Simulation Toolkit for Rigorous Interceptor Design and Evaluation

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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Presented by:

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U.S. Army Aviation and Missile Research, Development, and Engineering Center

Who is AMRDEC?

~9,211 FY17 Strength

2,945 Civilian

16 Military

6,250 Contractor

907 / 5343

SETA Non-SETA

FY17

$2,904M

6% Aviation S&T

7% Missile S&T

63% Army

24% Other

Core Competencies

- Life Cycle Engineering
- Research, Technology Development and Demonstration
- Design and Modification
- Software Engineering
- Systems Integration
- Test and Evaluation
- Qualification
- Aerodynamics/ Aeromechanics
- Structures
- Propulsion
- Guidance/Navigation
- Autonomy and Teaming
- Radio Frequency (RF) Technology
- Fire Control Radar Technology
- Image Processing
- Models and Simulation
- Cyber Security

Implementation of a Proven Idea

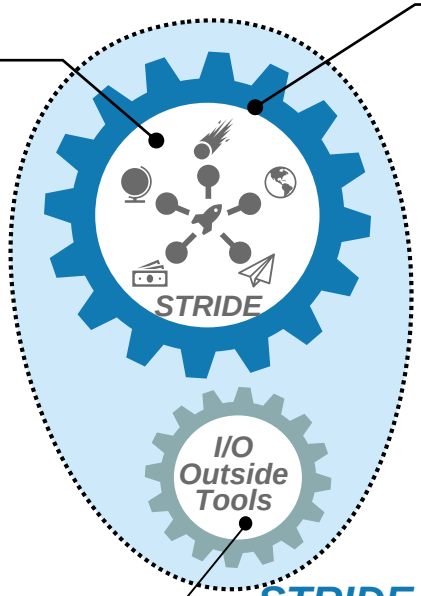
- Expert Systems, Knowledge Based Systems, and Knowledge Based Engineering have a long heritage in computing, design, and problem solving
- Overly Simplistic Definition for our case:
  - Expert System = CAD + design manager + simulation
- Result = easy-to-use simulation for exploring missile systems
- Expert Systems sometimes criticized as an attempt to remove the engineer from the engineering process. We disagree!
- We want to keep the good engineers and provide them with tools that check their work, hint at good design options, and in general make our engineers faster and less error prone

STRIDE in a Nutshell

Simulation Toolkit for Rigorous Interceptor Design and Evaluation

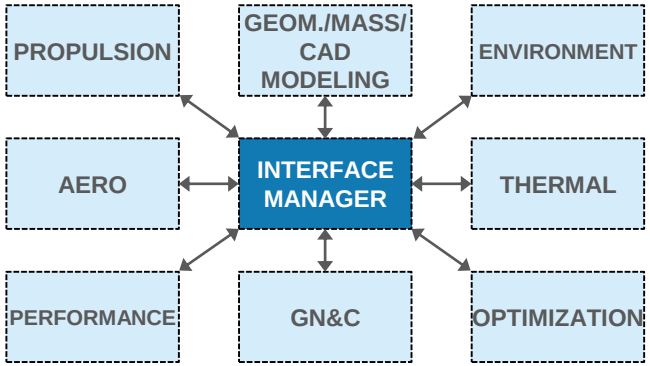
STRIDE

- *STRIDE is a physics-based toolset for modeling vehicles.*
- *STRIDE evaluates parameters for performance.*
- *STRIDE can model from boost to terminal.*
- *STRIDE delivers trajectories, signatures, tables*
- *STRIDE's functionality spans the breadth of conceptual vehicle design, performance assessment, and engagement analysis.*



STRIDE VEHICLE ELEMENT MODELS

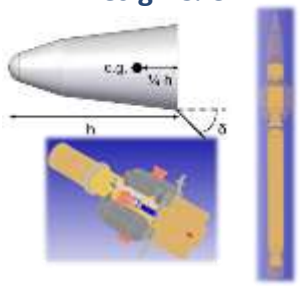
STRIDE's model architecture is modularized with a building-block approach. Vehicle modeling and simulation are supported via element models integrated via the STRIDE interface layer for 3/6DOF simulation and performance analysis.



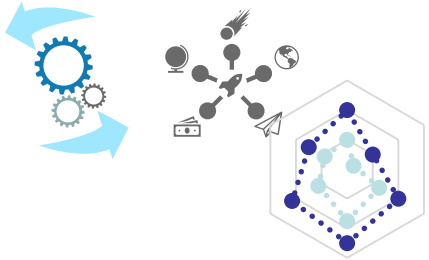
STRIDE INPUT/OUTPUT WITH PARTNER TOOLS

STRIDE was architected to integrate with outside tools, taking other tool's outputs as inputs and providing outputs in the necessary formats to other tools.

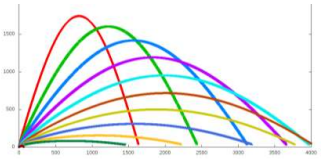
Parameters: Vehicle Design & CAD



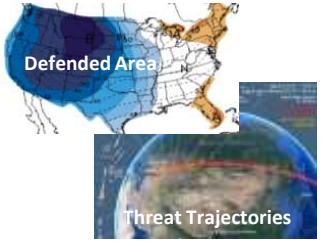
Performance: Iterative Design & Evaluation



Trajectory Generation & Flyout Tables



Analysis



Current Usage

Ground Based Interceptor

- *3 Versions*
- *Future Concepts*
- *Anchored*

THAAD Interceptor

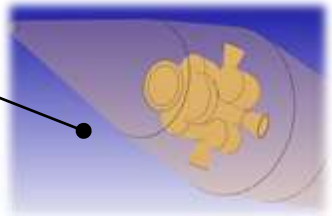
- *Early Anchoring*

Minute Man Systems

- *Early Anchoring*

Kill Vehicle Model with sensors

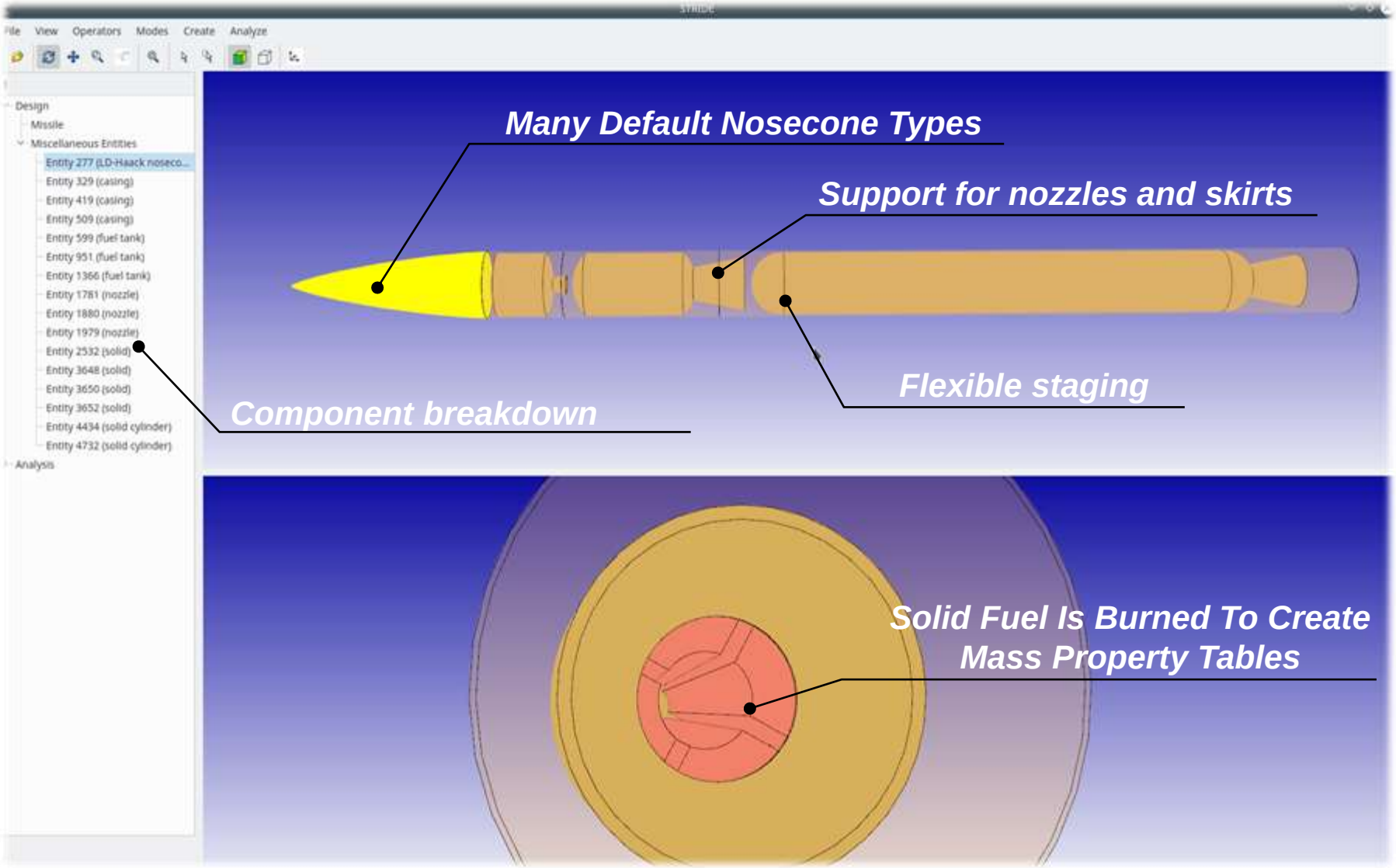
- *Early Anchoring*



Reentry Models

- *In testing and ready for upgrading*

“Baseball Card” representation

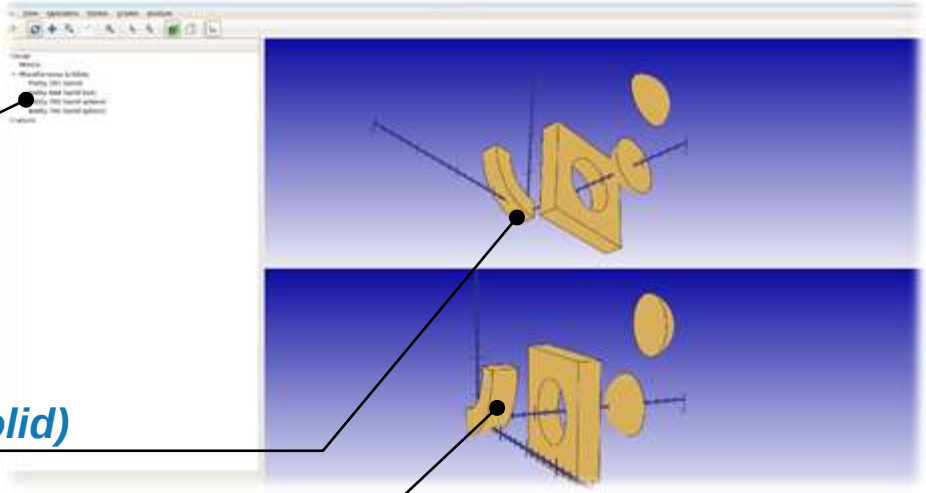


GUI + Scriptable Design Environment

GUI

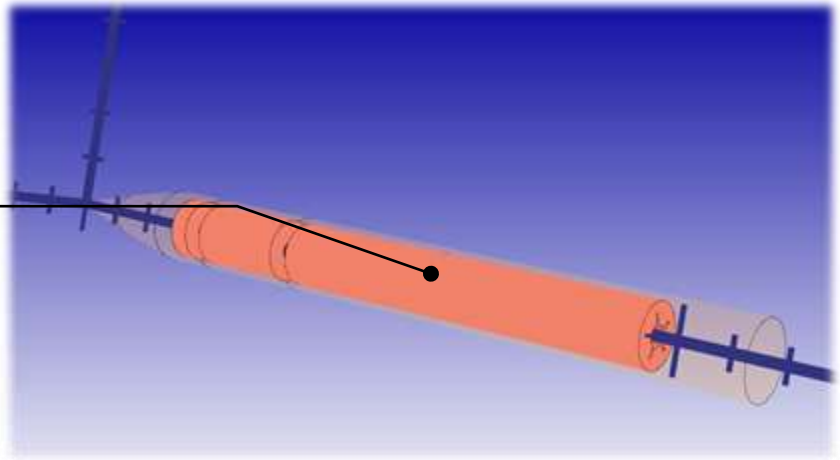
- *Controlled by GUI menu or STRIDE scripts and command line*
- *Missile development*
- *Component break-down*

Industry Standard CAD Library (Parasolid)



Multi-window Viewing

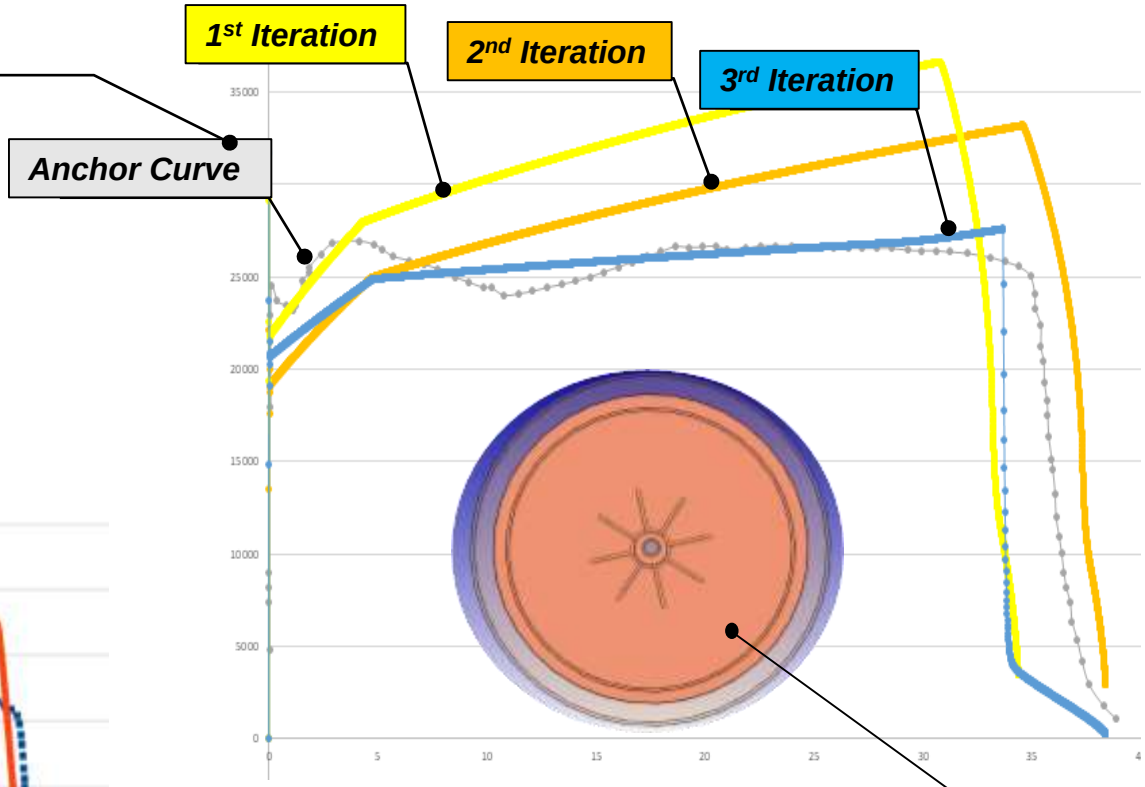
Visualization Of Fuel And Other Interior Components

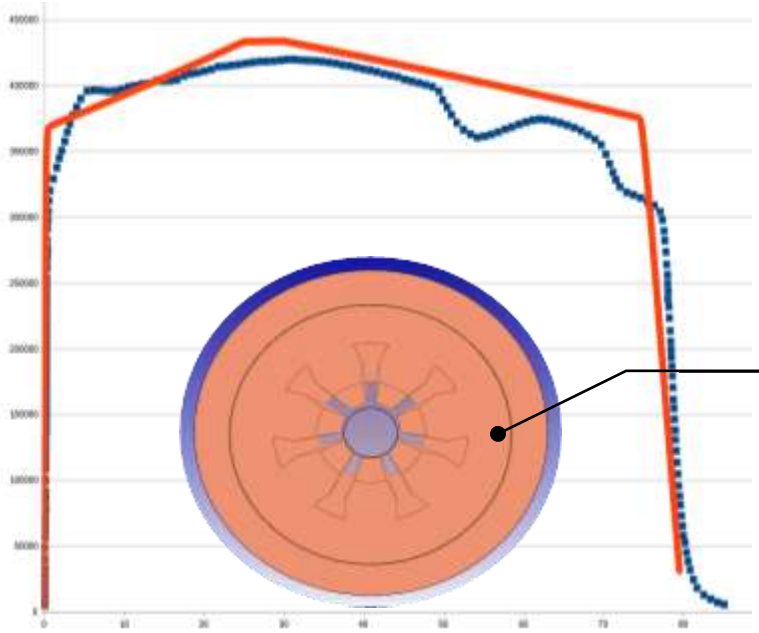


Motor Simulation

Thrust Curve Optimization

- *STRIDE offers a unique pairing of 3D fuel burn with trajectory generation and full missile design all in one tool*
- *Input parameters used to create motor models.*
- *Propulsion algorithms turn parameters into motor performance.*
- *Optimization/search allow iterative improvement of curves.*



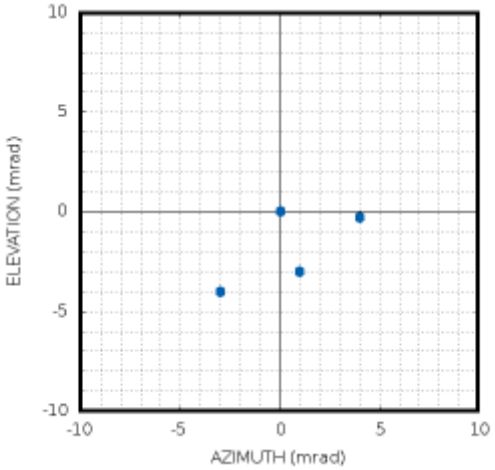


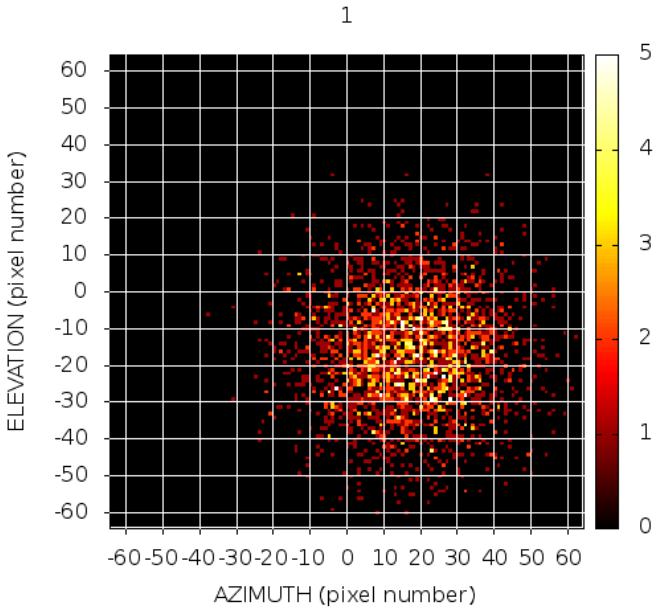
STRIDE Motor CAD Models

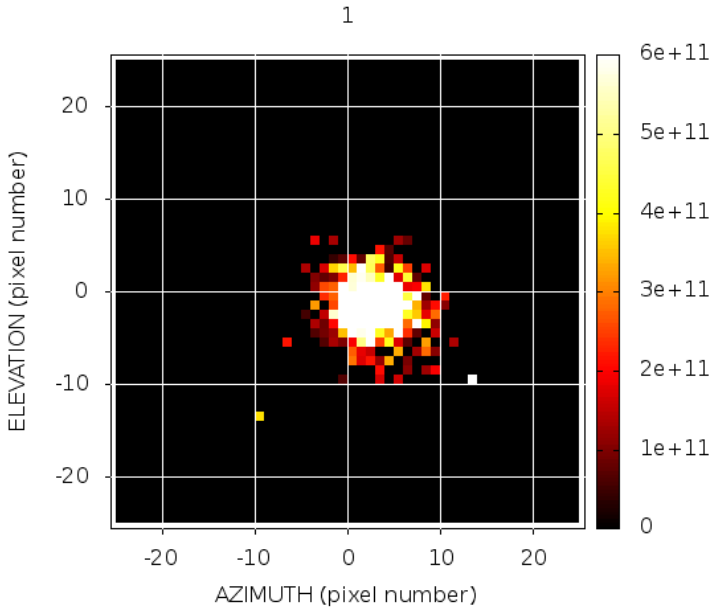
- *CAD supports precise measurement of exposed surface area of burn.*
- *Many fuel geometries are possible (star and wagon wheel shown).*
- *Geometry creates appropriate thrust curve shape.*

Extensions for STRIDE: Optical Sensor Modeling

- **Modular optical sensor with tunable parameters:**
  - **pixel count**
  - **angular resolution per pixel**
  - **spectral response function or wavelength band**
  - **angular mapping or photon count display**
  - **exposure/ integration time**

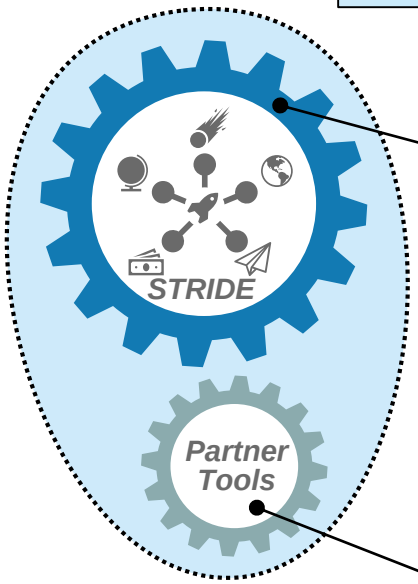






Rapid Simulation with Evolving Fidelity

Days	Weeks	Quarters
Rapid Characterization *Designs built from STRIDE Libraries/existing missiles*	***Increasing Design Representation*** *Designs upgraded with reference data/tailored library*	***Transition to Validated Data*** *Designs upgraded with Validated Data w/ gaps*



Trajectories & Signature Inputs

More Specific Parameters and Features

Anchored Parameters And Performance

Widest Envelope Of Performance

Constraining Performance Envelope With More Accurate Parameters

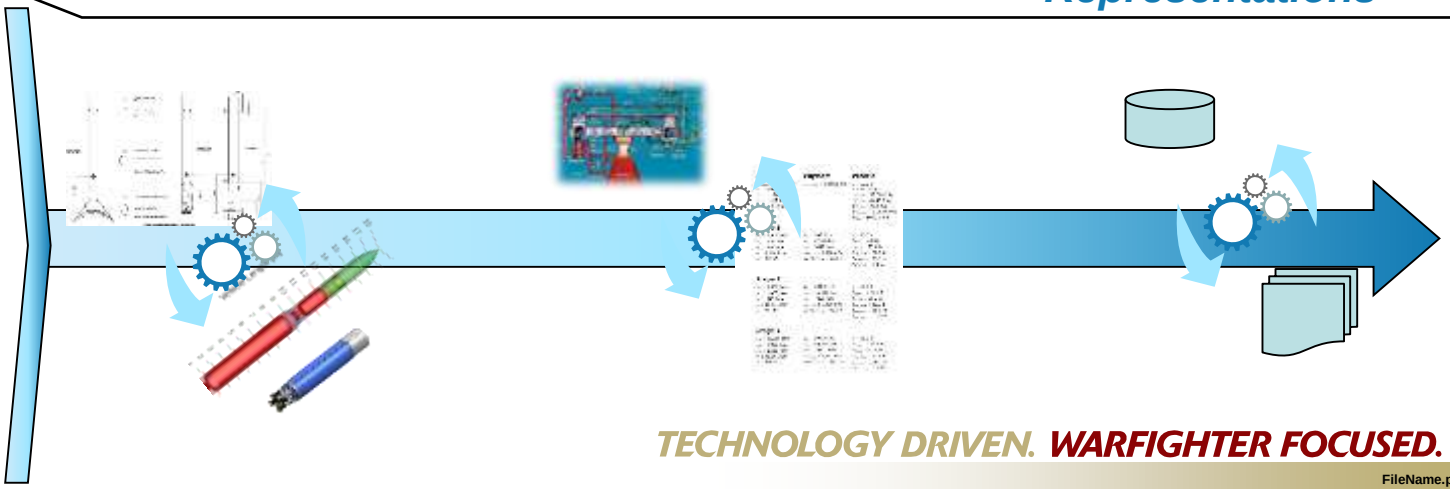
Most Accurate Representations

External structure/moldline
- Silhouette / geometry
- Surface material systems

Aerodynamic characterization
- CAD based coefficient outputs

Staging and motors
- Fuel/propellant mass
- Chemistry

Weights and balance

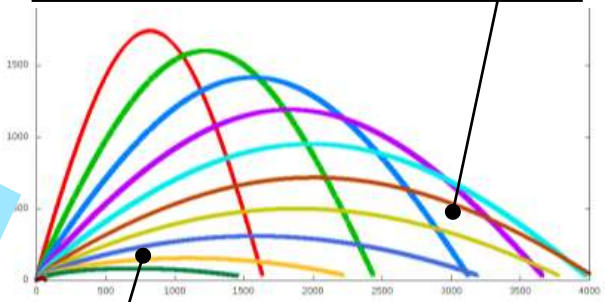


Workflow for Battlespace Study

Missile Designs

Kill Vehicle Designs

Interceptor Flyouts



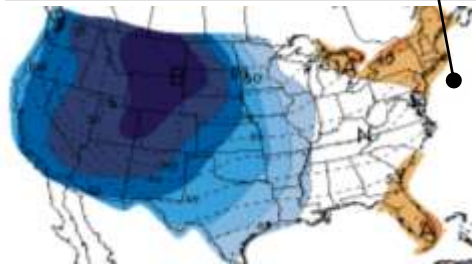
Anchored Trajectories

- *Anchored trajectories to ECCA flyout tables from MDA*

Analysis from Partner Tools

- *AMRDEC's Rapid Scenario Prototyping Lab performed battlespace and defended area analysis with the COVER tool*

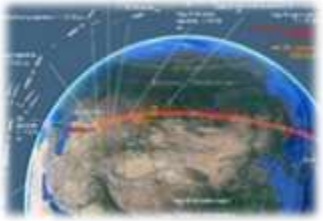
Defended Area



Rapid Iterations

- *Design changes are possible in hours, with new analysis sets weekly.*

Threat Trajectories



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Hypersonic Vehicle Modeling

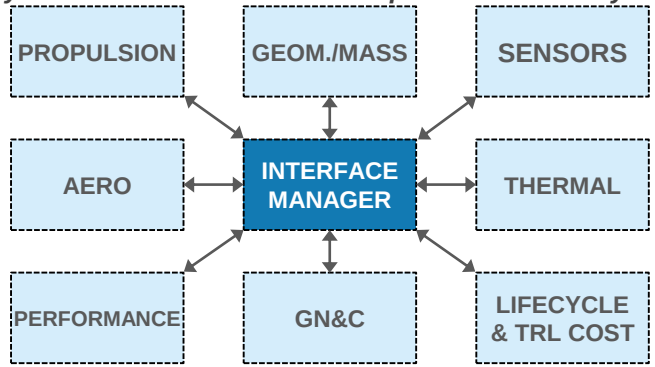
Simulation Toolkit for Rigorous Interceptor Design and Evaluation

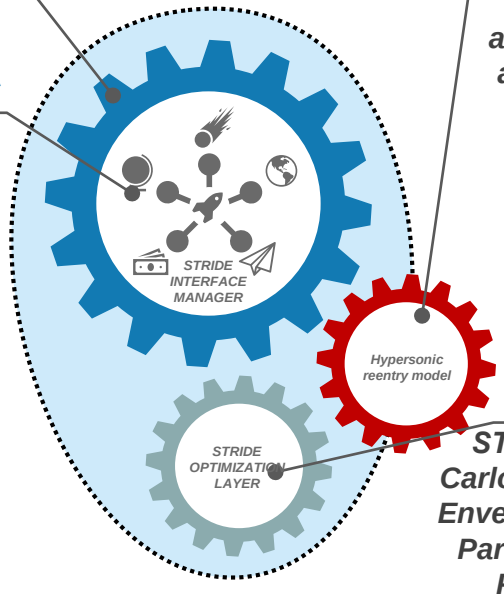
STRIDE

STRIDE's functionality spans the breadth of conceptual vehicle design, performance assessment, and engagement analysis

STRIDE VEHICLE ELEMENT MODELS

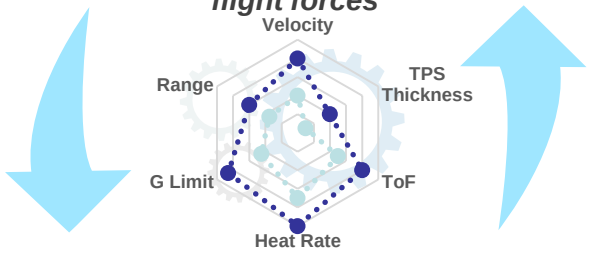
STRIDE's model architecture is modularized. Hypervelocity vehicle modeling and simulation supported via element models integrated via the STRIDE interface layer for 3/6DOF simulation and performance analysis





HYPERSONIC VEHICLES

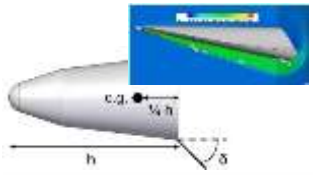
STRIDE has the physics-based tool stack to model and analyze re-entry, ablation, atmospheric skips, controls, kinematic reach, and to report on aerothermal conditions and flight forces



STRIDE OPTIMIZATION LAYER

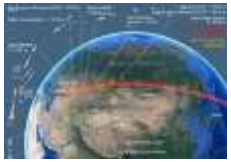
STRIDE's Optimization Layer Employs Monte Carlo & Search Routines To Explore Performance Envelope. Expandable Library (Downhill Simplex, Particle-Swarm, et cetera) Provide Efficient and Fast Search for Optimized Vehicle Design

Hypersonic Vehicle Design



Trajectory Generation

Threat Trajectories



Defended Area Analysis

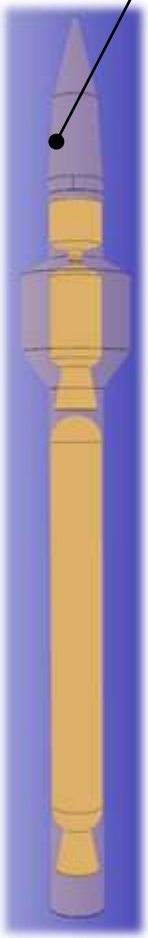
STRIDE application to hypersonic vehicle design and trajectory optimization leverages existing MDA GMD architecture for extension to hypersonic applications

Adding a new Model (Re-entry)

STRIDE

Threat Design -> CAD Model

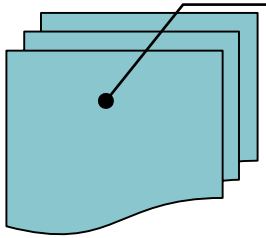
- Aero Coefs
- Mass Props
- Control Surfs
- Nozzles
- Motor types
- Interstages
- Nosecone Geom.
- Material layers



Trajectories

Thermal

Configurations & Data



New Model(s) Integration

New State Vector File f(t)

New Kinematic Dependent Model

IR/RF SIGS, TPS, Ablation, Skipping

New Aero-Thermal Dependent Model

- Motor performance
- Signature parameters
- Trajectories
- Materials

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

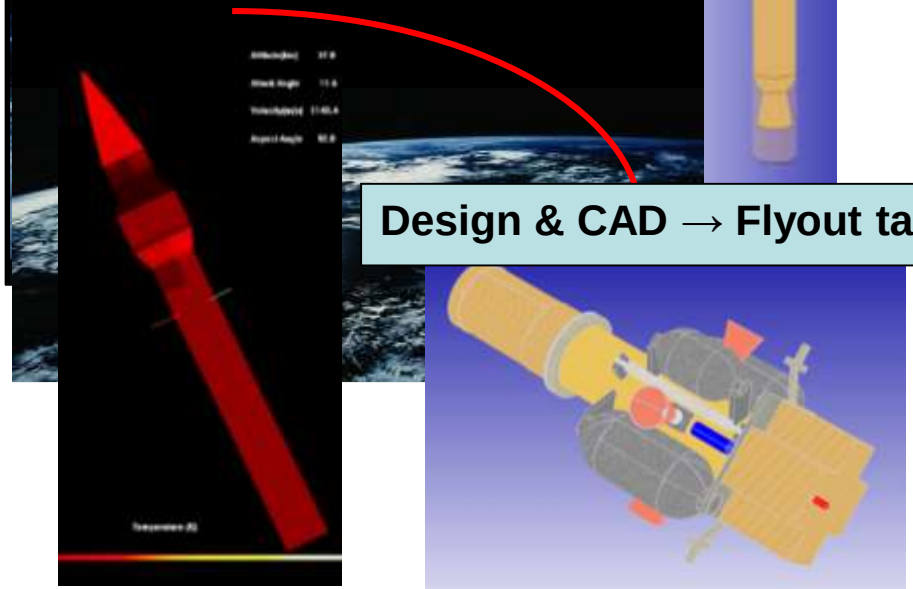
BACKUP SLIDES

- **STRIDE BACKUP SLIDES**

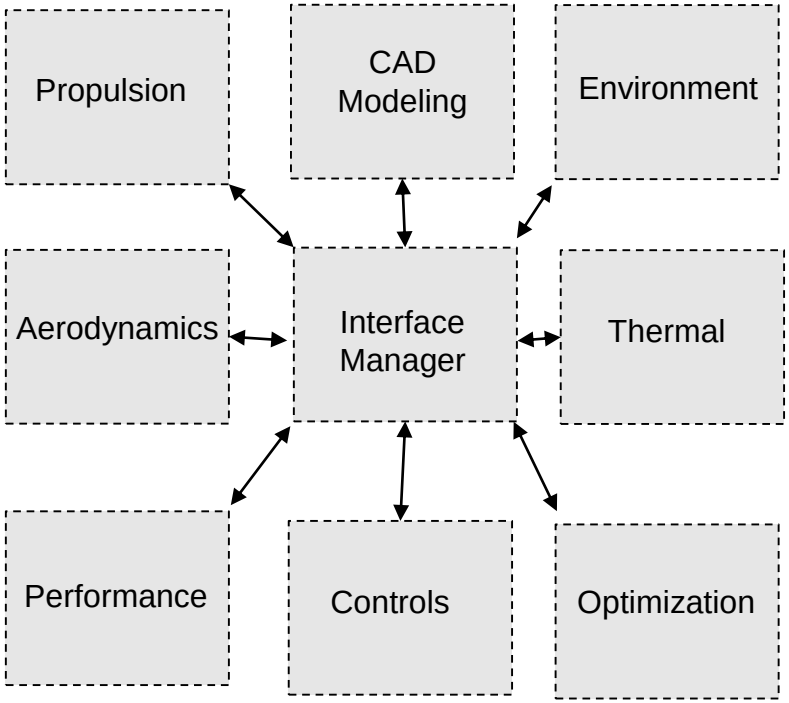
STRIDE in a Nutshell

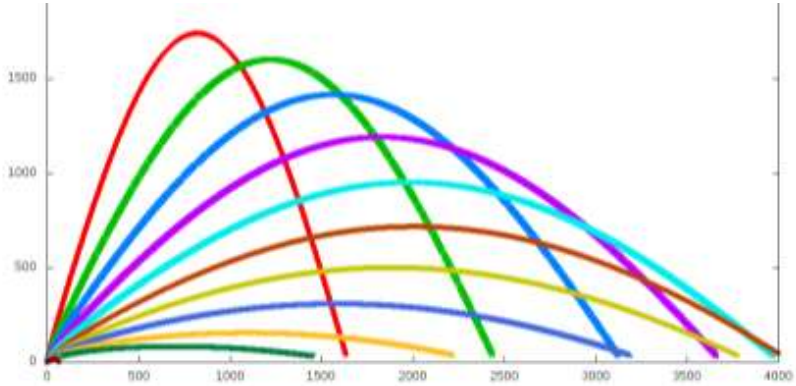
Simulation Toolkit for Rigorous Interceptor Design and Evaluation (STRIDE)

- **Leverages new and existing AMRDEC tools to model boost to terminal for Threats**
- **Delivers trajectories, signatures, tables**
- **Building block approach, multiple options for 3dof and 6dof**
- **Parameters → Performance**



Design & CAD → Flyout tables





Changing Settings

- STRIDE inputs for typical flyout tables:
  - ~40 parameters (when using pregenerated thrust curves)
  - ~20 extra parameters per motor to generate new curves as well
  - Motor might already exist in our growing catalog

- Inputs from our previous method (POST2/CSF + custom setup scripts):
  - Mass props, full thrust curves, all our guidance nuances, Aero coefficient calc w DATCOM, and signatures
  - Expands to over half a million lines of input

- ~500000 lines vs ~40 lines
  - STRIDE case fixed bugs in our “hand jammed” prior setups

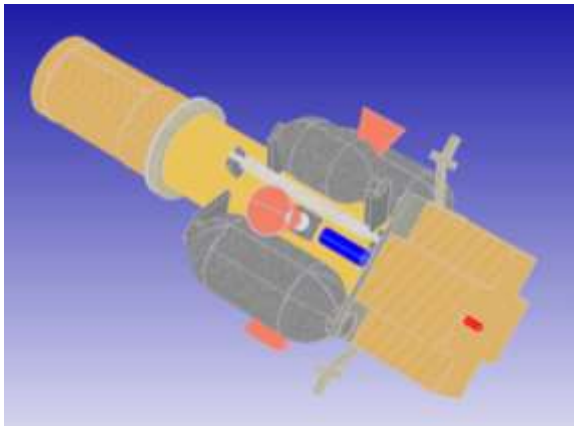
- New tool integrations in 2-4 weeks + familiarization time
  - down from 2-6 months + familiarization time

- Design changes are no longer feared

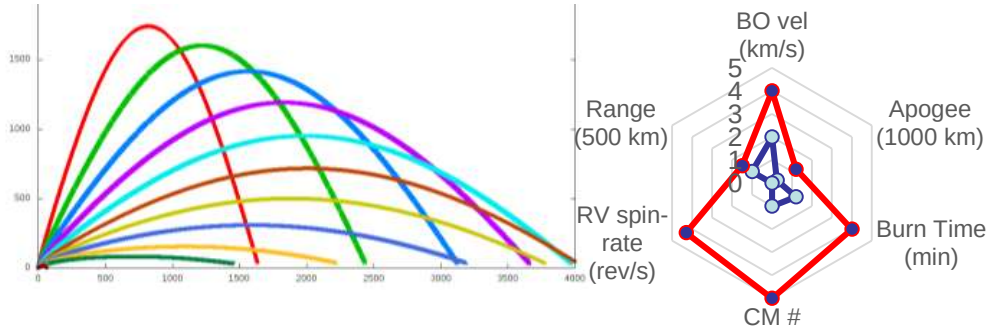
Flyout Tables

- Missile design data provides input for all modules that work to produce flyout data
- Various assumptions can be made, including:
  - 3dof, 3+dof, or 6dof run (can use NASA's POST2 or a custom DOF for STRIDE)
  - Spherical or oblate Earth
  - Spherical or J2 gravity
  - Nonrotating or rotating Earth
  - Drag simulation is also optional and adjustable between Std Atmos model and NASA GRAM

Design, CAD, Assumptions



Flyout Data



How did we improve on existing methods?

- Replicate existing flyout tables fast for anchoring

- Explore new missile designs quickly
  - New set of flyout tables based on an existing design in 15 minutes
  - Process tables into battlespace analysis in less than 1/2 day w 1 LOE

- Verify design's flight performance against anchoring data
- Then use more robust physics to explore these:
  - Day-of-flight behaviors
  - Wind permutations
  - Design permutations
  - New Guidance commands

- Design and implement an entirely new stage (commercial or conceptual) and fly it in a stack with 2 dozen parameters or less

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- **GSM BACKUP SLIDES**

STRIDE & GSM

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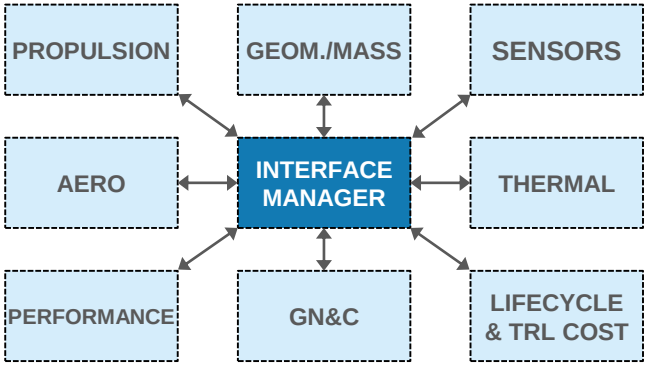
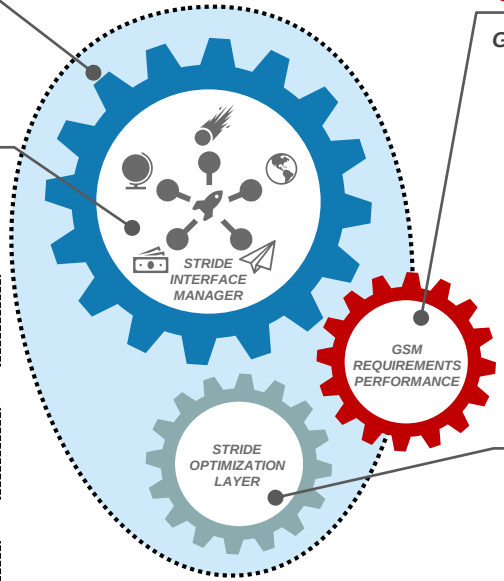
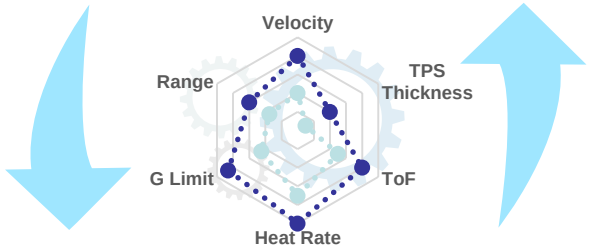




GSM

GMD Specification Model (GSM) Contextualizes Hypersonic Vehicle Design Requirements Space via STRIDE physics-based models for exploration of the performance space



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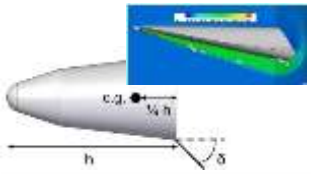
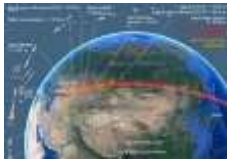


Trajectory Generation

Threat Trajectories



Defended Area Analysis

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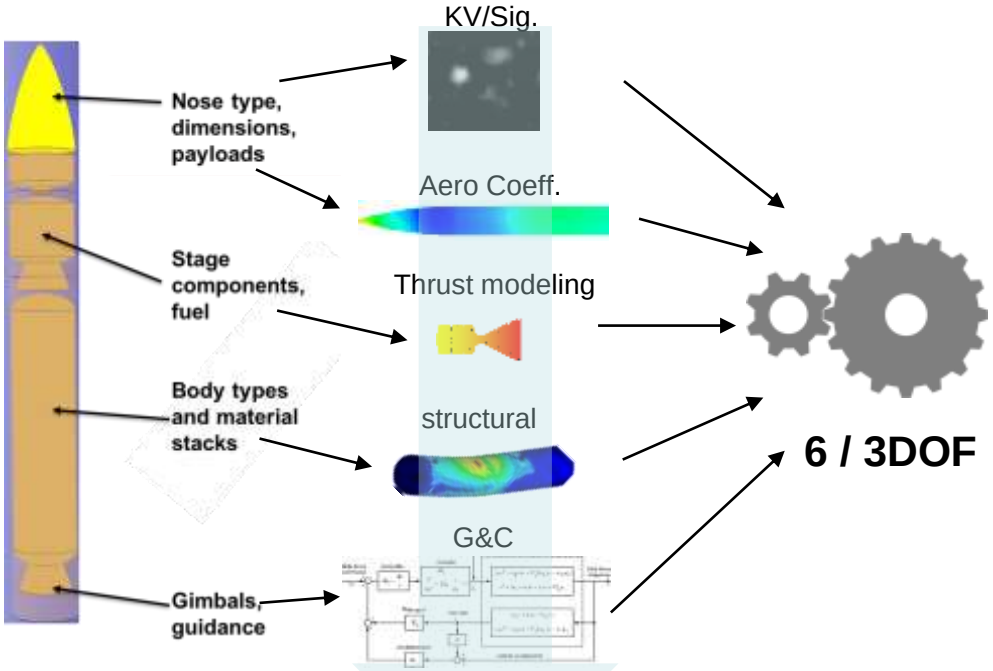
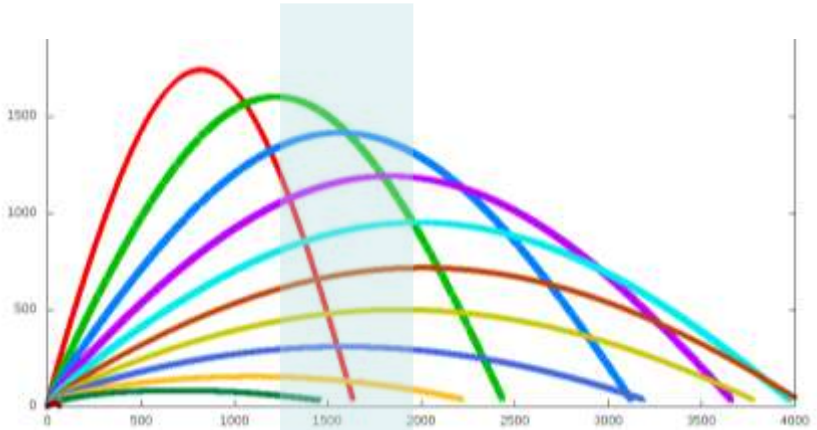
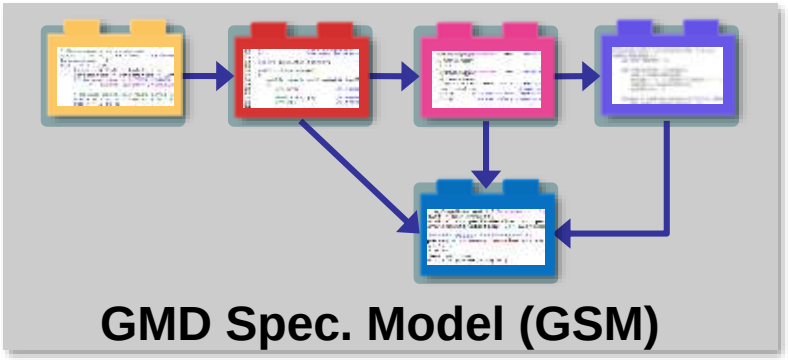
Tool partnerships (GSM & future)



Red and Blue Fly-out Modeling

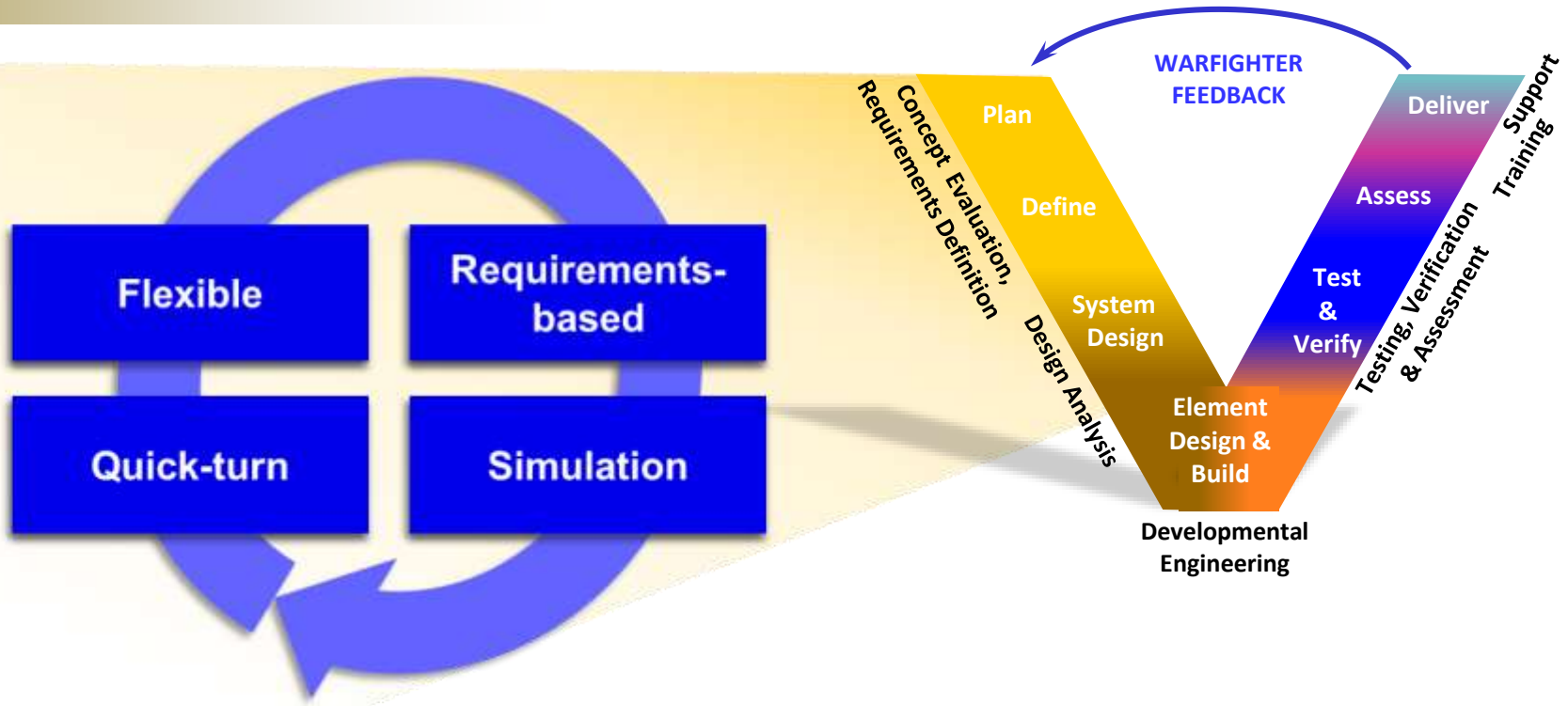


Embed algorithms



Interpolate Data

GMEM GMD Specification Model

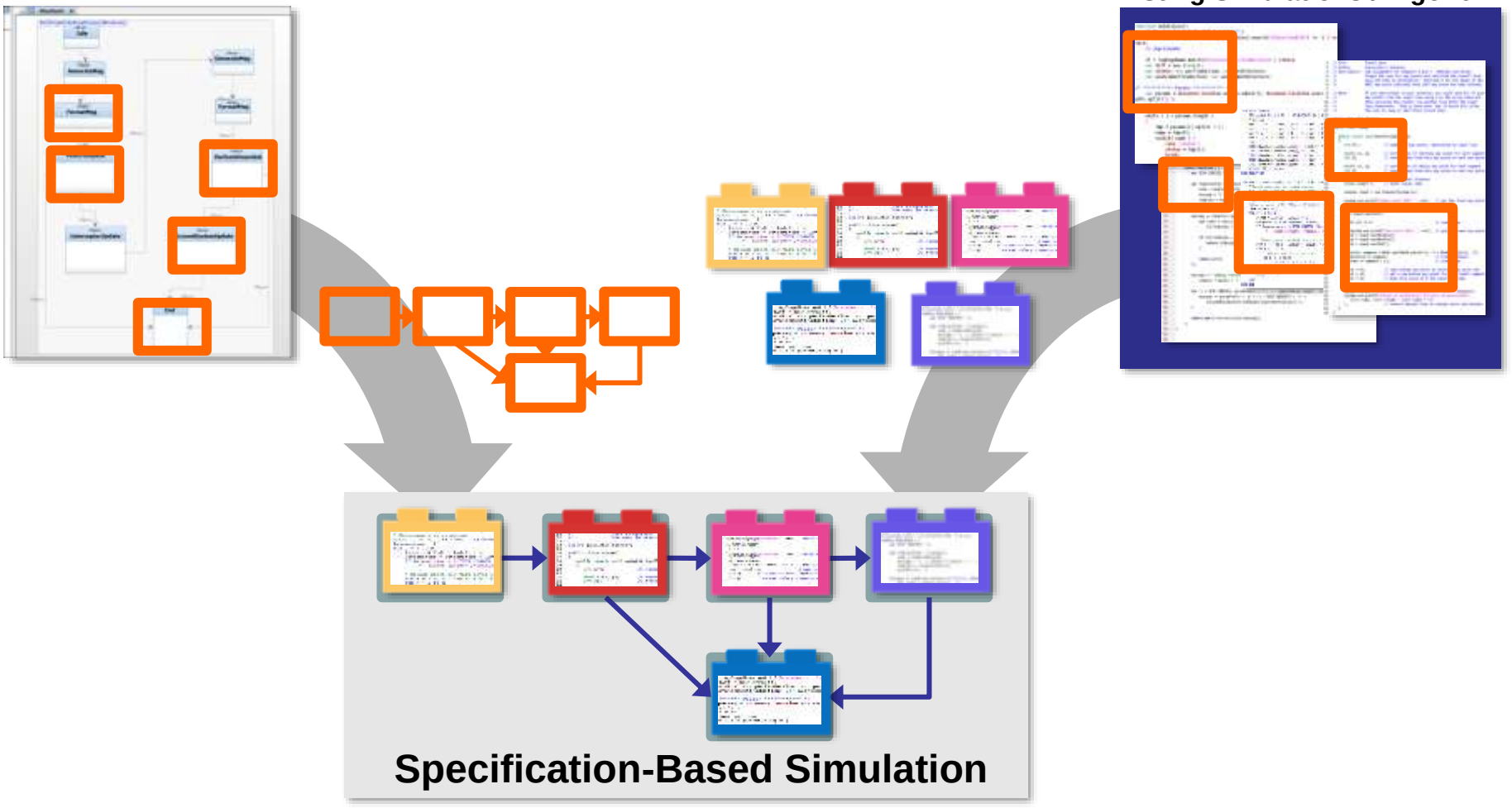


- GSM is a flexible, requirements-based simulation for providing quick-turn exploratory analysis, such as…
  - Early, design-neutral requirements performance
  - Parametric studies & sensitivity analysis
  - Feasibility studies, trade studies, analysis of alternatives

Specification Modeling Connects M&S to Requirements

MBSE Model / Specifications

Existing Simulations / Algorithms



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