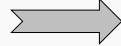# MBSE Driven Analysis

Improving MBSE Capabilities at Orbital ATK with ModelCenter

Virgil Hutchinson, Jr.

Sr. Manager, Advanced Programs Systems

Systems Engineering

Space Systems Group

Orbital ATK

Orbital ATK Overview

- Global Aerospace & Defense Systems Company Established by Merger of Orbital and Alliant Techsystems in 2015

- Leading Developer & Manufacturer of Innovative, Reliable and Affordable Products for Government and Commercial Customers
  - ▶ Launch Vehicles, Rocket Propulsion Systems and Aerospace Structures
  - ▶ Tactical Missile Products, Armament Systems and Ammunition
  - ▶ Satellites, Space Components and Technical Services

- More Than 13,000 Employees, Including About 4,200 Engineers & Scientists
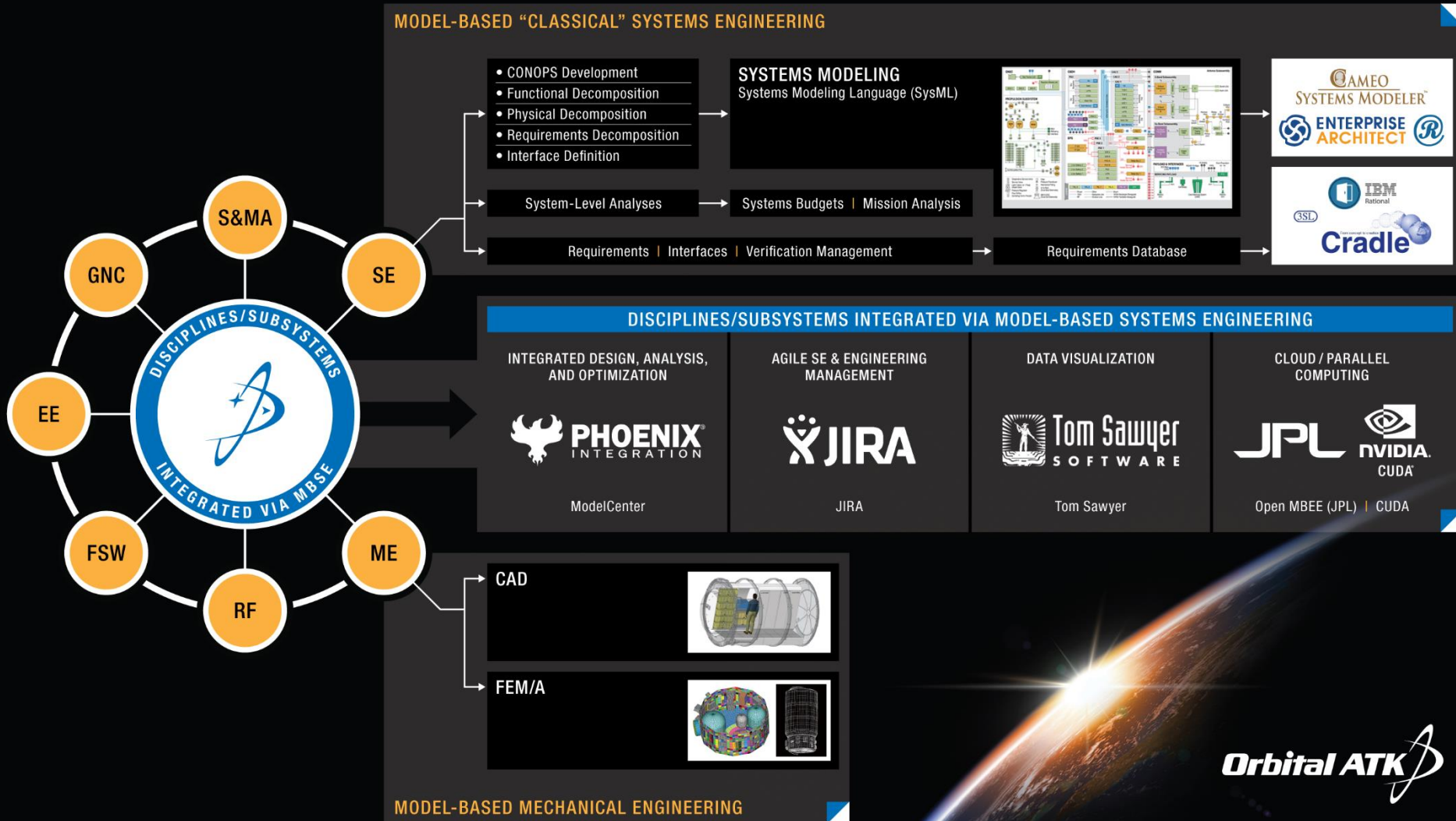
Flight Systems Group

Defense Systems Group

Space Systems Group

MBSE to Cover Waterfront of System Engineering

1 SYSTEMS MODELING

TOOLS: CAMEO, RHAPSODY
- Functional Decomposition
- Physical Decomposition
- Architecture Development
- System Behavior
- Interface Definition

2 SE/ENGINEERING MGMT

TOOLS: JIRA
- Agile SE Management
- Design/Analysis Cycle Management
- Engineering Linkage to IMS/EVMS
- Action Items & Issue Tracking
- Risk Management

3 REQUIREMENTS & VERIFICATION MGMT

TOOLS: DOORS, CRADLE
- Requirement Management
- Interface Management
- Verification Management
- Specific/ICD Generation

4 DATA VISUALIZATION

TOOLS: TOM SAWYER
- Visualize & Review Data Trends
- Translate SysML to Standard Views

5 INTEGRATED ANALYSIS DESIGN

TOOLS: MODELCENTER (MC)
- Perform Integrated Trades & Probabilistic Analyses
- Integrated Multi-Discipline Analyses
- Design Optimization
- Automated Tool/Analysis Execution
- Direct Data Exchange Between Models & Tools

6 CLOUD/PARALLEL COMPUTING

TOOLS: CUDA, OPEN MBEE, MC CLOUD
- Execute Analysis & Process/Review Data from Cloud/Web Interface
- Parallelization of Analyses/Computations
- Reduce Licenses Need to Access Tools & Data
- Improve Computing Capability/Reduce Time

MODEL-BASED SYSTEMS ENGINEERING

Focus Areas
- Established (blue)
- Adopting; Implementing (green)
- Exploring; Not Adopted (orange)

D17-08672_02

Integrated Analysis & Design
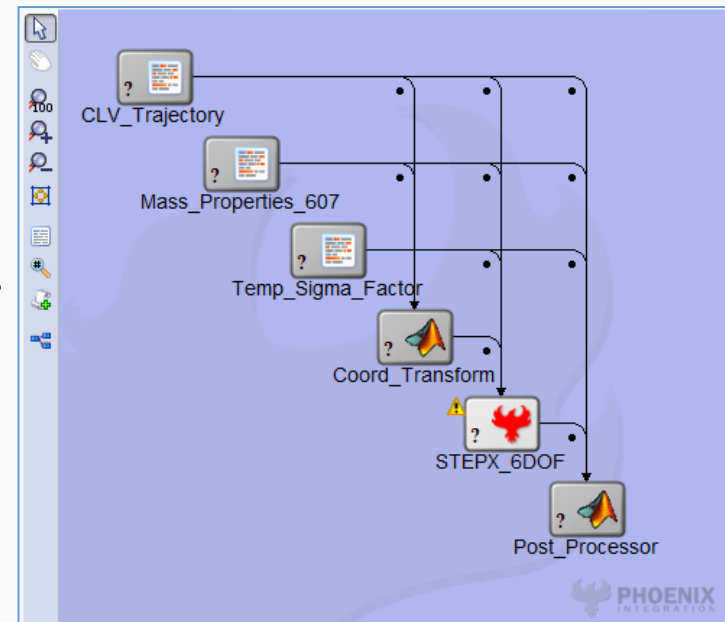
- **Integrated Analysis & Design**
  - ▶ Multiple discipline tools connected in single model
  - ▶ Explore & evaluate large design spaces, generate robust designs, & perform/automate complex analyses
- **SSG has extensive experience performing multi-disciplinary analyses using ModelCenter®**
  - ▶ Integrate & automate analysis models across different software programs & platforms
  - ▶ Optimize design with many optimization methods
  - ▶ Explore design space sensitivity w/ parametric trade studies & Design of Experiment tools
  - ▶ Assess/verify design robustness with probabilistic analysis tools (Monte Carlos)

Orion LAS Mission Analysis N² Diagram

- CM Mass Properties (Excel)
- LAS Mass Properties (Excel)
- ATB Trajectory (Excel)
- Abort/Jettison Motor Thrust Profile (Text File)
- Coordinate Transformation (Matlab/Script)
- 6-DOF (STEPX)
- Post-Processing (Matlab)

1. CM Mass Properties
2. LAS Mass Properties
3. LAV Abort Initial Conditions (IC's)
4. Abort Motor (AM) & Jettison Motor (JM) Burn Rate and Thrust History
5. Transformed Mass and IC's
6. 6-DOF Analysis Results

- Inputs from Lockheed Martin
- Data from Motors Vendors
- Orbital Products

Orion LAS Mission Analysis in ModelCenter

- CLV_Trajectory
- Mass_Properties_607
- Temp_Sigma_Factor
- Coord_Transform
- STEPX_6DOF
- Post_Processor

PHOENIX INTEGRATION

5

SSG Experience with MBSE & ModelCenter®

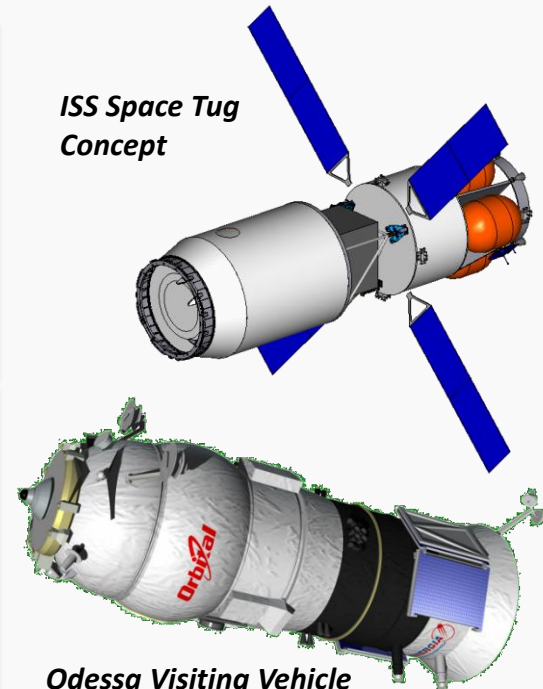## ICCS/COTS Proposal

Integrated vehicle sizing & mission analysis.

- Optimization of spacecraft design with FSG/SSG trajectory tools (Matlab) & SSG spacecraft sizing tools (Excel)

- Parametric trades to explore sensitivity of vehicle design to variation in launch vehicle, cargo mass, # of missions, ConOps
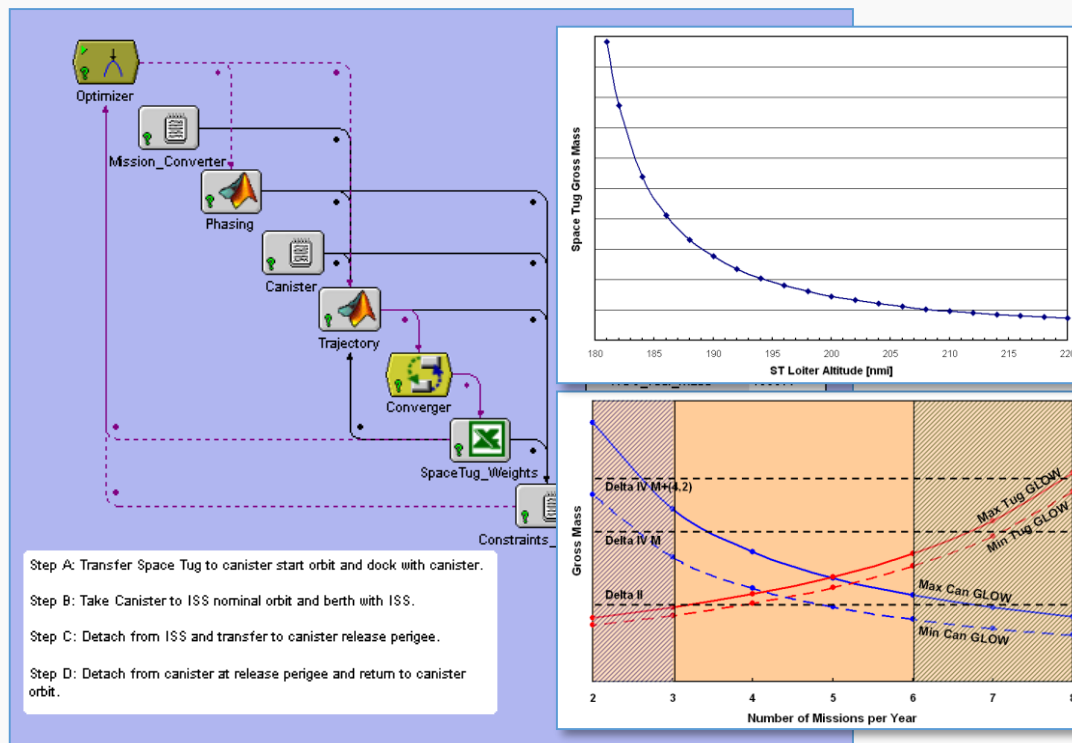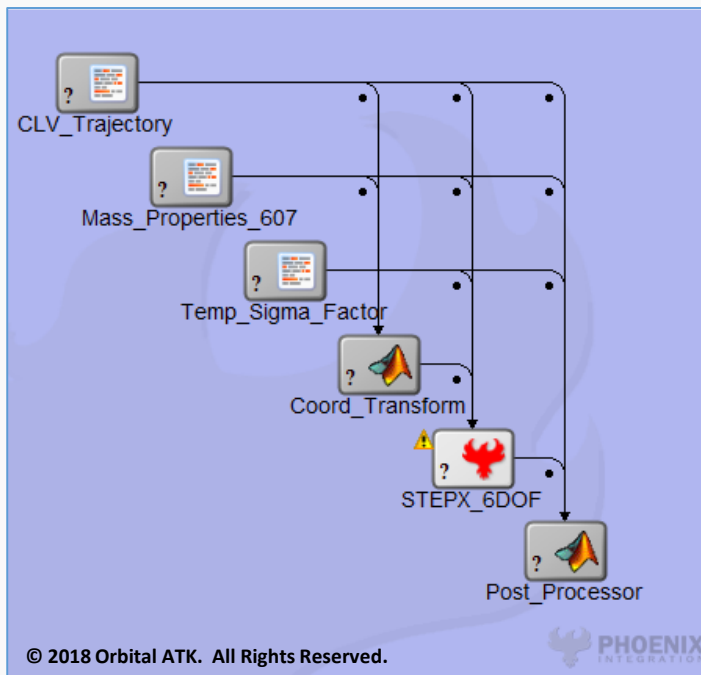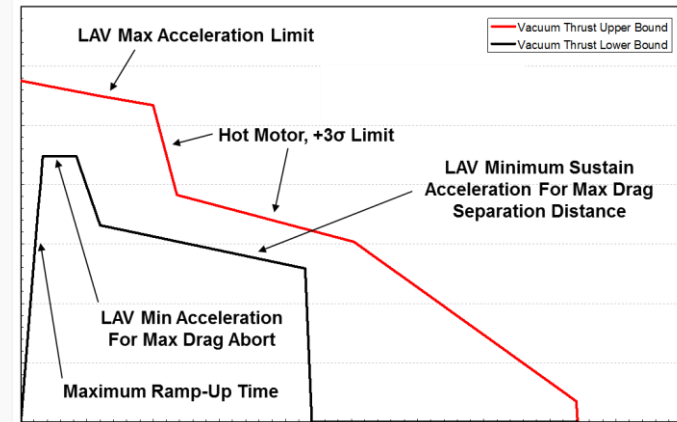

ISS Space Tug Concept

Odessa Visiting Vehicle

SSG Experience with MBSE & ModelCenter®

Orion LAS PA-1 Flight Test Validation & Verification

- Optimization of abort motor thrust profile
- 6-DOF trajectory analysis for all capsules, abort conditions, & motors performance
- Validation & verification Monte Carlo analysis
- Results linked to Cradle requirements database

LAV Max Acceleration Limit
Vacuum Thrust Upper Bound
Vacuum Thrust Lower Bound
Hot Motor, +3σ Limit
LAV Minimum Sustain Acceleration For Max Drag Separation Distance
LAV Min Acceleration For Max Drag Abort
Maximum Ramp-Up Time

CLV_Trajectory
Mass_Properties_607
Temp_Sigma_Factor
Coord_Transform
STEPX_6DOF
Post_Processor

Orion Pad Abort-1 (PA-1) Flight Test
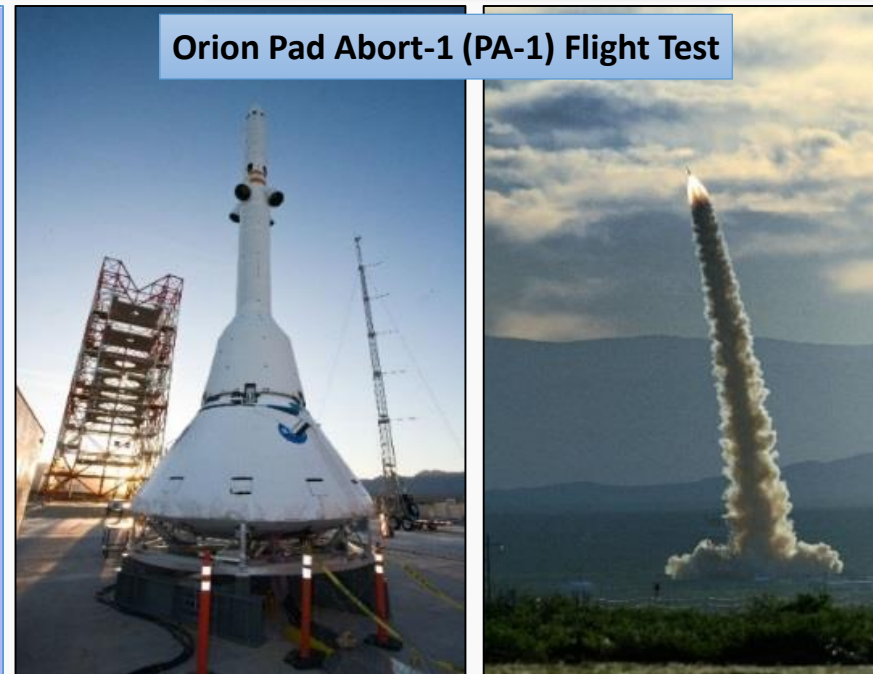
SSG Experience with MBSE & ModelCenter®

Antares Launch Vehicle Performance Analysis

- POST 3-DOF trajectory analysis (Fortran) integrated with mass properties (Excel) & upper stage motor ballistics (ASCII)

- Parametric trades to explore sensitivity of payload performance to variation in orbit altitude, inclination, & launch site.

**2008**

Antares Launch from NASA WFF

Orbit_Calculations

Launch_Site

T2_POST_NPSOL_2Stage

Post_Processor

Analysis Home
Name
homePath

Taurus II 2-Stage X16 LEO Performance

28.7 deg
51.6 deg
SSO

Low Inclination Launches from Cape Canaveral
Mid Inclination Launches from Wallops
High Inclination Launches from South Vandenberg

Payload Mass (kg)

Altitude (km)

8
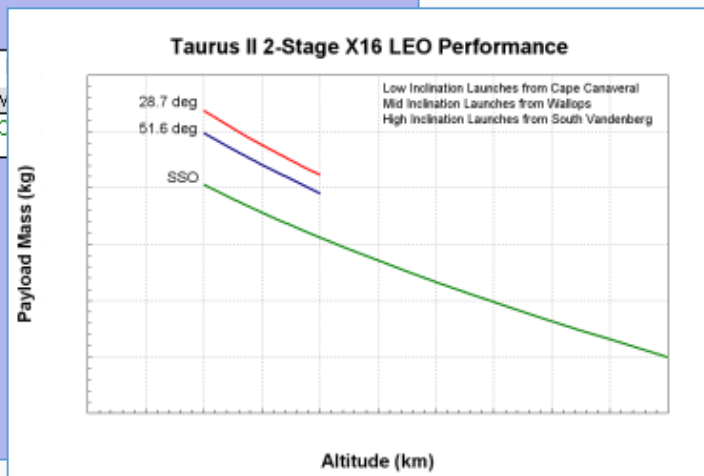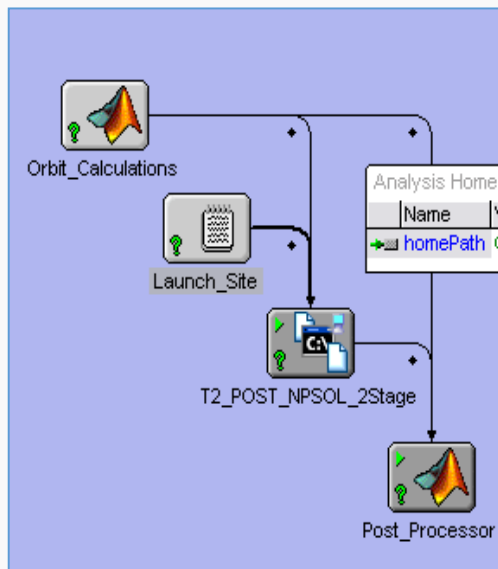
SSG Experience with MBSE & ModelCenter®

## CCDev2 Proposal Abort Black-Out Zones

- POST 3-DOF analysis integrated with LV trajectory (Matlab), LAS mass properties & abort motor performance (Excel)
- Calculated abort impact points & crew load limits
- Parametric trades to evaluate abort simulations at intervals of the LV trajectory to determine Black-Out Zones

2010

Prometheus Crew Vehicle

9
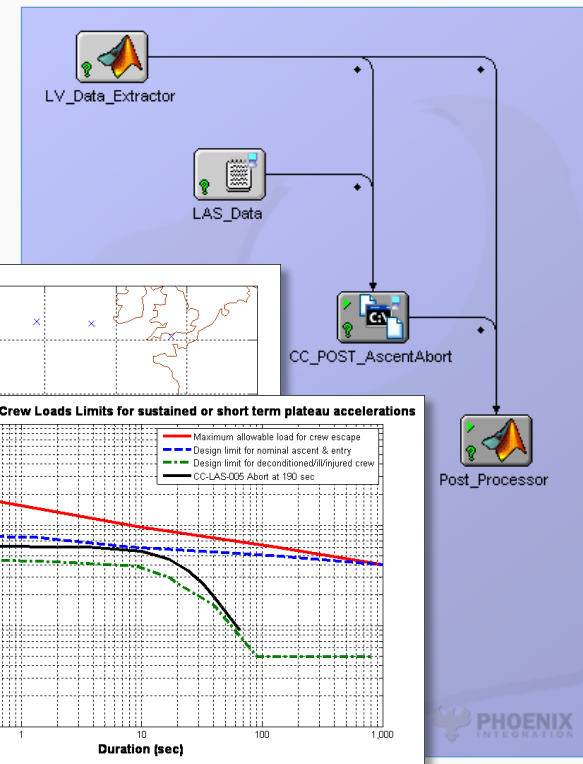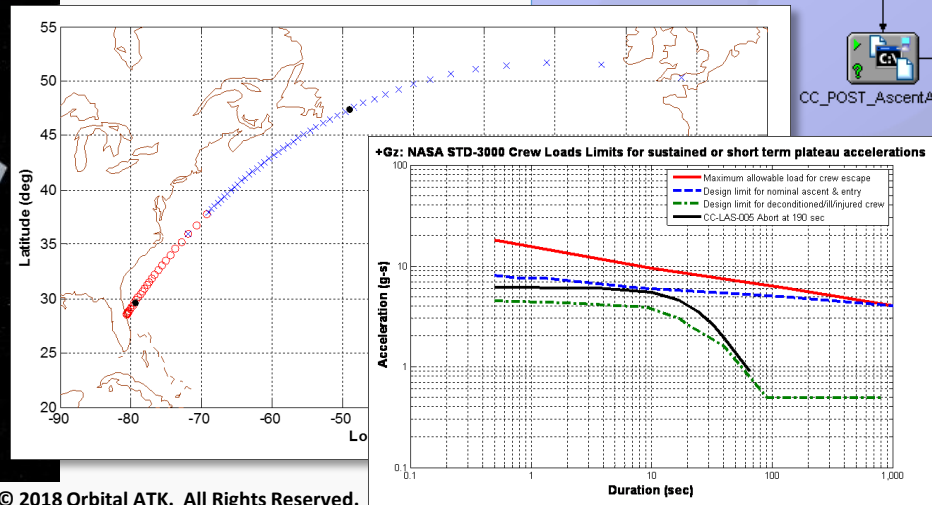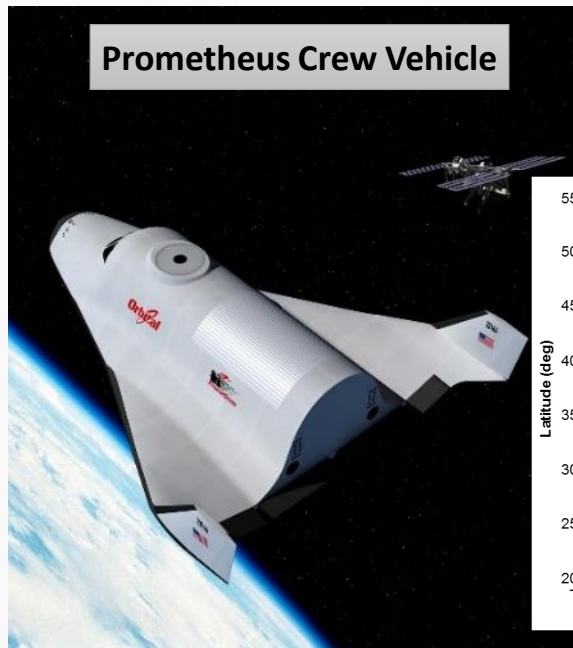
SSG Experience with MBSE & ModelCenter®

NASA Heavy Lift Launch Vehicle Study

- POST 3-DOF trajectory analysis integrated with stages & fairing sizing (Excel) for optimization of 30⁺ LV configurations

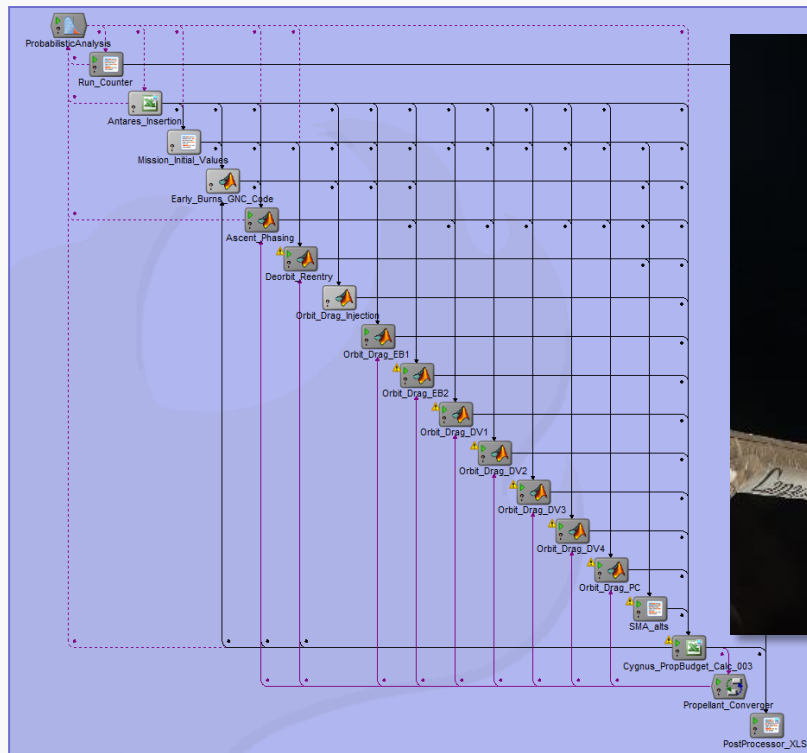- MBSE processes used with integrated analysis to define requirements & provide traceability
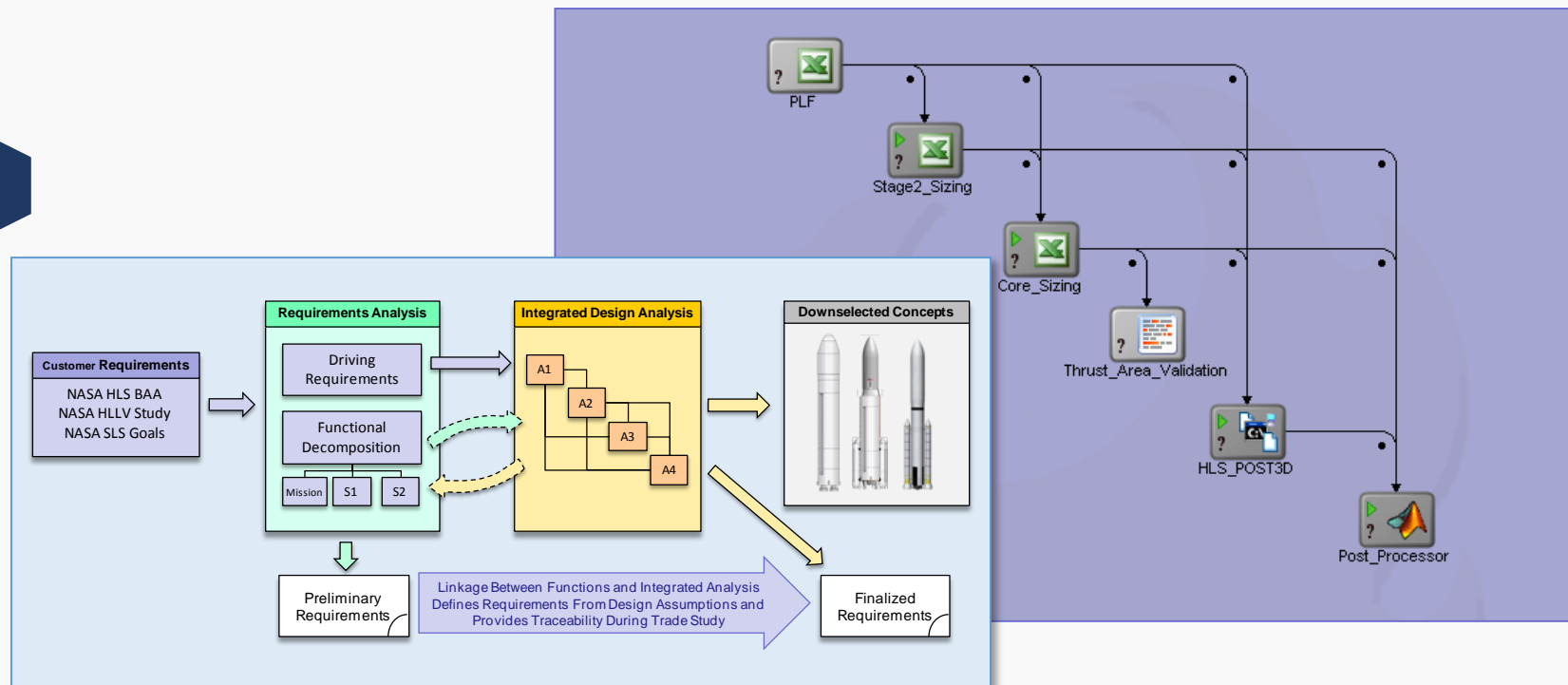
2010

SSG Experience with MBSE & ModelCenter®

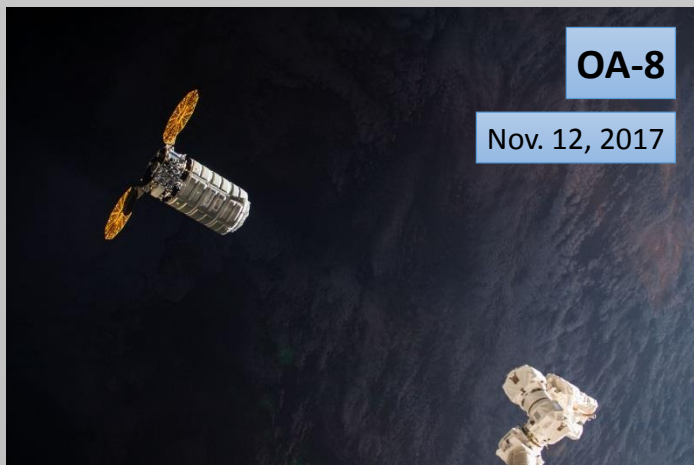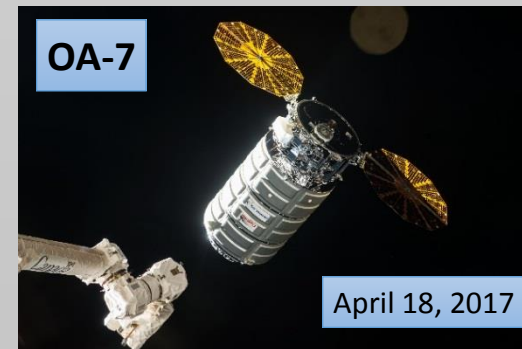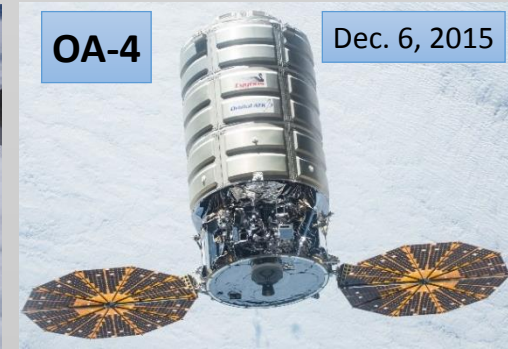## Cygnus Mission Analysis & Propellant Usage Modeling

- Integrated analysis tools from LV, Flight Dynamics, Propulsion, GN&C and Systems
- Optimize propellant usage during the CRS missions & validate Cygnus propellant load
- Used for CRS missions & CRS2 development

2011

OA-7 Cygnus Spacecraft

11

ISS Cargo Resupply with Cygnus

Orb-D
Sept. 18, 2013

Orb-1
Jan. 9, 2014

Orb-2
July 13, 2014

OA-4
Dec. 6, 2015

OA-5
Oct. 17, 2016

OA-6
Mar. 22, 2016

OA-7
April 18, 2017

OA-8
Nov. 12, 2017

- Cygnus carries crew supplies, spare equipment & scientific experiments to the International Space Station (ISS)
- 20 mT of cargo delivered to ISS in 8 flights
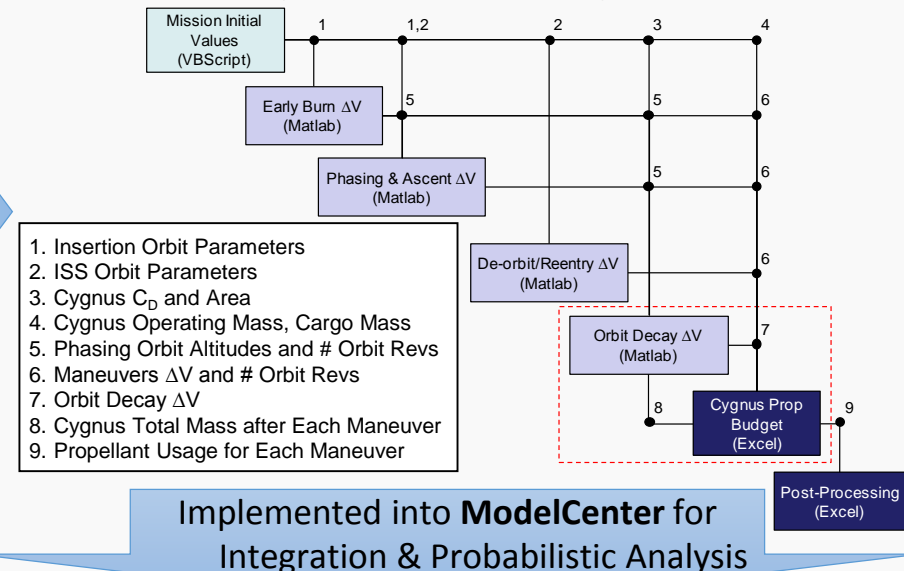- 3 CRS flights from 2018 to 2019
- 6 CRS2 flights starting in 2019

Cygnus Mission Performance Optimization Process

Orbital ATK

Assumptions & Dispersions Spreadsheet

Antares	• Launch Mass • Insertion Orbit Parameters
PSS	• DVE & REA Propulsion Parameters • Pressurant & Residual Propellant Data
GN&C	• Effective DVE + REA Isp vs. C.G. • 6-DOF propellant usage distributions for attitude control, slews, JOPS, Aborts, and Departure • Early Burn Algorithm
FDS	• ISS reference trajectory • Ascent Phasing Plan • Deorbit/Reentry Trajectory Plan
Systems	• Mass Properties • Mission Cargo Manifest

Integrated Analysis of End-to-End Mission Performed using Inputs/Models across Cygnus Subsystems
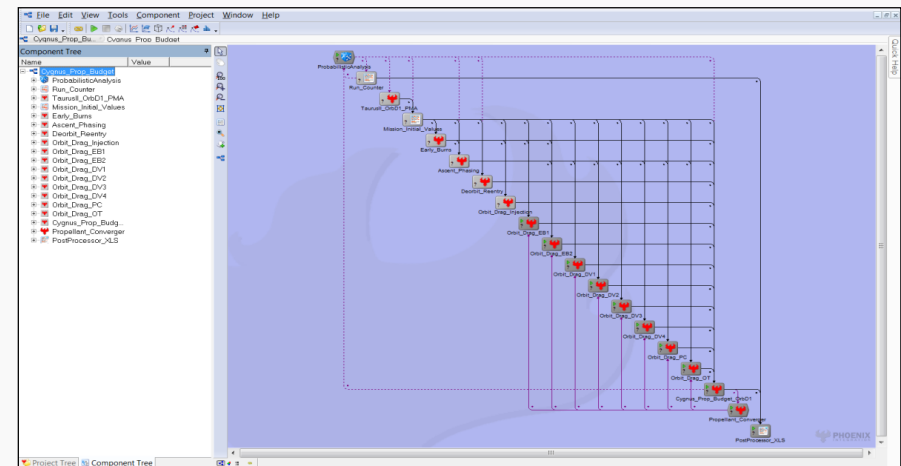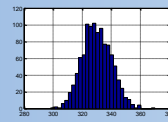
Integrated Analysis N^2 Diagram

Mission Initial Values (VBScript)

Early Burn ΔV (Matlab)

Phasing & Ascent ΔV (Matlab)

De-orbit/Reentry ΔV (Matlab)

Orbit Decay ΔV (Matlab)

Cygnus Prop Budget (Excel)

Post-Processing (Excel)

1. Insertion Orbit Parameters
2. ISS Orbit Parameters
3. Cygnus C_D and Area
4. Cygnus Operating Mass, Cargo Mass
5. Phasing Orbit Altitudes and # Orbit Revs
6. Maneuvers ΔV and # Orbit Revs
7. Orbit Decay ΔV
8. Cygnus Total Mass after Each Maneuver
9. Propellant Usage for Each Maneuver

Implemented into ModelCenter for Integration & Probabilistic Analysis

Propellant Budget Calculated from Probabilistic Analysis Statistics (1000+ runs)

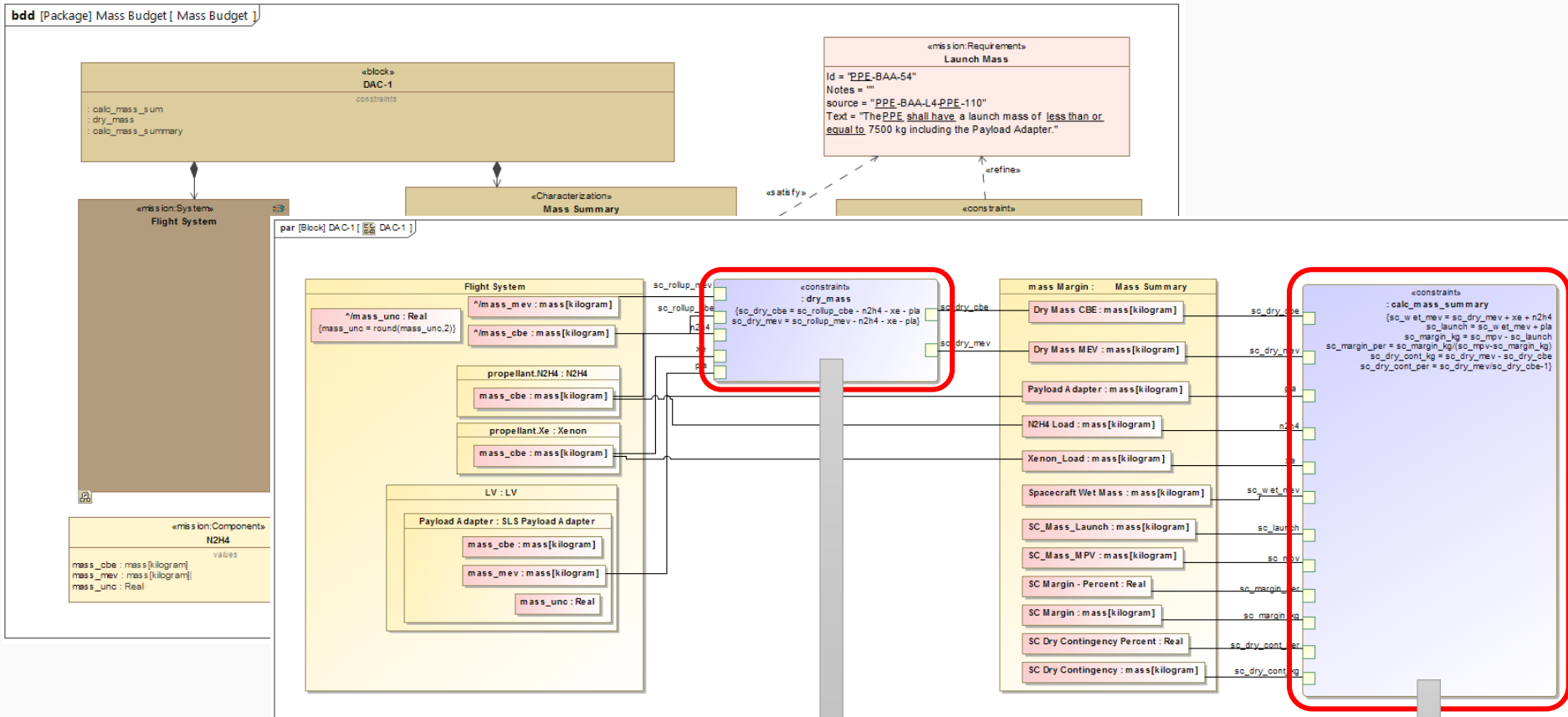| Orb-4 Propellant Budget		
Maneuver	**mean**	**+3σ**
Ascent Propellant		
Prox-Ops Propellant		
Deorbit/Reentry Propellant		
Residual Propellant		
Total Mission Propellant		

Cygnus Performance Integrated Analysis with ModelCenter

- Performance integrated analysis model within Phoenix Integration's ModelCenter® collaborative design environment

- **ModelCenter integrated analysis performed for every CRS mission to validate the Cygnus propellant load**

Integrating with SysML Modeling

Orbital ATK
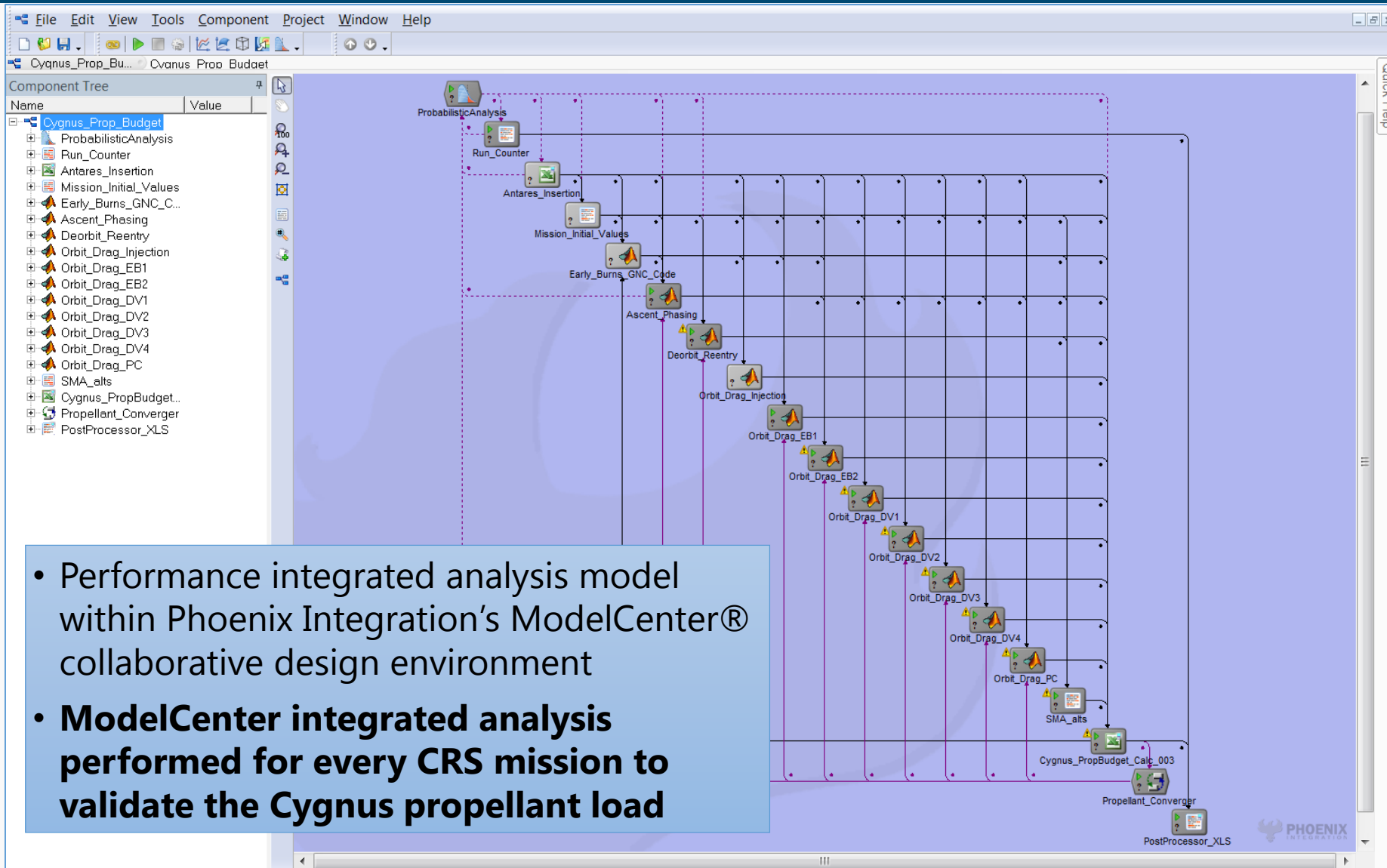
- Utilize ModelCenter to involve existing analysis tools with SysML parametric models

Integrating PLM Metadata

- Utilize ModelCenter to pull metadata from Product Lifecycle Management (PLM) databases like Windchill

- Metadata can be used for integrated analyses in ModelCenter

Component & Coordinate System metadata rendered in ModelCenter geometry view

16
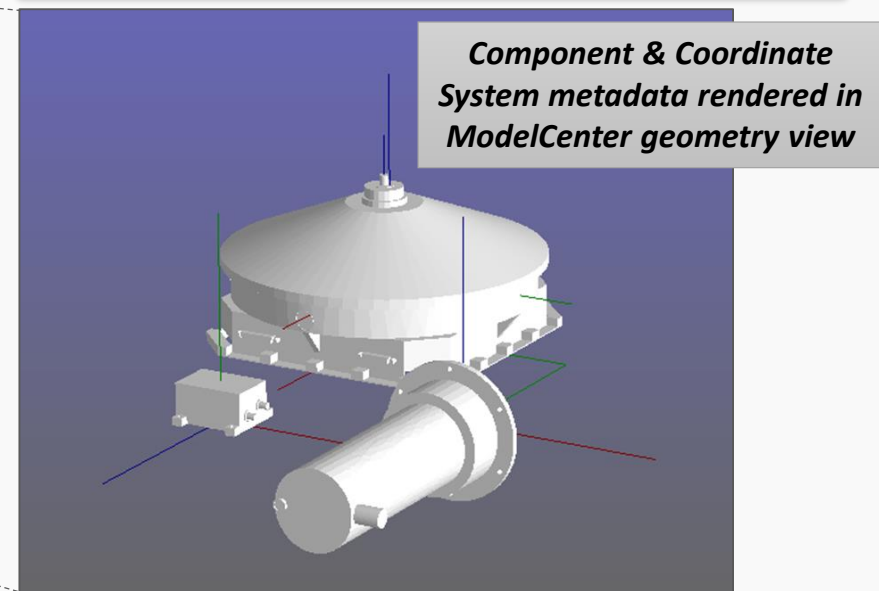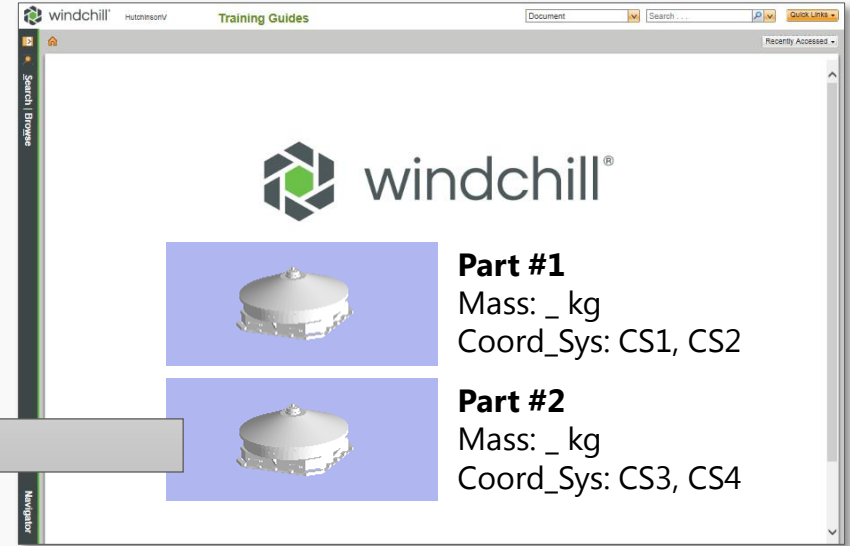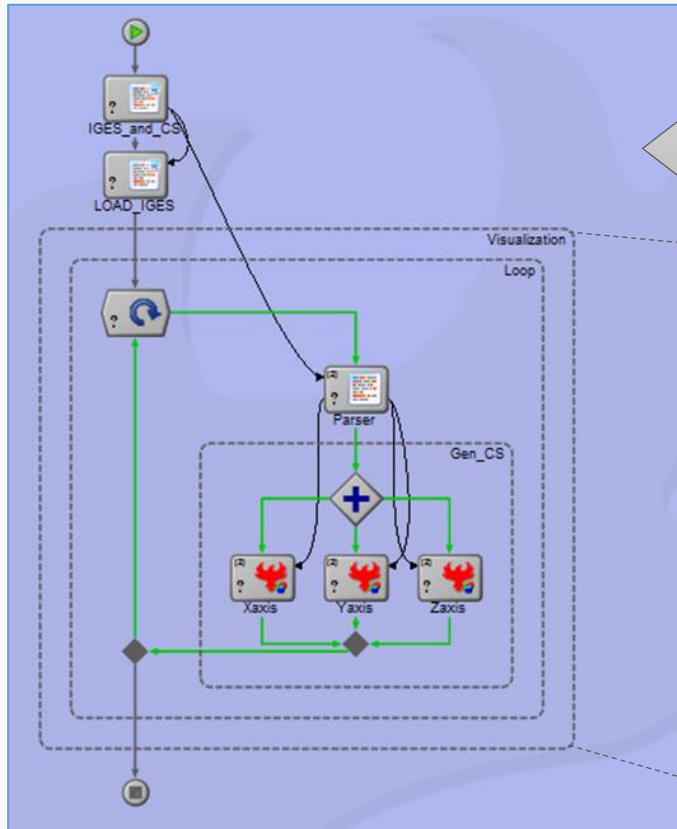
Summary

- MBSE ≠ SysML: MBSE is also managing integration of engineering efforts, providing capabilities to visualize data & information, and improve the performance & capabilities of engineering tools/processes.

- SSG has extensive experience performing multidisciplinary integrated analyses using Phoenix Integration ModelCenter

- ModelCenter integrated analysis performed for every CRS mission to validate the Cygnus propellant load

Continued Efforts

- Integrating parametric analyses & trades into SysML models

- Extracting metadata (IGES files, coordinate systems, mass, etc.) from Windchill directly into integrated analysis models

Thanks for your time and participation!
Please feel free to ask or follow-up with any questions