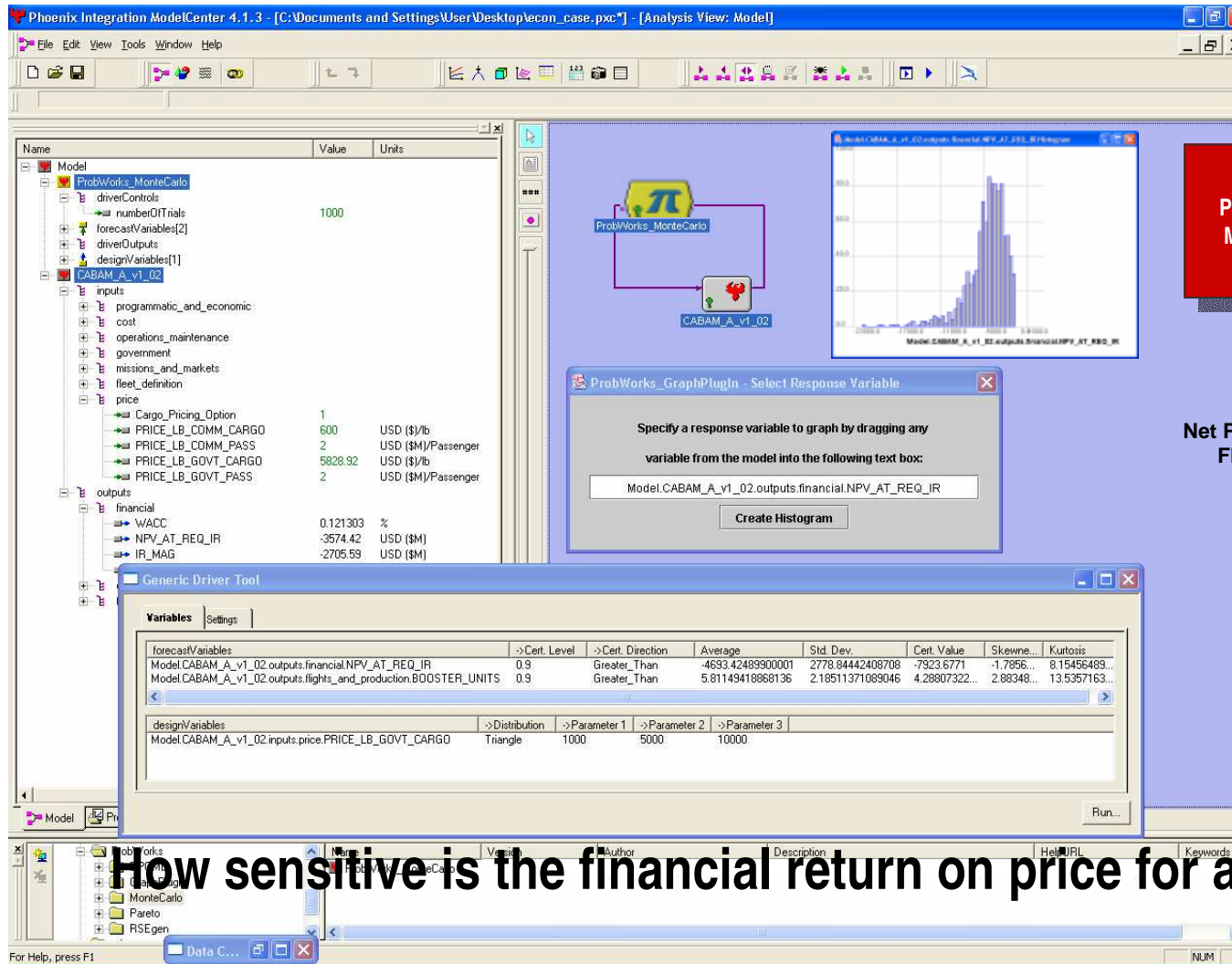
- ▶ **Not analysis component but plug-in utility to provide fast-acting graphical analysis of results of other analyses**
- ▶ **Once installed, available from the Data Collector after analysis is performed in ModelCenter®**
- ▶ **Graph plug-in produces histograms from Monte Carlo and Pareto charts from sensitivity analyses**
- ▶ **User selects either histogram from Monte Carlo data or Pareto chart from Pareto analysis**
- ▶ **User specifies variables to graph by either typing complete variable name into text box, or dragging variable from Component Tree into text box and then clicking “Create Histogram” or “Create Pareto Plot”**
- ▶ **Histograms can be created from nearly any numerical variable within ModelCenter®**
- ▶ **Pareto charts can only be created from individual response variables in Pareto Analysis component**





# ProbWorks Case Studies

# Case Study: Economic Uncertainty



## Why ProbWorks?

Unknown Market Conditions  
Visualize ModelCenter® Data

# How sensitive is the financial return on price for a launch vehicle

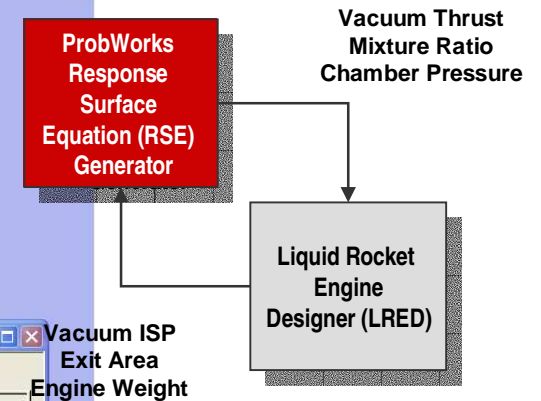
# Case Study: Meta Model Generation for Liquid Rocket Engine Analysis

The screenshot displays the Phoenix Integration ModelCenter 4.1.3 interface. The main window shows a project tree on the left with components like 'ProbWorks\_RSEgenerator' and 'LRE\_Designer\_v42'. The central workspace contains a diagram with a 'ProbWorks\_RSEgenerator' icon and a 'LRE\_Designer\_v42' icon. A 'Generic Driver Tool' window is open in the foreground, showing a table of variables and their settings.

Variables	R Squared	R Sq. Adj.
ModelLRE_Designer_v42.Outputs.Performance.Primary_Nozzle.Isp_vac	0.993353	0.999884
ModelLRE_Designer_v42.Outputs.Performance.Primary_Nozzle.Nozzle_Exit_Area	0.999953	0.999991
ModelLRE_Designer_v42.Outputs.Weight.Total_Engine_Weight	0.999549	0.999918

designVariables	->Low Setting	->High Setting
ModelLRE_Designer_v42.Inputs.Global_Engine_Parameters.Vacuum_Thrust	400000	600000
ModelLRE_Designer_v42.Inputs.Global_Engine_Parameters.Chamber_Pressure	2500	3500
ModelLRE_Designer_v42.Inputs.Global_Engine_Parameters.Engine_Inlet_Propellant_Mixture_Ratio	5.75	6.25



## Why ProbWorks?

**Protect proprietary models**  
**Reduce model execution time**

**How to allow for rapid optimization and robust design of a rocket engine**

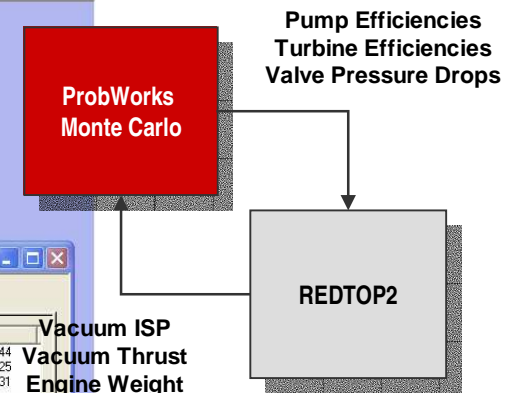
# Case Study: Probabilistic Simulation for Liquid Rocket Engine Analysis

**Generic Driver Tool**

forecastVariables	-> Cert. Level	-> Cert. Direction	Average	Std. Dev.	Cert. Value	Skewness	Kurtosis
Model.REDTOP2.Outputs.Weight	0.8	Less_Than	7048.09	28.1639631442985	7075.66	-0.203679240991976	1.32352313257444
Model.REDTOP2.Outputs.Vacuum_Isp	0.8	Greater_Than	449.0103	0.141316700993117	448.94	0.123110101186225	1.69281025451325
Model.REDTOP2.Outputs.Vacuum_Thrust	0.8	Greater_Than	502807.9	158.508327806872	502617	0.120981162600702	1.32624483951331

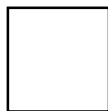
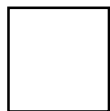
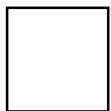
designVariables	-> Distribution	-> Parameter 1	-> Parameter 2	-> Parameter 3
Model.REDTOP2.Inputs.LPOTP_Eta	Triangle	58	63	67
Model.REDTOP2.Inputs.LPOTP_Turbine_Eta	Triangle	58	62	68
Model.REDTOP2.Inputs.LPFTP_Eta	Triangle	61	65	70
Model.REDTOP2.Inputs.LPFTP_Turbine_Eta	Triangle	50	52	60
Model.REDTOP2.Inputs.HPOTP_S1_Eta	Triangle	65	67	72
Model.REDTOP2.Inputs.HPOTP_S2_Eta	Triangle	75	80	85
Model.REDTOP2.Inputs.HPOTP_Turbine_Eta	Triangle	72	79	83
Model.REDTOP2.Inputs.HPFTP_Eta	Triangle	67	73	77
Model.REDTOP2.Inputs.HPFTP_Turbine_Eta	Triangle	72	78	82
Model.REDTOP2.Inputs.MOV_DeltaP	Triangle	10	15	20
Model.REDTOP2.Inputs.MFV_deltaP	Triangle	2.5	5	8



## Why ProbWorks?

Actual values requires testing  
Ease of integration with tool

How to ensure a rocket engine meets performance requirements



# ProbWorks Demonstration

- Future?** - **Ubiquitous Space Transportation Systems**
- Need?** - **Revolutionary Improvements in Enabling and Enhancing Technologies**
- Uncertain Technologies?** - **Technology Impacts on Vehicle Design Parameters**
- Uncertain Models?** - **Limitations of Design Codes to Model Reality**
- Techniques?** - **Faster Acting Monte Carlo Probabilistic Data Assessment (PDA)**

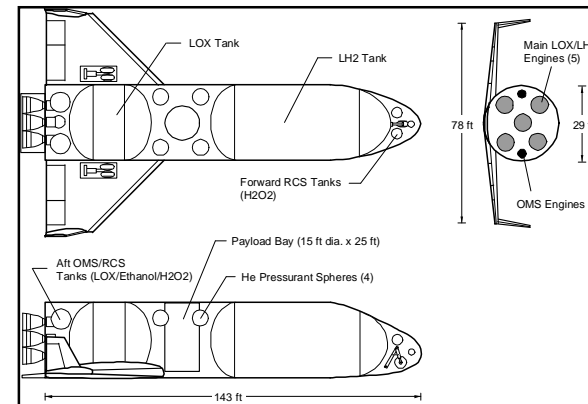


## Probabilistic Vehicle Design

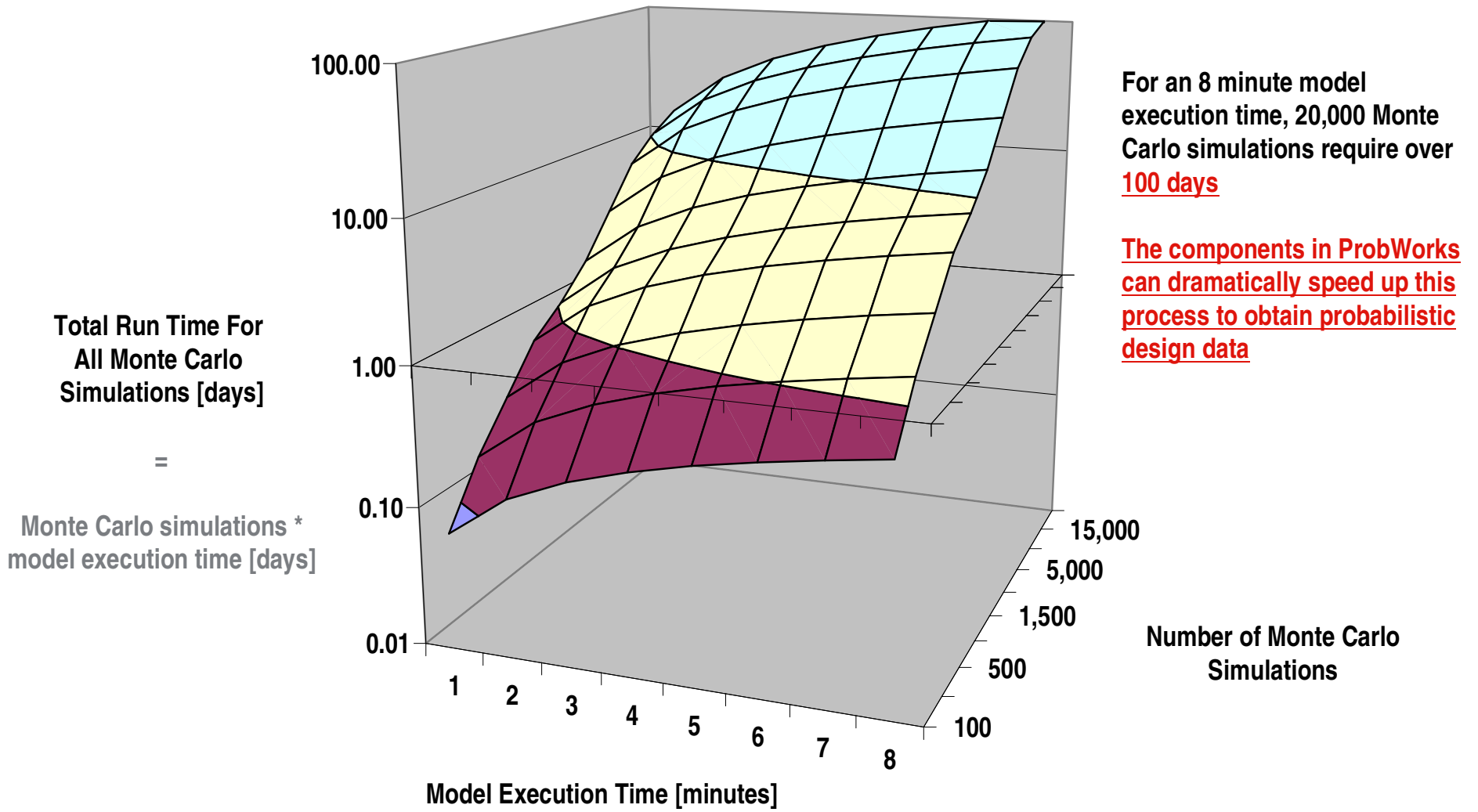


## Design Study: ACRE-92 Reusable Launch Vehicle (RLV)

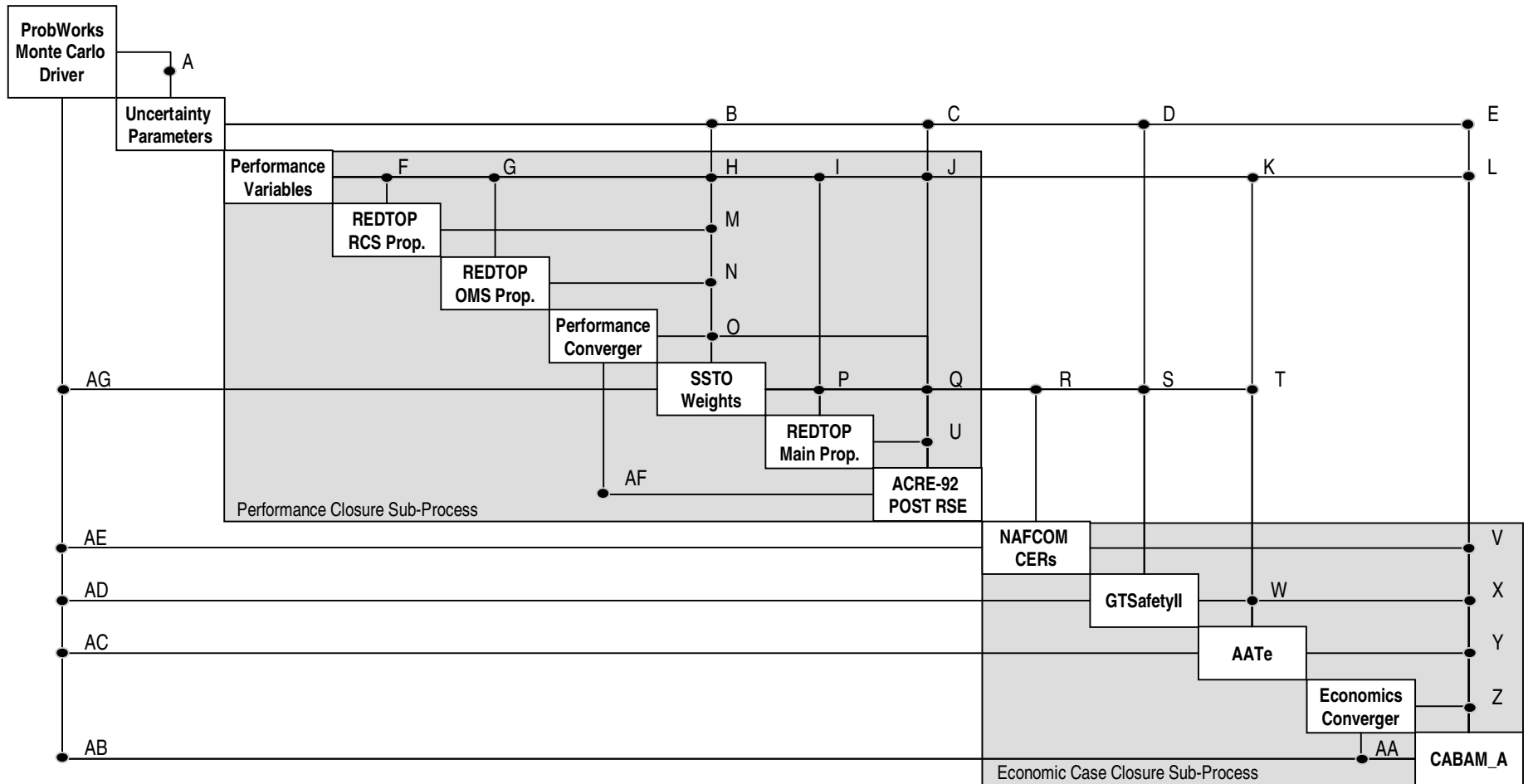
Item	Characteristics
Concept	Single-Stage-To-Orbit (SSTO) Vertical Take-Off Horizontal Landing (VTHL) Earth-To-Orbit (ETO) Reusable Launch Vehicle (RLV); commercial focus with initial flight capable in 2025, technology freeze date of 2018
Reference Mission	Payload: 40k lbs. (100 nmi. @ 28.5 degrees inclination from KSC), Cargo delivery or passenger delivery and return
Propulsion	Engines: 5 Advanced Staged Combustion Engines (Pc 4000 psi, mixture ratio 6.9) Propellants: NBP LOX and NBP LH2 T/We: ~92
Sizing	GLOW: 2.3M lbs. (system), Dry Wt.: 224k lbs Length: 163 ft
Analyses Performed	Creation of ROSETTA analysis model for probabilistic examination; modeled in ModelCenter distributed framework with eight disciplines



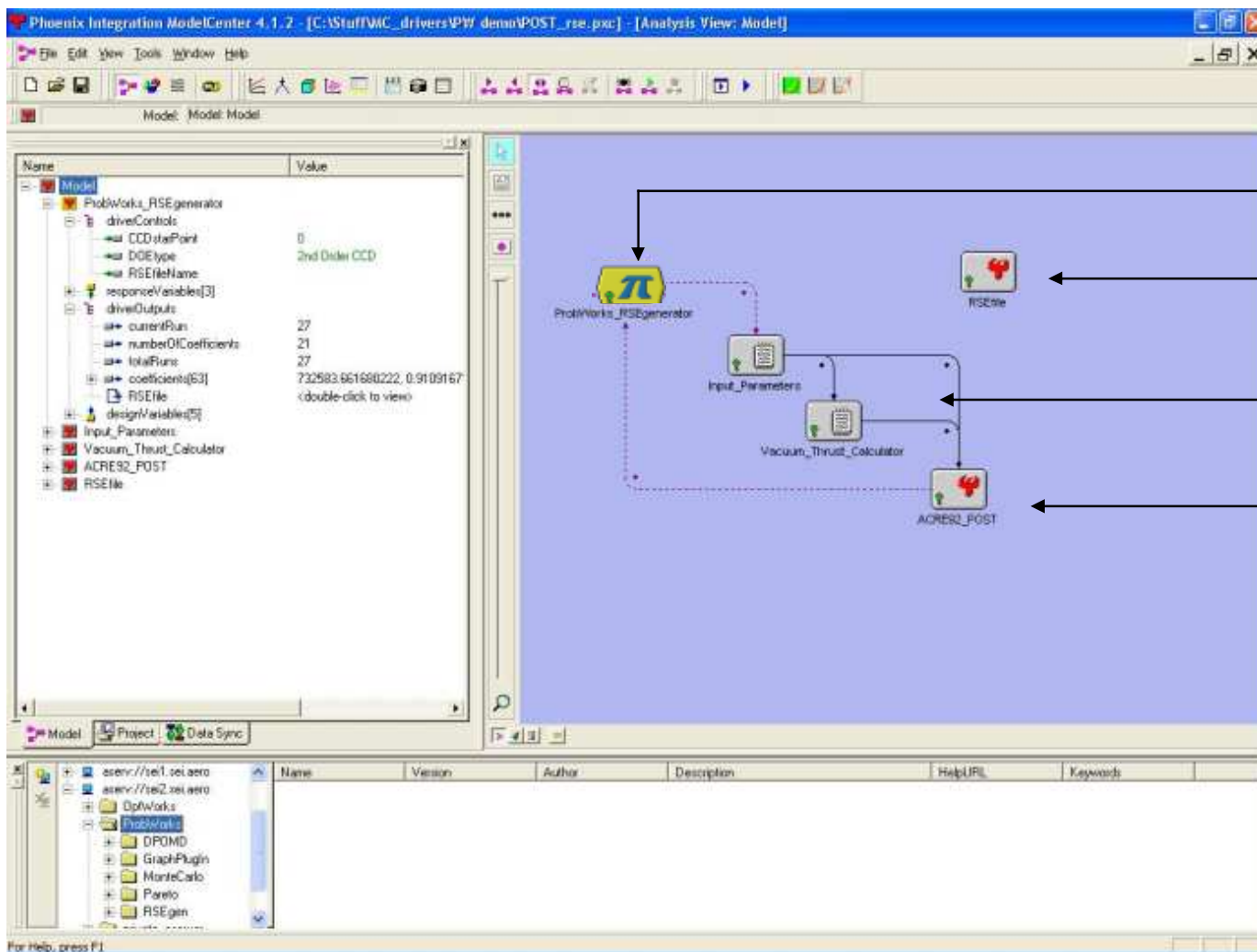
## The Need to Speed Up Probabilistic Design



# ACRE-92 Reusable Launch Vehicle (RLV) Design Structure Matrix (DSM)



# ProbWorks Response Surface Equation (RSE) Generation in ModelCenter® Environment



## Why ProbWorks?

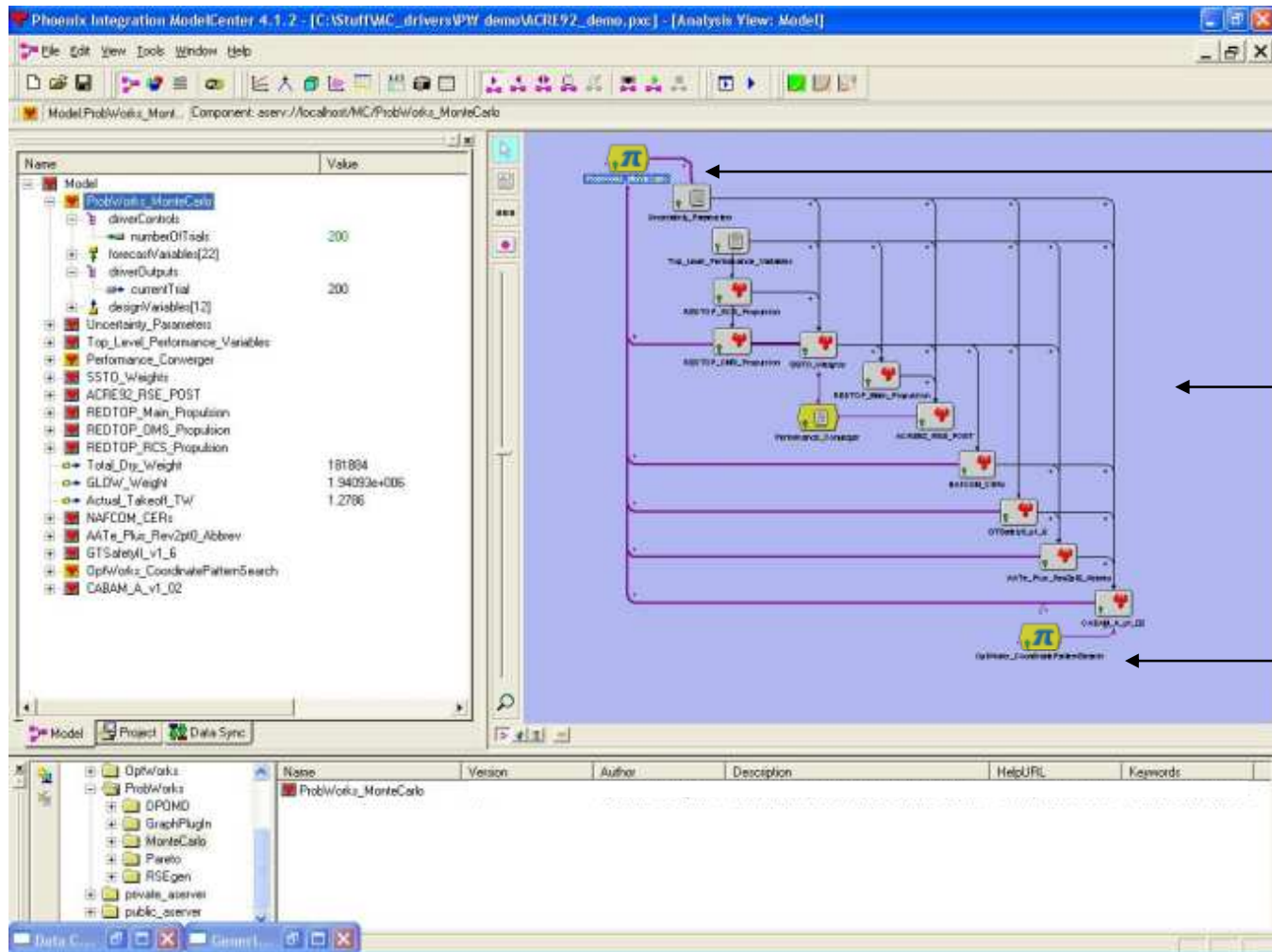
To Reduce Long Run Time  
Easy RSE Generation

## Speeding Up The Performance Closure Design Loop Using ProbWorks

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- ▶ **Since Probabilistic Data Assessment (PDA) sometimes requires many thousands of Monte Carlo simulations (i.e. converged design points), reduced code calculation time is essential in obtaining time relevant uncertainty assessments**
  
- ▶ **Two different formulations of vehicle performance sub-process closure loop generated**
  - High fidelity trajectory code (POST tool) on an SGI
  - ProbWorks Response Surface Equation (RSE) of POST tool in MS Excel (RSE POST)
  
- ▶ **If performing a Monte Carlo simulation of this performance closure sub-process by itself for 2,000 simulations:**
  - Full fidelity process would take approximately 8.3 days
  - RSE trajectory would take approximately 22.2 hours
  - RSE POST method was only 0.8% higher in terms of Gross Lift-Off Weight (GLOW) full fidelity
  - RSE POST method was only 0.65% higher in terms of dry weight versus full fidelity

# ProbWorks Vehicle Design Demonstration in ModelCenter® Environment



ProbWorks Monte Carlo Driver

Launch Vehicle Performance and Life Cycle Analysis

OptWorks Coordinate Pattern Search (CPS) Optimizer

## Why ProbWorks?

**Monte Carlo Analysis  
Directly on Complex  
Distributed Model**

## Sample Input and Output Uncertainty Parameters

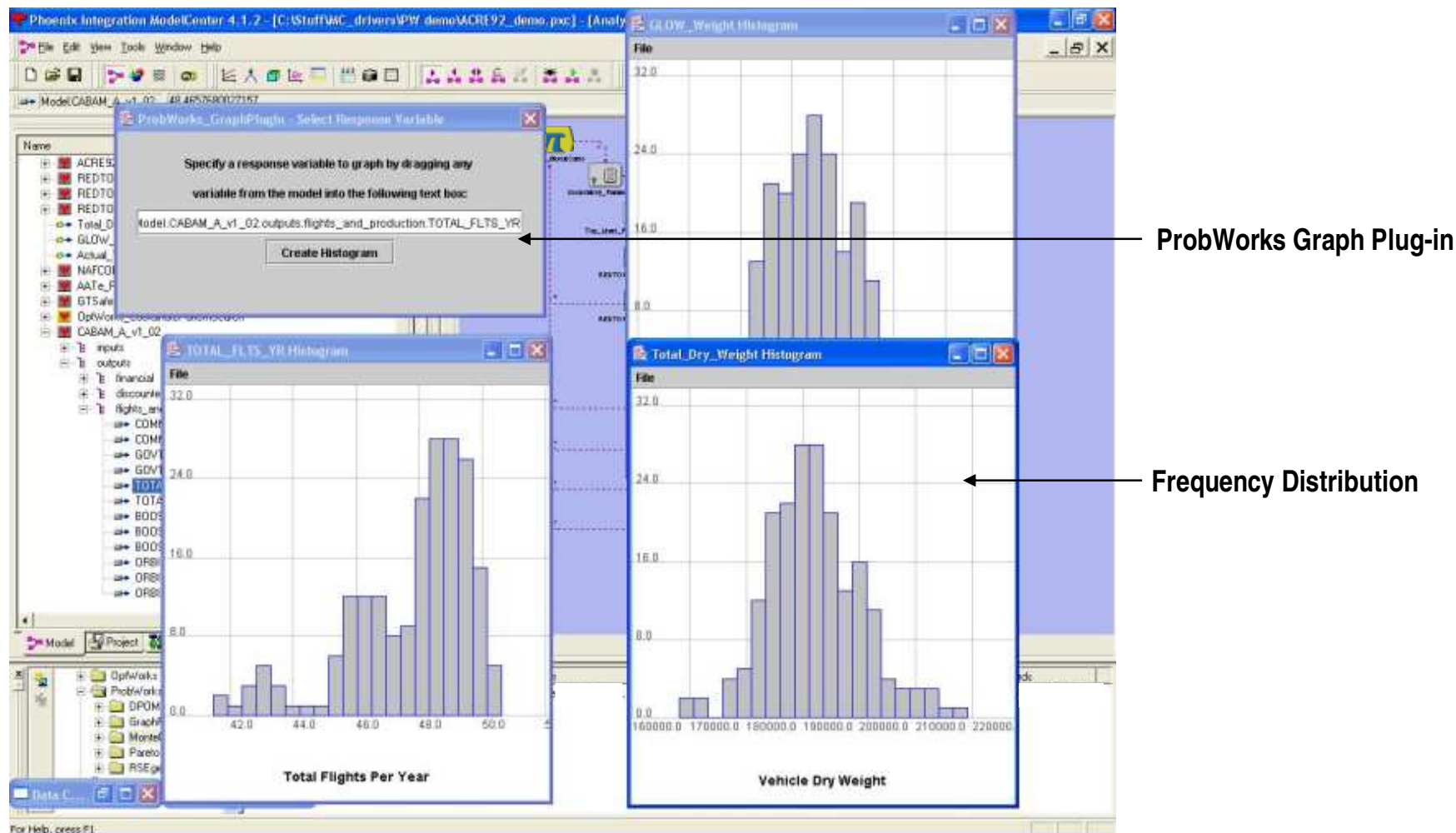
### INPUT UNCERTAINTY DISTRIBUTIONS (NON-DIMENSIONAL)

Item	Low	Most Likely	High	Distribution Type
Main Engine Thrust to Weight Ratio	0.85	1	1.1	Skewed Triangular
Main Engine Vacuum Isp	0.99	1	1.01	Triangular
Main Engine Thrust	0.95	1	1.05	Skewed Triangular
OMS Engine Weight	0.95	1	1.04	Skewed Triangular
OMS Engine Vacuum Isp	0.95	1	1.2	Skewed Triangular
RCS Engine Vacuum Isp	0.95	1	1.04	Skewed Triangular
Primary Structure Weight	0.95	1	1.2	Skewed Triangular
Landing Gear Weight	0.98	1	1.2	Skewed Triangular
Passenger Flight Rate	0.5	1	1.5	Triangular

### OUTPUT PROBABILISTIC STATISTICS FOR 100 MONTE CARLO SIMULATIONS

Item	Mean	Standard Deviation	90% Certainty	Skewness	Kurtosis
Vehicle Dry Weight	191,855	9,413	204,420	0.3	3.35
Vehicle Gross Weight	2041,476	101,266	2,175,385	0.219	3.34
Vehicle Length	155.5	2.616	158.9	0.105	3.20
Price per Pound for Govt Cargo	2238	88.8	2283	2.35	9.67
Fixed Operations Cost Per Year	40.75	0.276	41.1	0.276	3.38
Variable Operations Cost	3.202	0.013	3.22	0.283	3.37
Booster Airframe DDTE	7,121	195	7,365	0.254	3.16
Booster Airframe TFU	1,683	54.1	1,750	0.263	3.17
Total Flights Per Year	47.8	1.70	49.7	-0.983	8.03

# ProbWorks Probabilistic Data Assessment (PDA) in ModelCenter® Environment

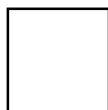
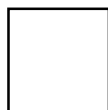
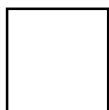




## Conclusions from Demonstration

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- ▶ Probabilistic Data Assessment (PDA) allows designers to quantify risks of various projects and determine the likelihood of meeting programmatic goals
- ▶ Comparison of nominal (or deterministic) output values versus probabilistic mean output values reveals a substantial difference for some vehicle metrics
- ▶ Ranges of some of output variables are greater than the potential error in the RSE
- ▶ Response Surface Equations (RSEs) are a critical piece for making these probabilistic processes accessible to management who cannot wait a few weeks for output results
- ▶ These analyses are most relevant when evaluation of new concepts or technologies is required



# Summary



ProbWorks: ModelCenter<sup>®</sup> suite consists of **four tools to help employ uncertainty analysis techniques** implemented as Java-based components which can function on any platform running Phoenix Integration's ModelCenter<sup>®</sup> or Analysis Server<sup>®</sup>. ProbWorks: ModelCenter<sup>®</sup> easy to implement as drag-and-drop components for treating uncertainty and risk in product designs

Phoenix-Integration, Inc. serves as the primary reseller for Pi Blue's Optworks: ModelCenter<sup>®</sup>, and ProbWorks: ModelCenter<sup>®</sup>, products. For sales and pricing info, please contact [sales@phoenix-int.com](mailto:sales@phoenix-int.com) or call Phoenix Integration at 1.800.500.1936. Individual and discounted division-wide licenses with annual maintenance plans are available. Individual-user licenses are priced at \$1999.00 (one-time charge).



## Conclusion



Pi Blue Software, Inc. introduces a new suite of **optimization** tools for incorporation with Phoenix Integration’s ModelCenter® collaborative design environment.

Entitled OptWorks: ModelCenter®, this suite consists of **eight non-gradient based optimizers** each implemented as Java-based components which can function on any platform running Phoenix Integration’s ModelCenter® or Analysis Server®.



# OptWorks: ModelCenter



These tools enhance the current gradient based optimization tools in ModelCenter<sup>®</sup> to allow **solution of previously intractable problems.**

Characteristics of these sets of applications include the capability to handle problems with high dimensionality, discrete or mixed variables (continuous and discrete), and multi-modal solutions spaces.

This package is currently available for purchase through **individual/group site licenses.** The full product suite includes optimizers in Java byte code, documentation with case study examples, and selected online support.



# OptWorks: ModelCenter Capabilities

## Pi Blue Software, Inc.

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### Contact Information

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