
PHOENIX INTEGRATION

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# Rocket Flight Termination Behaviors Bridged to Analytical Simulation in MBSE

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Dr. J. Simmons – Phoenix Integration

https://www.youtube.com/watch?v=rxju3eGr_7Y

# Introduction

- Showing an example that can be used to guide the development of V&V activities for future applications of mission models
- Bridging to Descriptive Systems Models in Cameo Systems Modeler
- Driving the behavioral model with analytic domain models in Python and ModelCenter
- Demonstrating running regression tests on a SysML State Machine through MBSEPak using DOEs

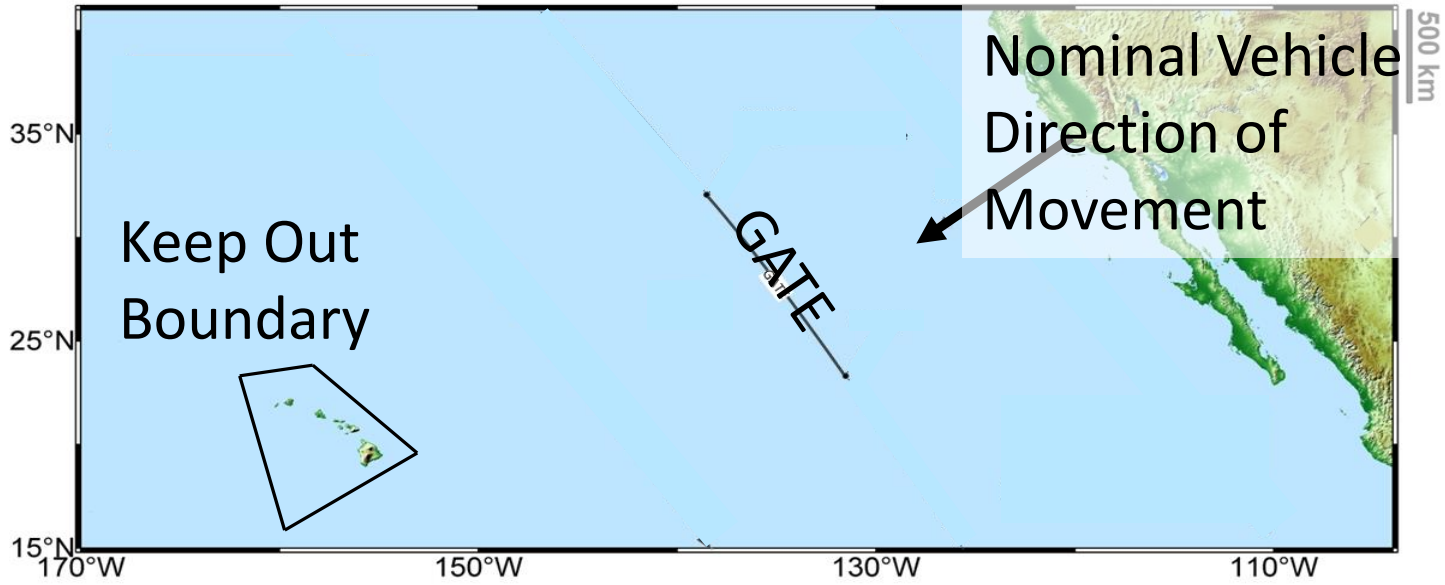
# Presentation Outline

- Pegasus Flight Termination Background
- Motivation for Simulation
- Project Objective, Goals, Obstacles, Solutions
- Descriptive Systems Model
- Domain Analytical Model
- Descriptive to Domain Integration Bridge
- Automated Testing of Behaviors with DOEs

# Flight Termination Motivation

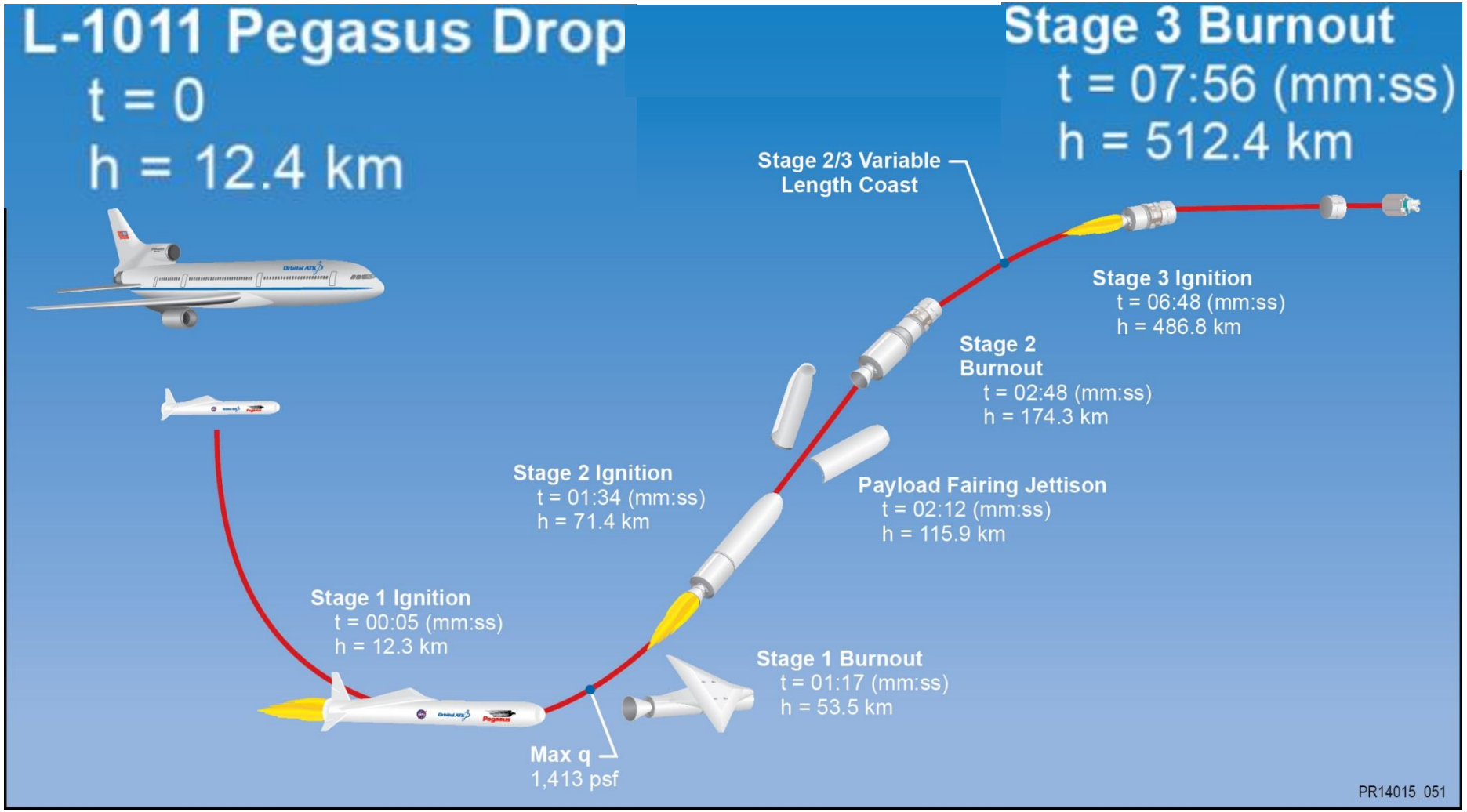
## Protect Against Errant Rocket Flight

- Manual Termination If “Out of Bounds”



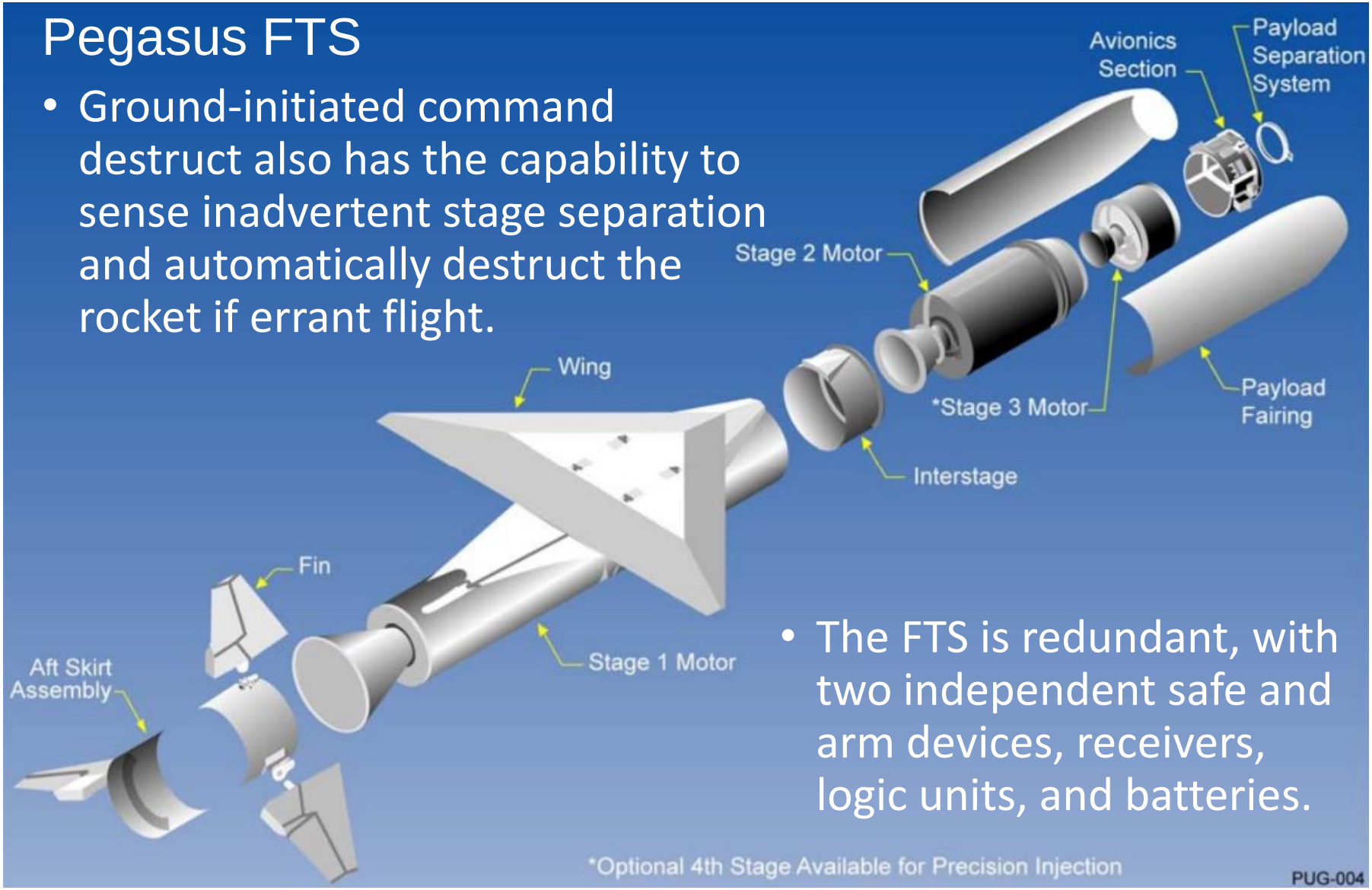

- Auto Termination If “Inadvertent Stage Separation”

# Nominal Mission, Concept of Operation



# Pegasus FTS

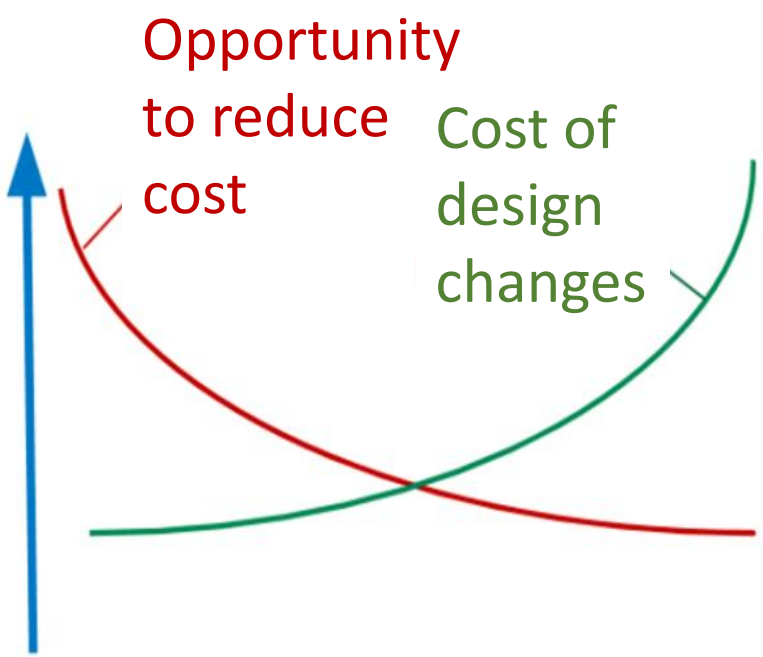
- Ground-initiated command destruct also has the capability to sense inadvertent stage separation and automatically destruct the rocket if errant flight.




- The FTS is redundant, with two independent safe and arm devices, receivers, logic units, and batteries.

# Motivation for Simulation

# Biggest Simulation Impact is Early in the Design Process




Simulation Motivation - Gain system understanding without manipulating the real system, either because it is not yet defined or available, or because it cannot be exercised directly due to cost, time, resources or risk constraints.

DoDI 5000.02 E3:9 Policy for Management of all Acquisition Programs Instructs SEs Approach to Modeling and Simulation

# Industry MBSE and MBE Examples

- DoD Digital Engineering Strategy
  https://www.acq.osd.mil/se/briefs/19819-NDIA17-Zimm-DE-Strat.pdf
- SET – Systems Engineering Transformation, Navy
  http://www.sercuarc.org/final-technical-report-published-transforming-systems-engineering-through-model-centric-engineering/
- GBSD - Model Based SE, USAF
  http://www.afmc.af.mil/News/Article-Display/Article/1260958/afnwc-nuclear-experts-capture-acquisition-awards/
- ARVC iMBE – Integrated Modeling Environment, ARDEC, Army
  http://www.sercuarc.org/publications-papers/technical-report-transforming-systems-engineering-through-model-centric-engineering-3/
- Europa Model Based SE, JPL
  click on the associated icon text for whitepaper
- e.Deorbit, European SA, Airbus
  click on the associated icon text for whitepaper


Europa


e.Deorbit

# Project Objective, Goals, Obstacles, Solutions

# Project Objective and Goals

Objective - Path find an MBSE behavioral model Validation and Verification (V&V) approach for FTS logic

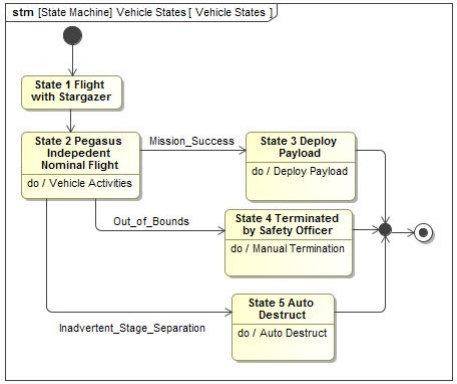
Goals - V&V Behavioral Models with Simulations

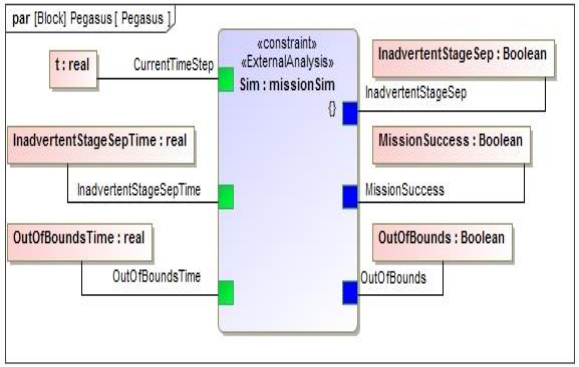
- Verify State Machine Logic
- Validate Regression Testing of State Machine Logic
- Verify the Bridge between Descriptive and Analytic Simulations

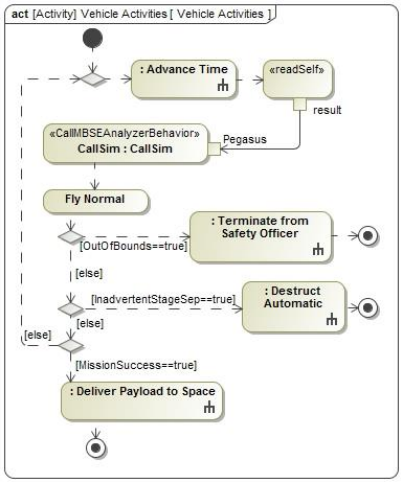
| Project Obstacles | Solutions |
| --- | --- |
| ITAR restrictions | Genericized the application |
| Logic Complexity – Well over a dozen States with multiple triggers on each | Simplified the System Architecture Model without sacrificing the Project Objective |
| Test Complexity | Isolated Testing to avoid Full-Fidelity-Analysis-Model issues and to reduce run times |

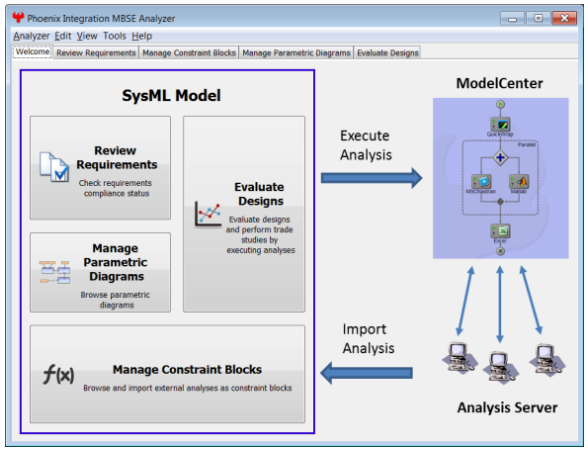
| Project Obstacles | Solutions |
| --- | --- |
| Complexity of Repetitive Time Based Activities | Synchronize time between the behavioral and analytical simulations |
| Multiple Mission Scenarios | Stimulate all scenarios ensuring expected mission outcomes with DOE methods |
| Each Modeling Layer (STM, ACT, Domain Sim) has Similar Triggers and Responses for Each Event (eg, Inadvertent Stage Sep) | Ensure Capture of Mission Results Occurs in the Behavioral Simulation |

# The Pegasus FTS Project is a Digital System Model built in three layers using commercial tools




Descriptive Systems Model (Cameo Systems Modeler)

Descriptive/Domain Integration Bridge (ModelCenter MBSEPak)

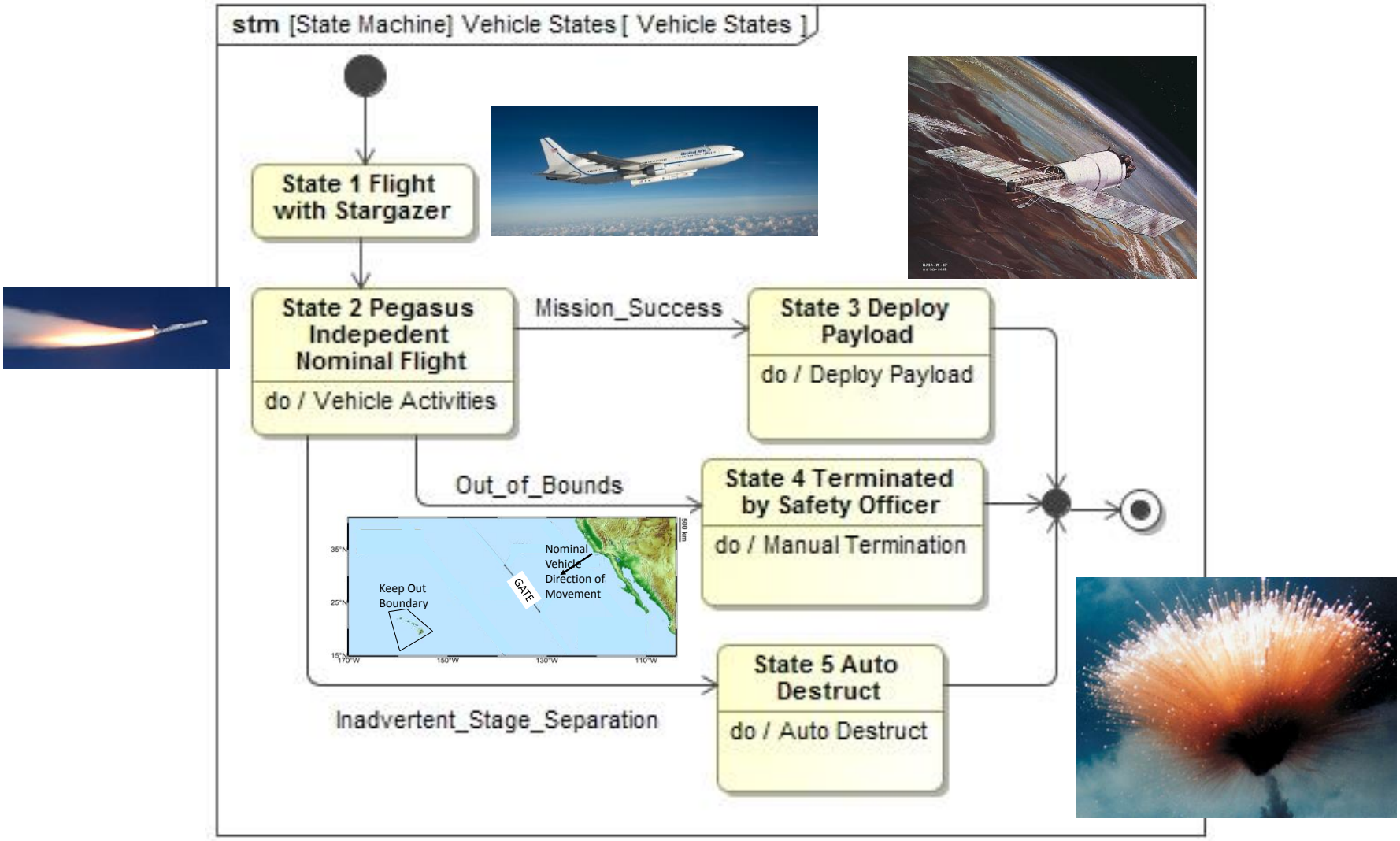
Domain Analytical Models (Python, ModelCenter Integrate)

# Descriptive Systems Model

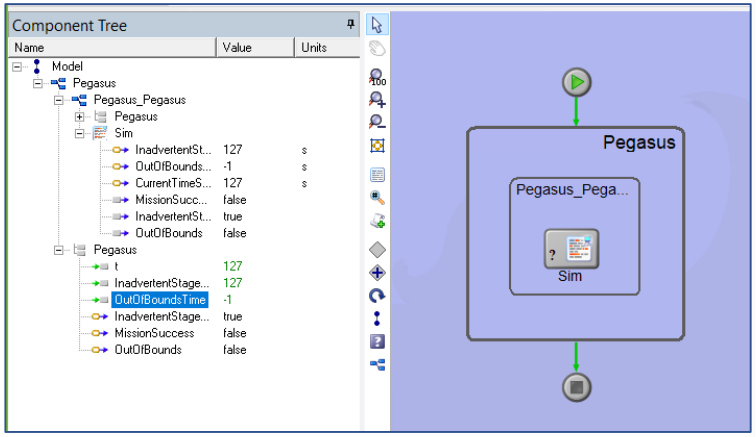
# Use Case – Terminate if Inadvertent Stage Separation

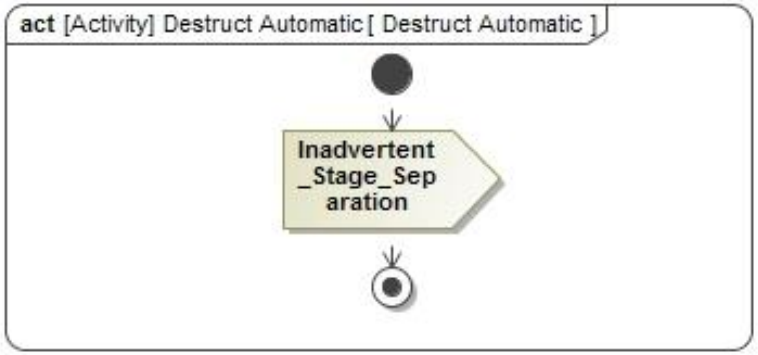


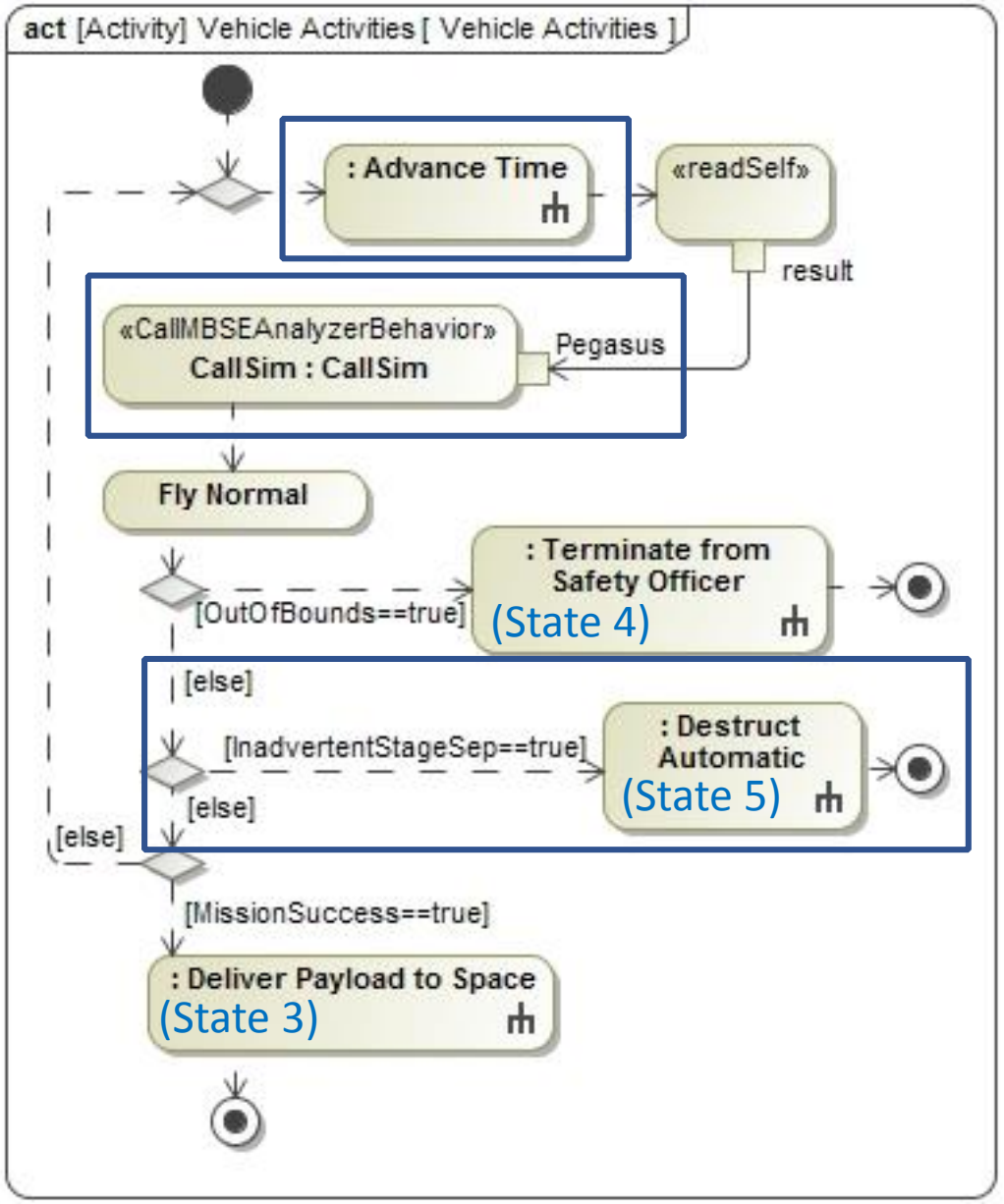

# Goal – V&V State Machine Logic



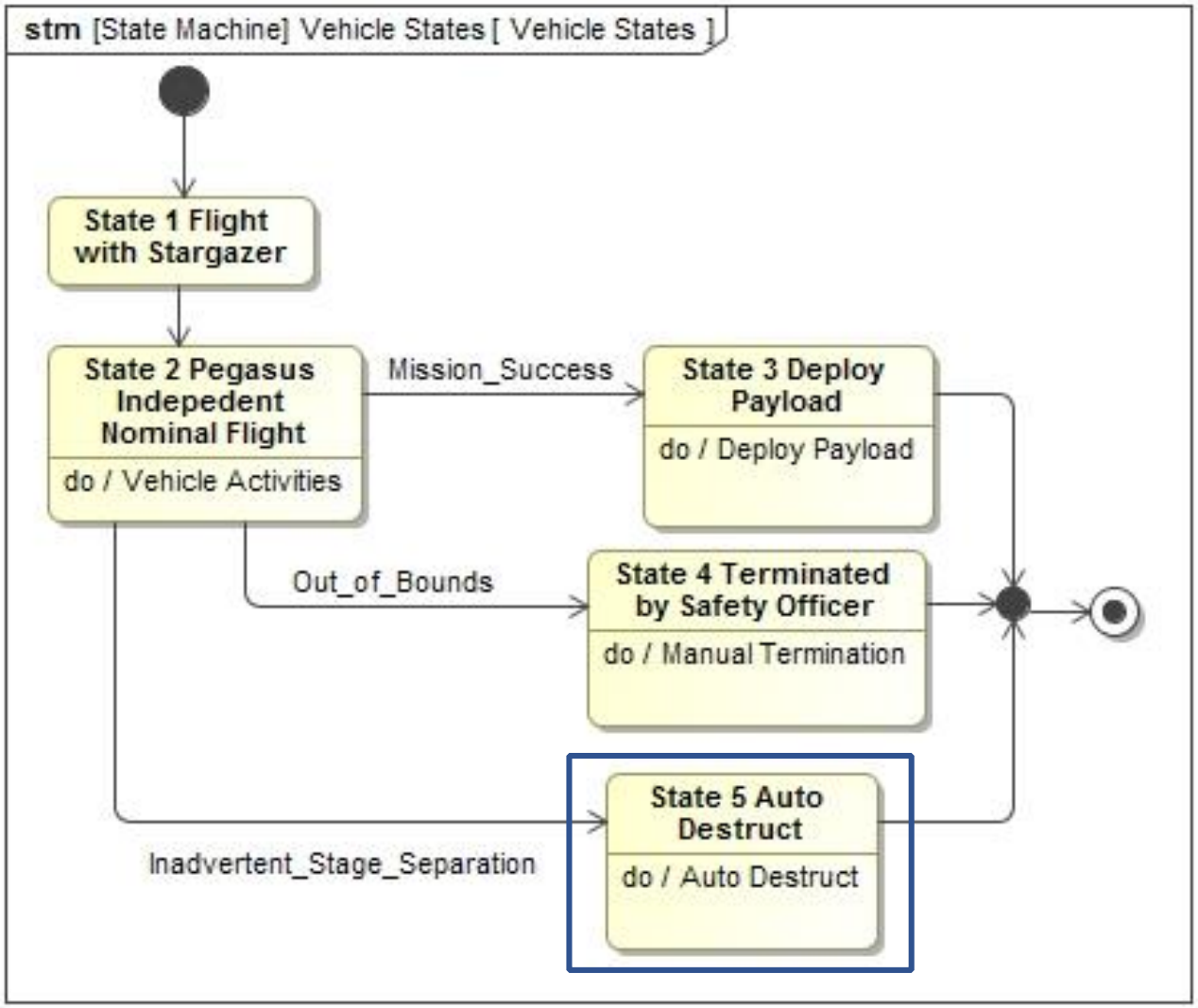
# Vehicle Activities Diag



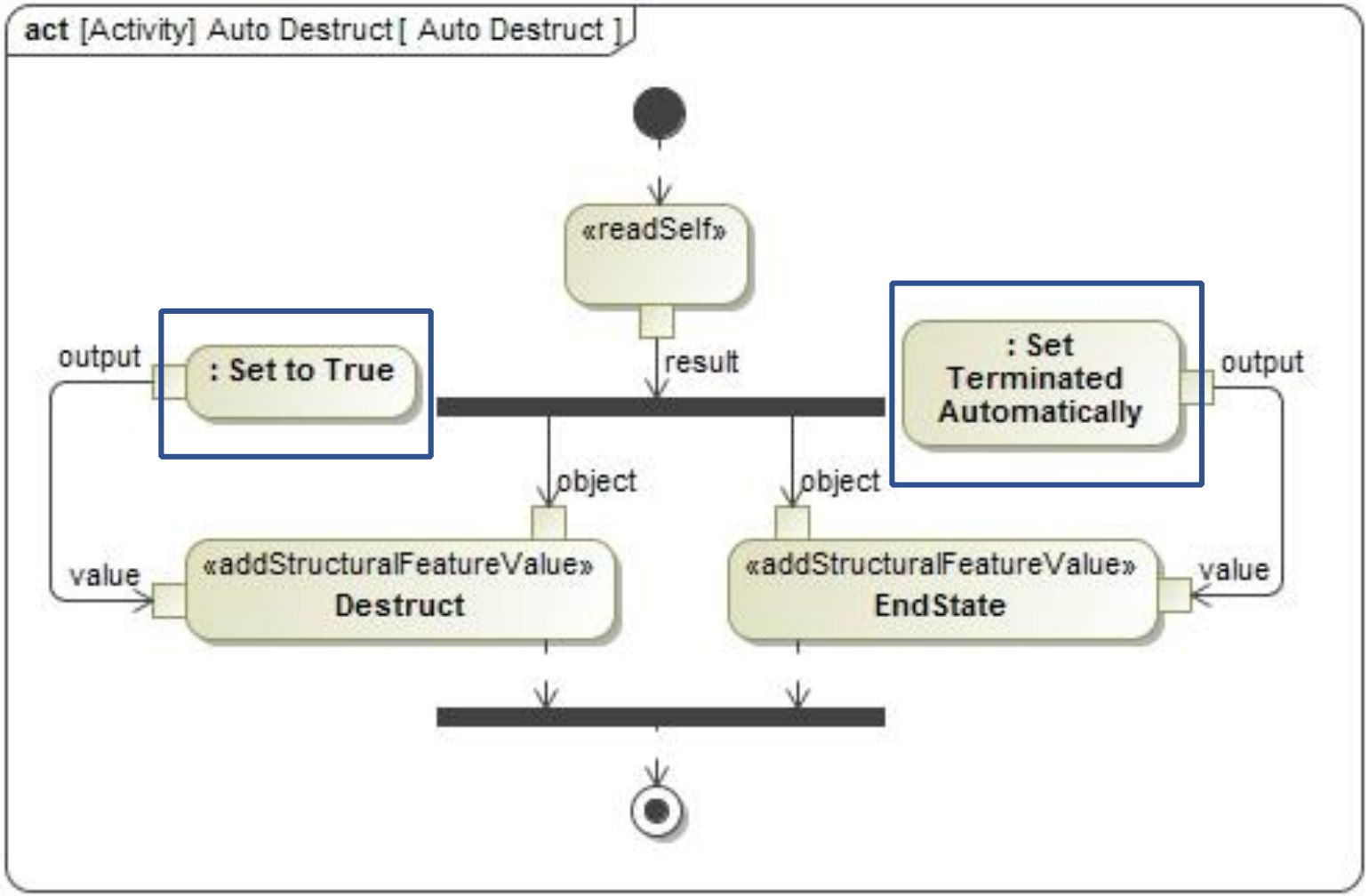



# Goal – V&V State Machine Logic



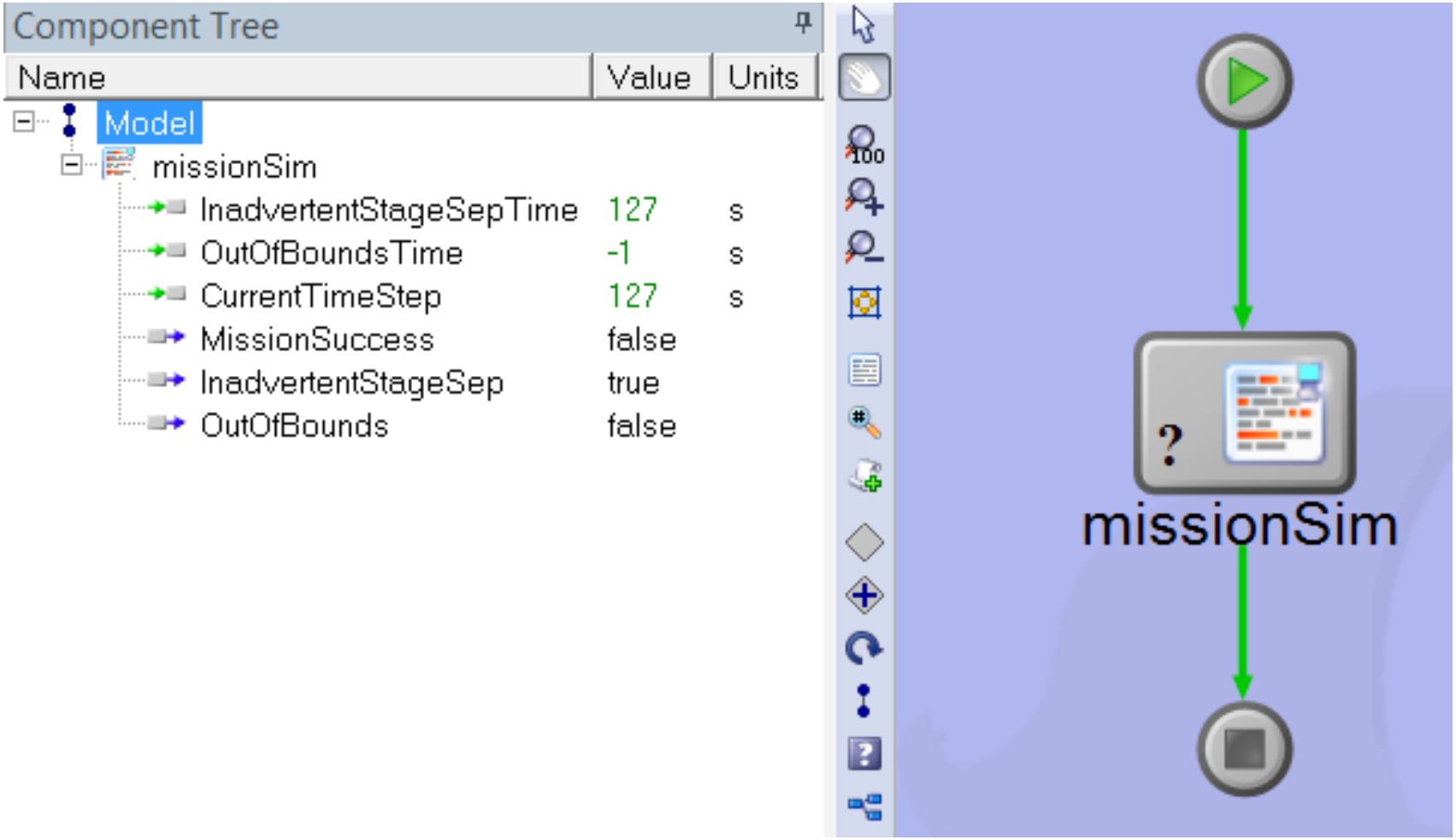
# Auto Destruct Activity Diagram (State 5) (if inadvertent stage separation occurs)



# Domain Analytical Model

missionSim.scriptwrapper

# Domain Analytic Model: Python mock Mission Simulation



# Domain Model Verification Test Results

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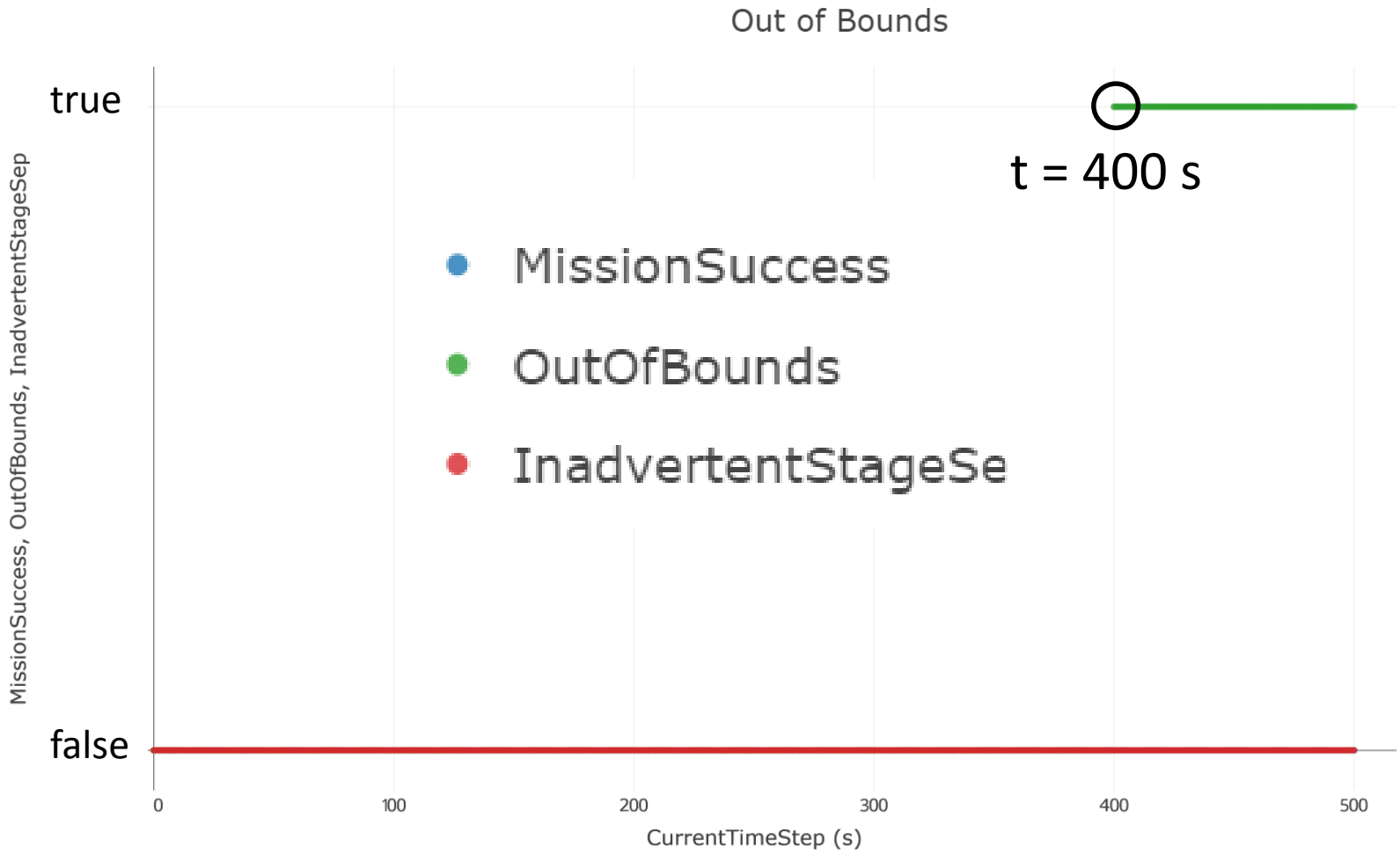

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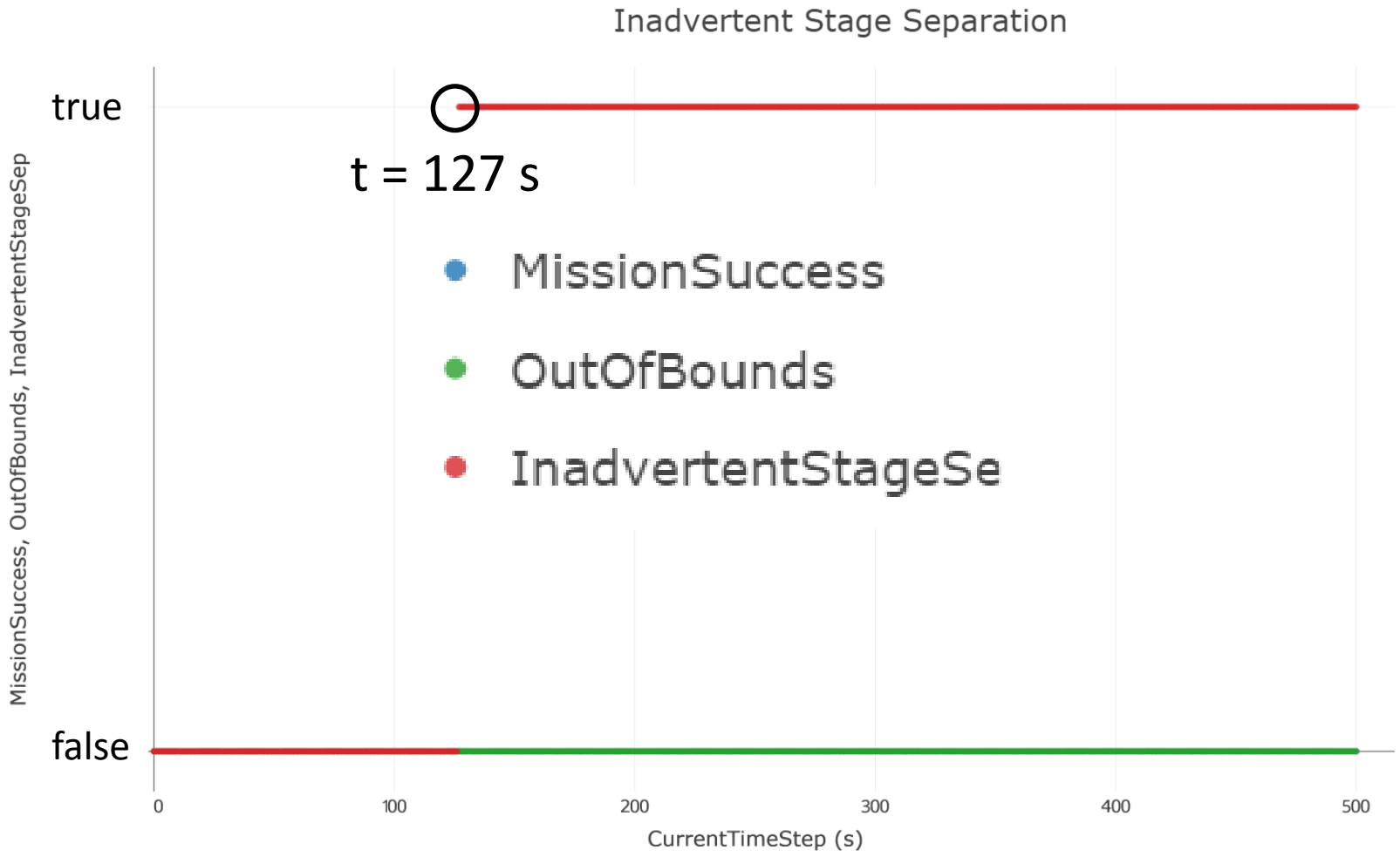
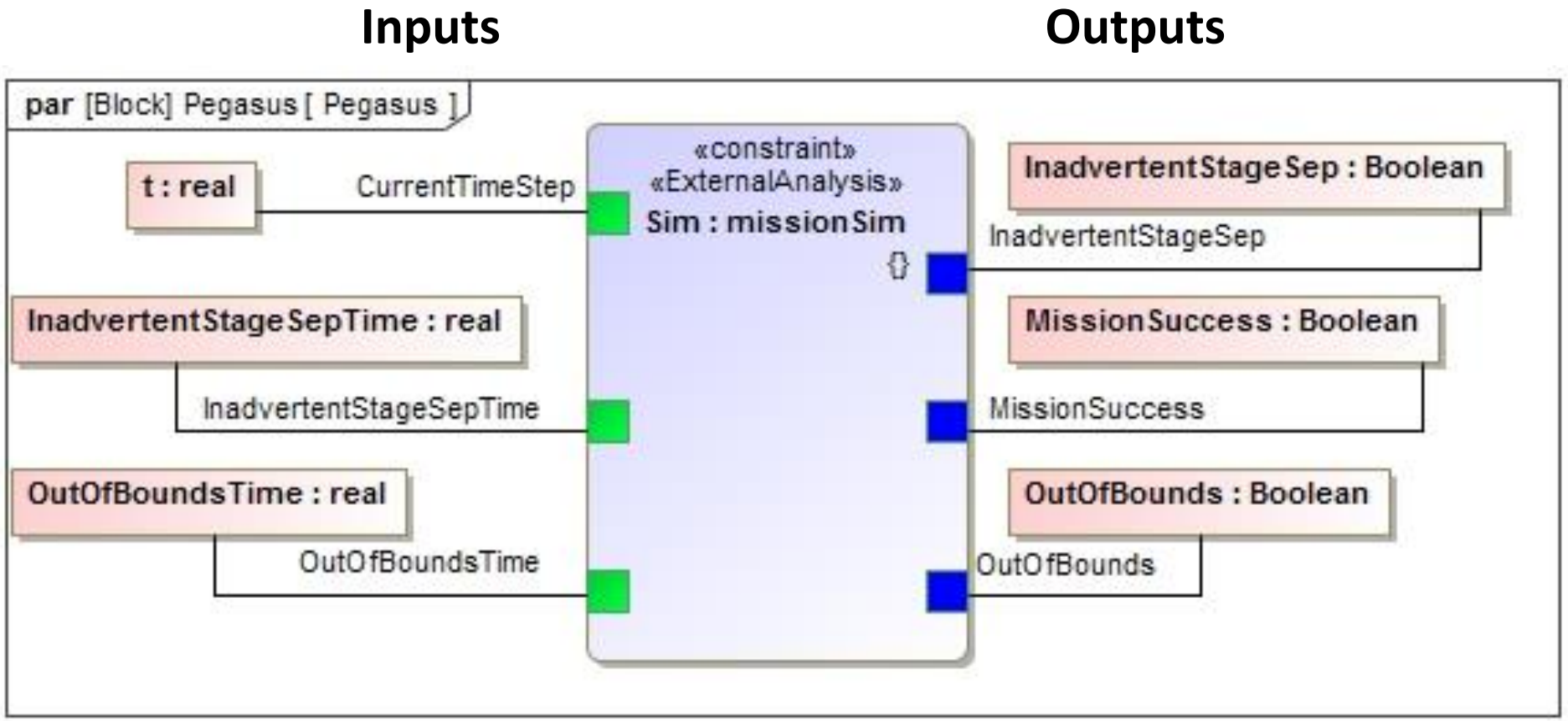
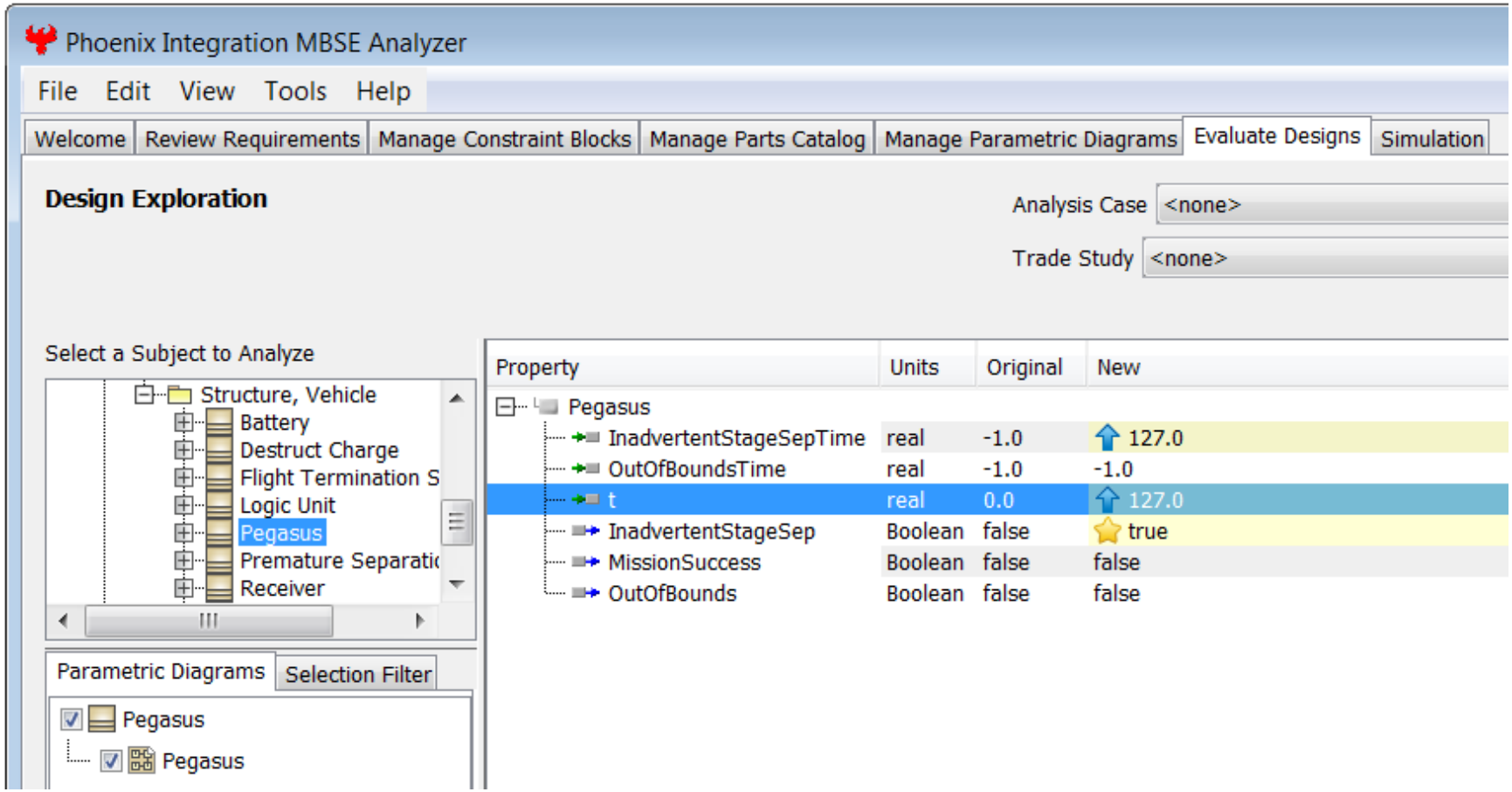


# Descriptive/Domain Integration Bridge

# FTS Parametric Diagram

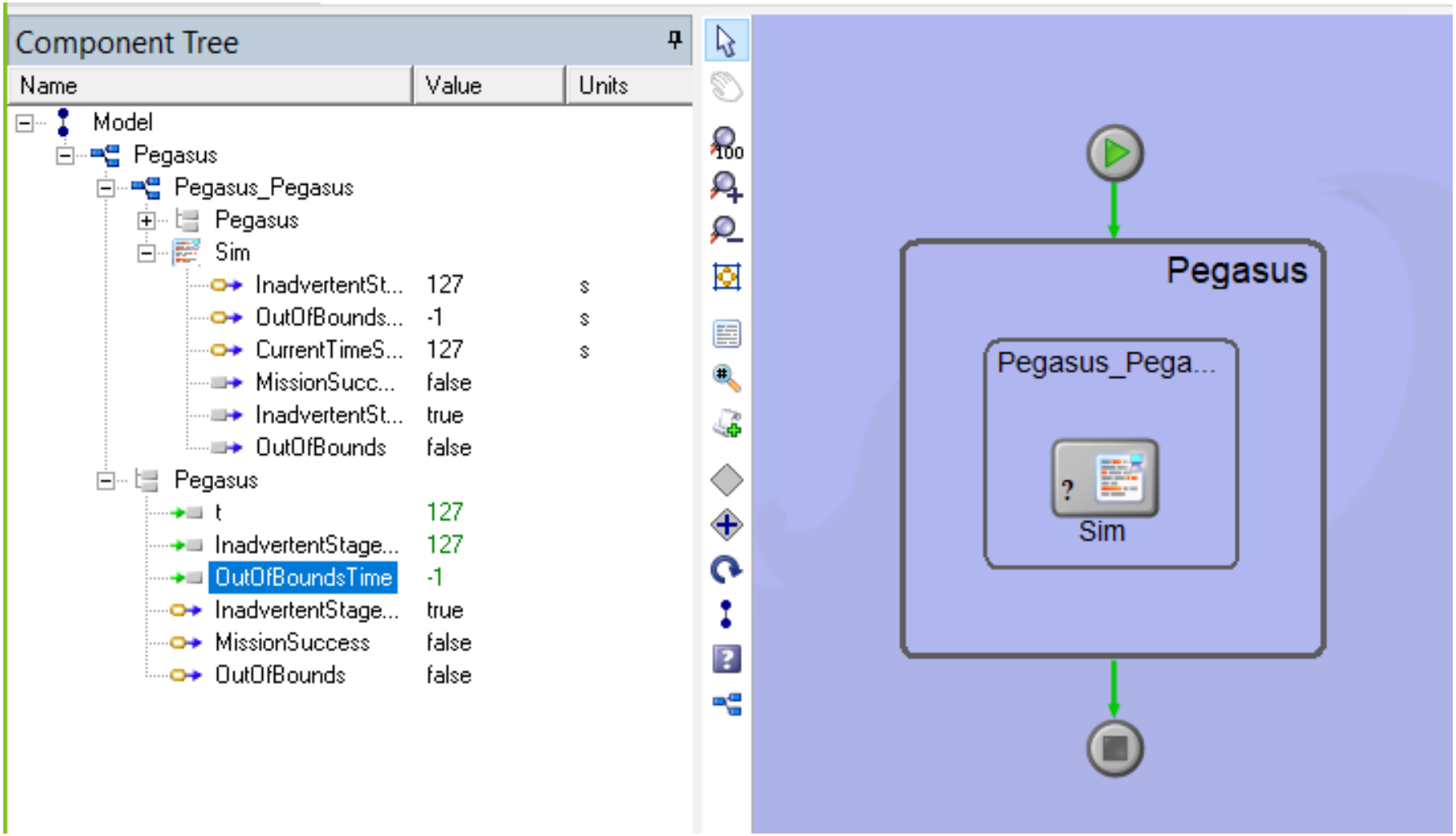


# MBSEPak Bridges from Descriptive Parametric Diagram to Domain Analytical ModelCenter Workflow

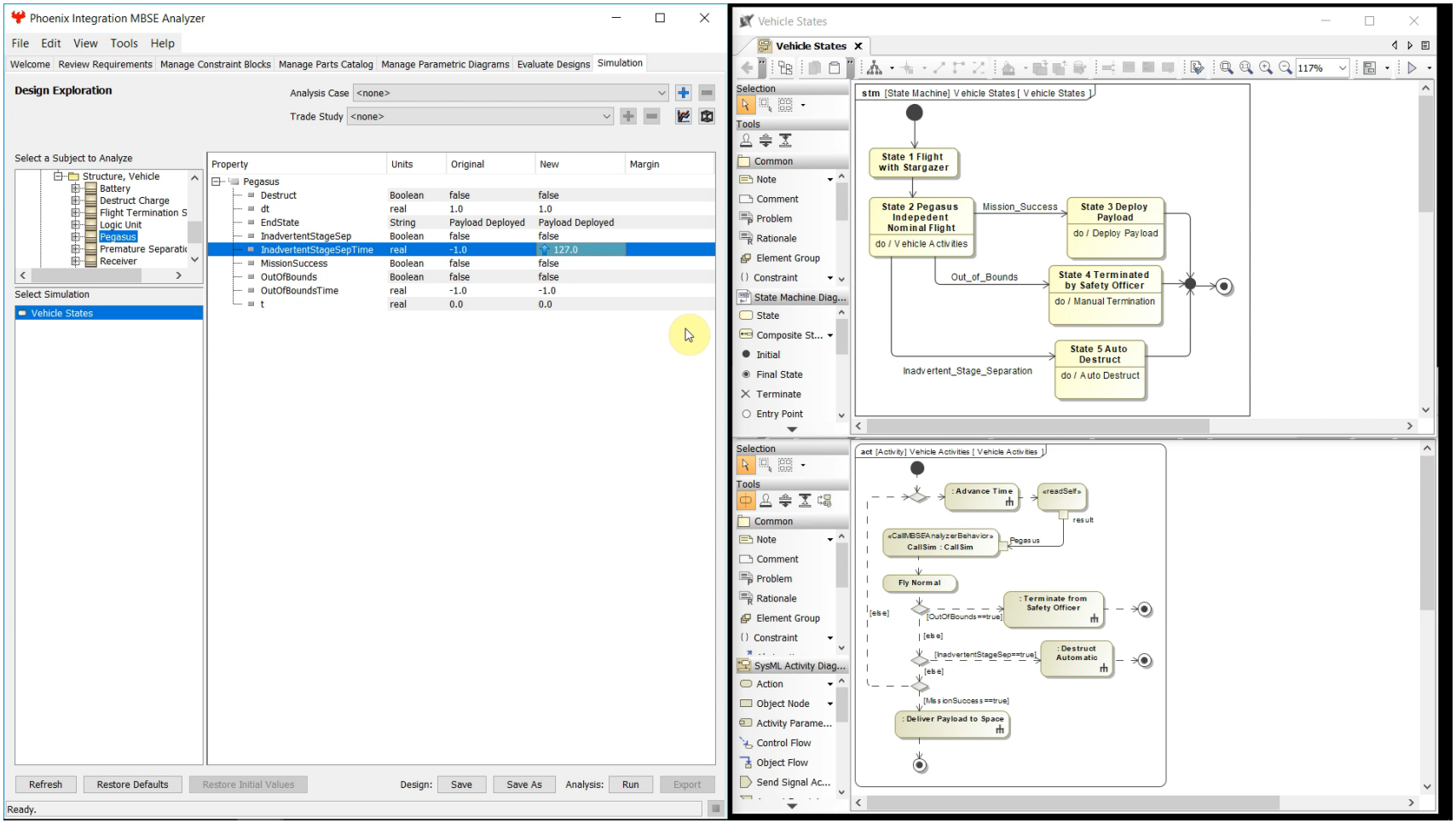


# ModelCenter Workflow Automatically Generated from the SysML Parametric Diagram

missionSim.scriptwrapper



# Mission Simulation - Demonstration



# Automated Testing of Behaviors with DOEs

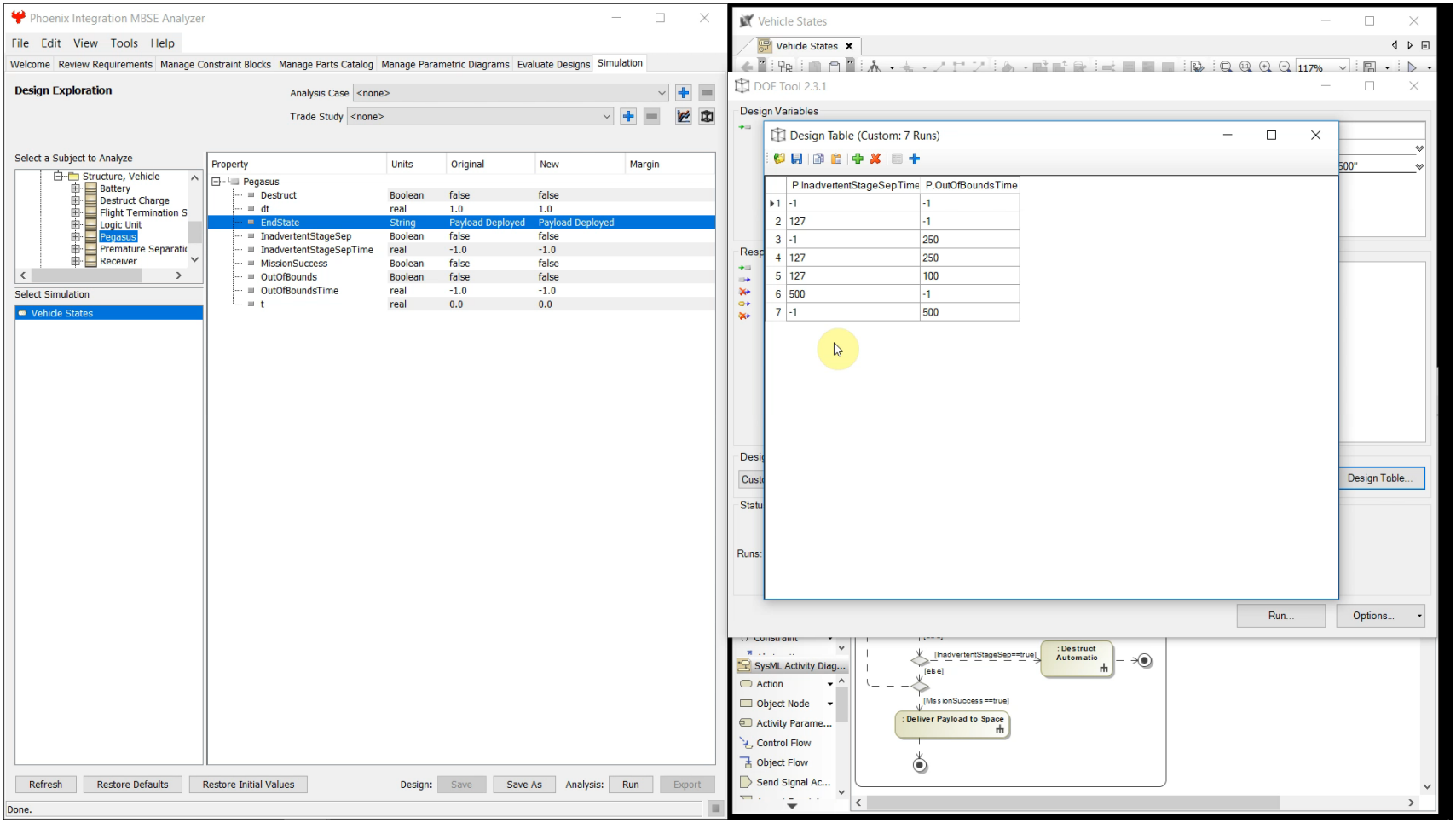
# Custom DOE – Goal - Exercise All the Different Scenarios

| Inputs | | Expected Outputs | | |
|---|---|---|---|---|
| **InadvertentStageSepTime** | **OutOfBoundsTime** | **SimDuration (t)** | **Destruct** | **End State** |
| -1 | -1 | 476 | False | Payload Deployed |
| 127 | -1 | 127 | True | Terminated Automatically |
| -1 | 250 | 250 | True | Terminated by Safety Officer |
| 127 | 250 | 127 | True | Terminated Automatically |
| 127 | 100 | 100 | True | Terminated by Safety Officer |
| 500 | -1 | 476 | False | Payload Deployed |
| -1 | 500 | 476 | False | Payload Deployed |

# Regression Testing Verifies the Model After Making Changes to the Model

- Software Development Technique
- Leverages Automated Testing
- Repurpose this by re-running the DOE whenever the Model is changed
- MBSEPak Automated Regression Testing

# DOE Demonstration of Mission Simulation

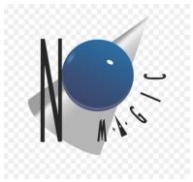


# Summary

- Demonstrated running regression tests on a SysML State Machine using DOEs in MBSEPak
- Driven by analytic domain models in Python and ModelCenter
- Bridged to Descriptive Systems Models in Cameo Systems Modeler
- In an example that can be used to guide the development of V&V activities for the actual Pegasus models and future Applications

# Thank You

Discovery Canada for the Mighty Planes video clip



No Magic, Inc for the Cameo Systems Modeler Tool

Phoenix Integration for the ModelCenter and MBSEPak Tools

Customers for pulling MBSE into new Programs

# Abstract

Bridge development is being evaluated for Rocket Systems between SysML behavioral simulations and analytical simulations to not only verify logical system architecture earlier but also predict consequences of failures earlier in the product development life cycle. The idea of rolling behavioral simulation results across the input bridge from SysML programming into analytical iterations expands the input field. For example, a rocket system termination model progressing through flight states has been simulated for scenario iteration in rocket tracking. Progress on the MBSE bridge development between rocket system behaviors and analytical solutions will be demonstrated.