27th Annual Systems & Mission Engineering Conference

Oct 28-31, 2024

MBT&E Instructed Composable Modeling Supporting T&E Execution Phase Planning & Analysis

GOVERNMENT INITIATIVES (AGI)

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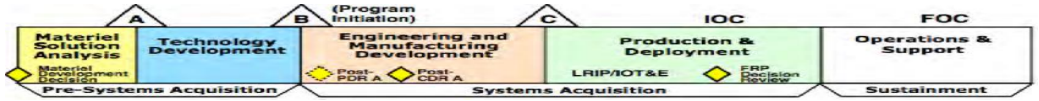
Digital Mission Engineering Vision

(All Depicted Data is Notional)



- Multidomain, physics-based environment
- Mission model
- System of systems model
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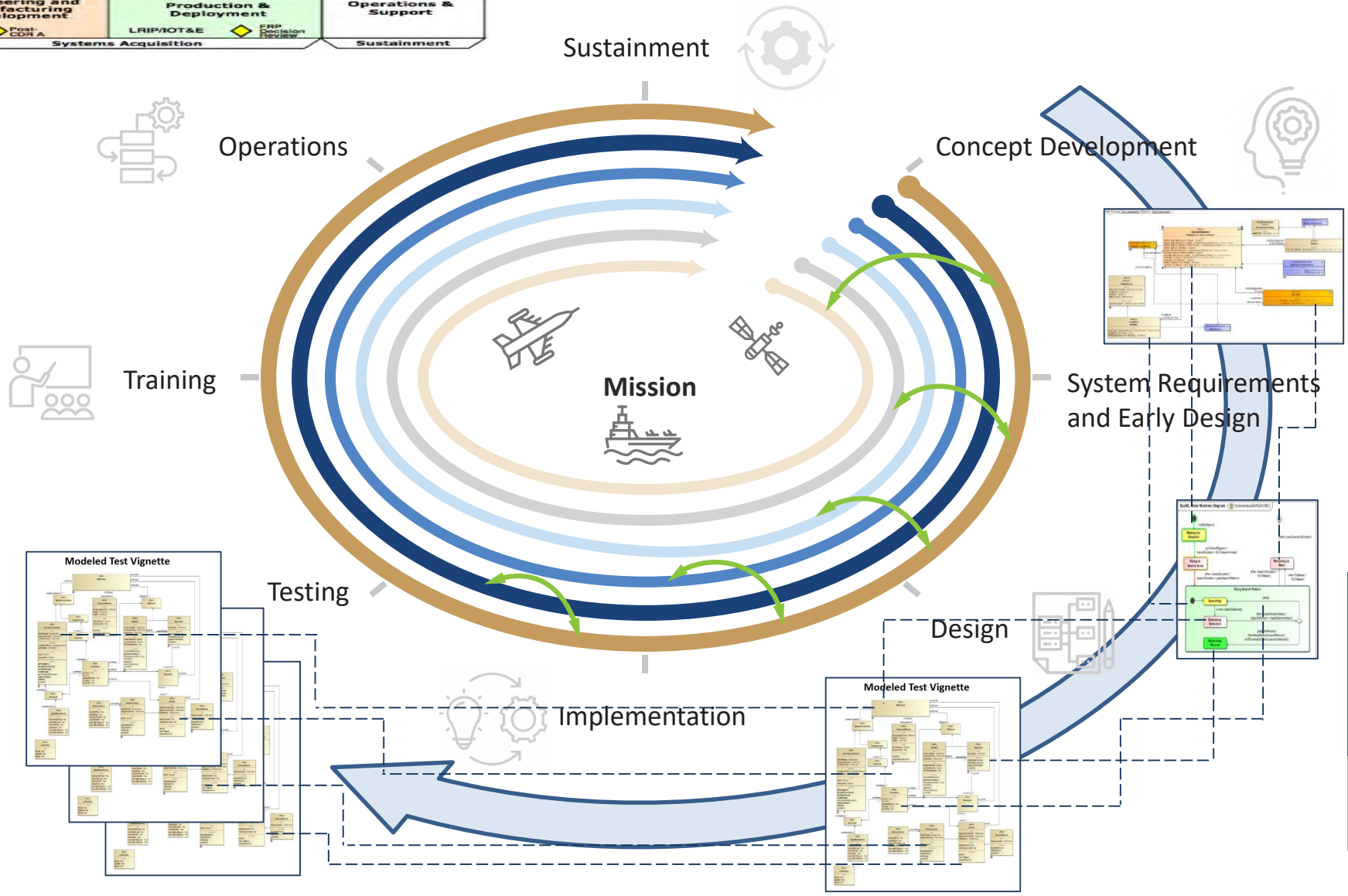
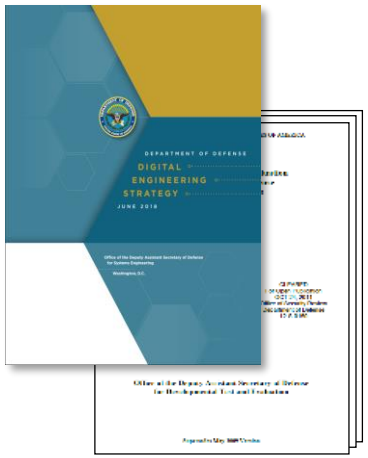
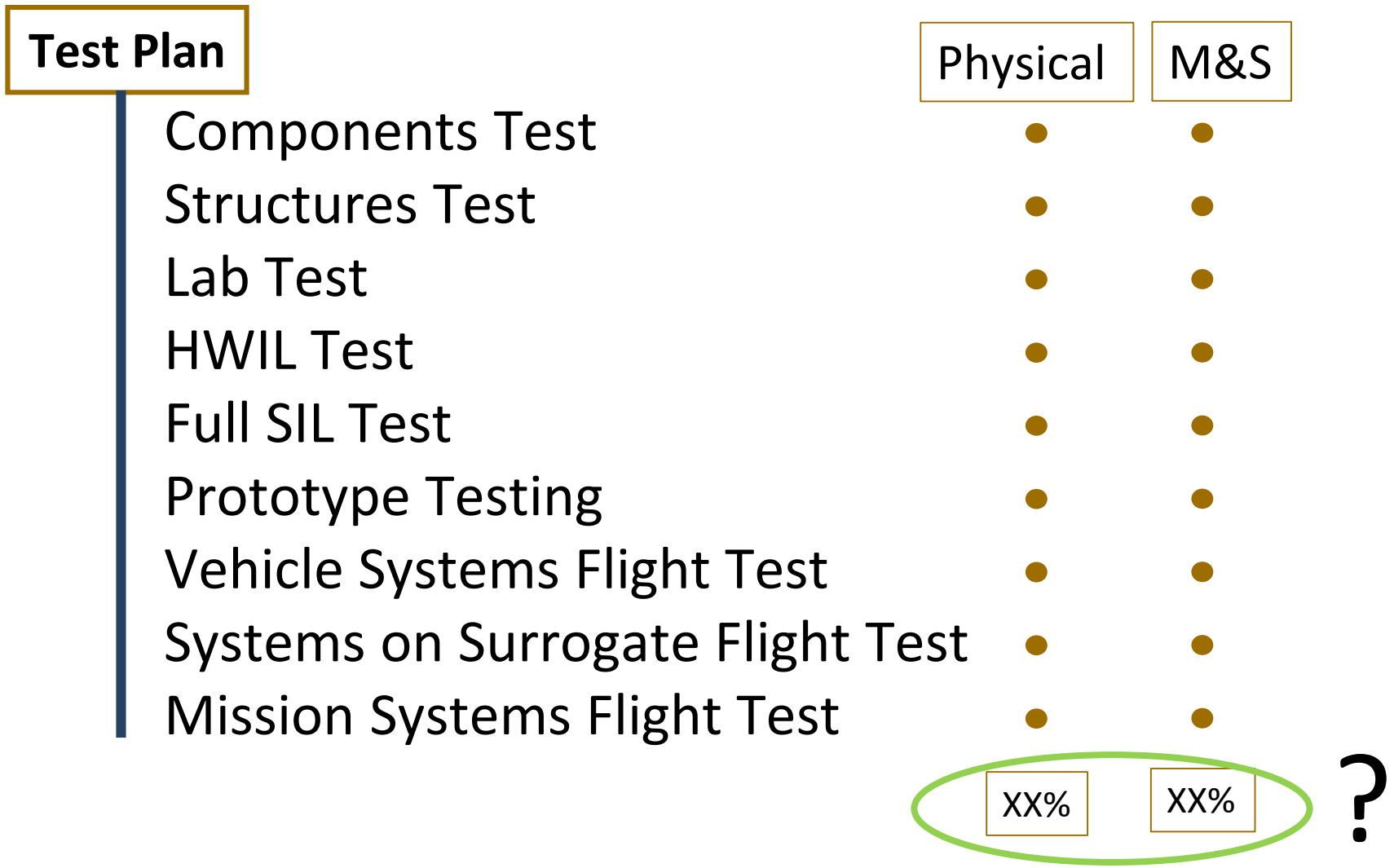
- Platform model
- Component model





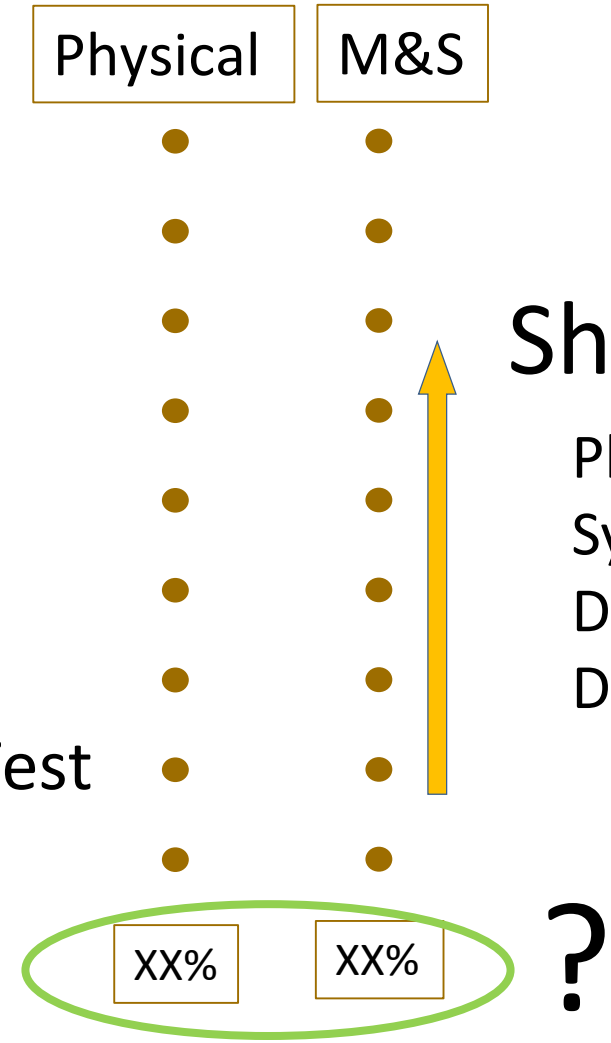
Overall Test Plan – Incorporation of Modeling



Overall Test Plan – Incorporation of Modeling

Test Plan

- Components Test
- Structures Test
- Lab Test
- HWIL Test
- Full SIL Test
- Prototype Testing
- Vehicle Systems Flight Test
- Systems on Surrogate Flight Test
- Mission Systems Flight Test



Shift Left

- Physics-based
- Systems Simulation
- Digital Prototypes
- Digital Twins

Overall Test Plan – Incorporation of Modeling

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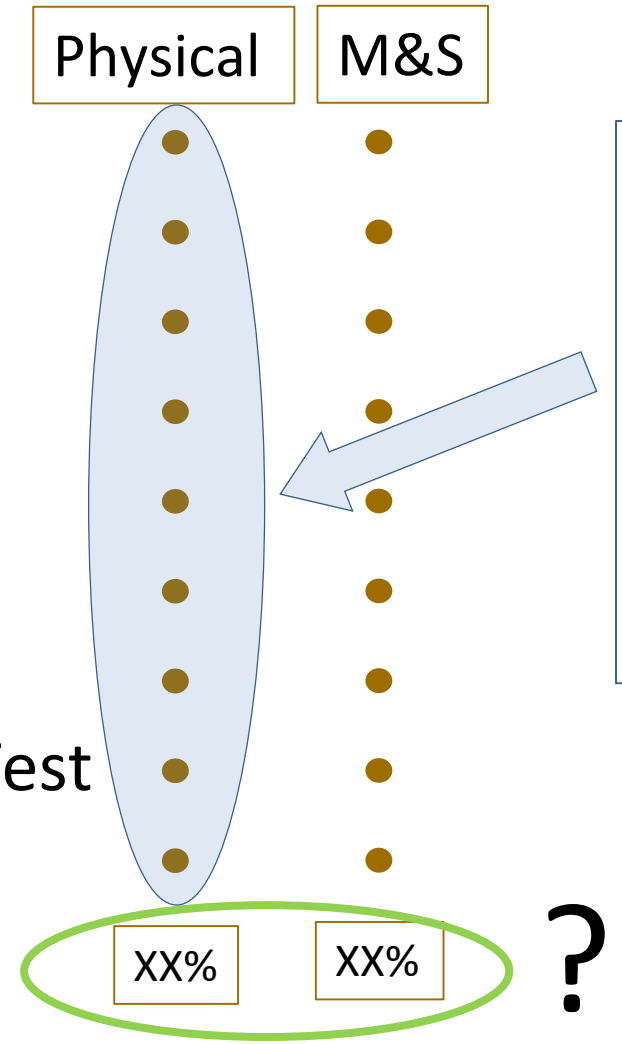

Using Simulation to Increase Efficiency & Effectiveness Of Test Operations

Challenges to Digital Transformation

- Testing the MBSE Designs for:
  - Correctness - Accuracy - Completeness - Cohesiveness
- Designing the proper Test Plan DOEs considering all relevant factors and MBSE designs
- Build up of fully representative “Digital Twins”
  - Components >> Vehicle >> System >> System-of-Systems
- Enablement of engineering & mission physics based simulations to be used by execution-phase test-practitioners
- Enabling the validation of models built into the execution test process
  - Model – Test – Evaluate – Refine – Model

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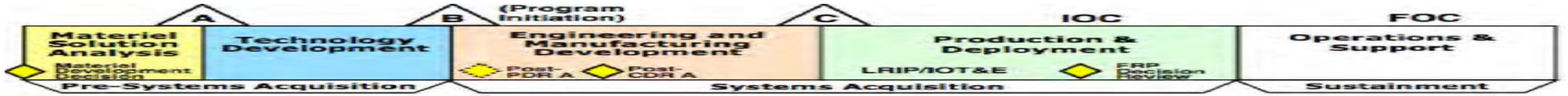
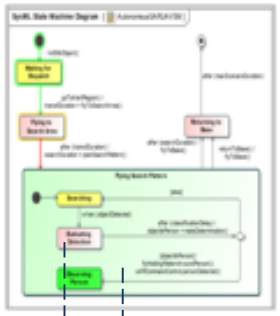
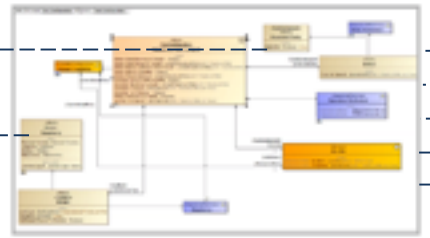
Effective MBT&E tied in Early and Throughout Program



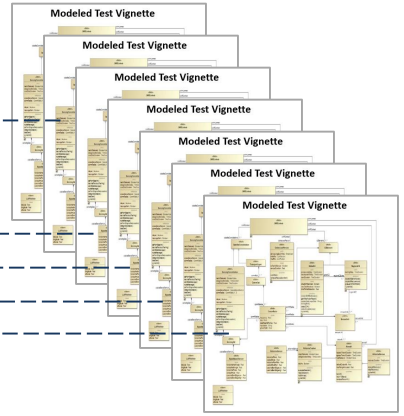


Design Engineering

MBSE



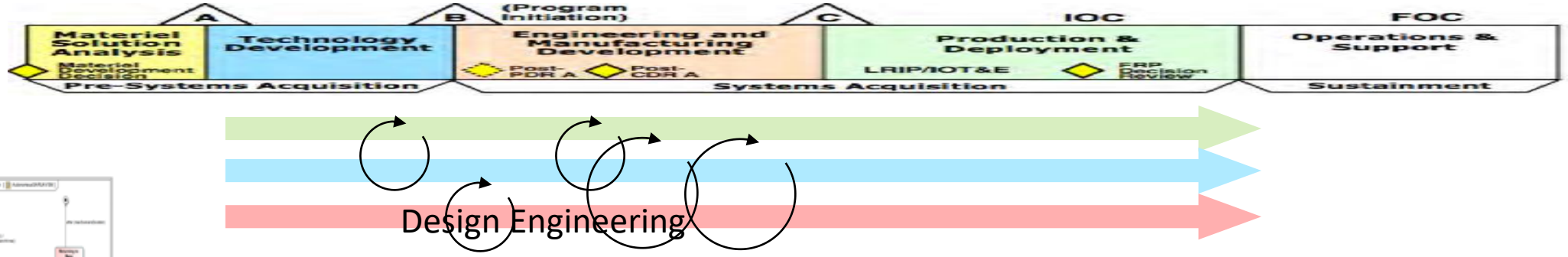
MBT&E



MBT&E Driven Test Execution

(All Depicted Data is Notional)

Effective MBT&E tied in Early and Throughout Program



(All Depicted Data is Notional)

Programmatic Evolution of Digital Twins

Component Twins

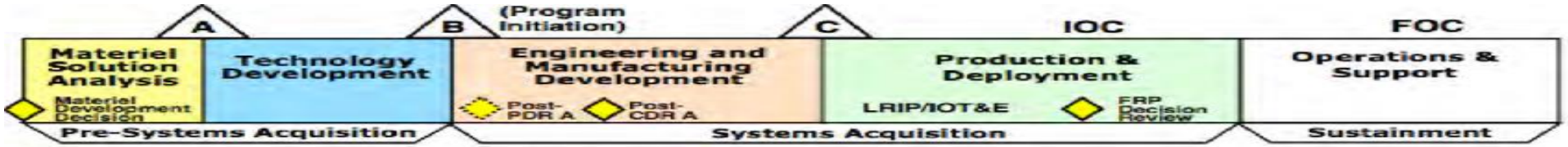
Physics Simulation Models

Vehicle Subsystem Twins

Engineering Simulation Models

Systems of Systems Twins

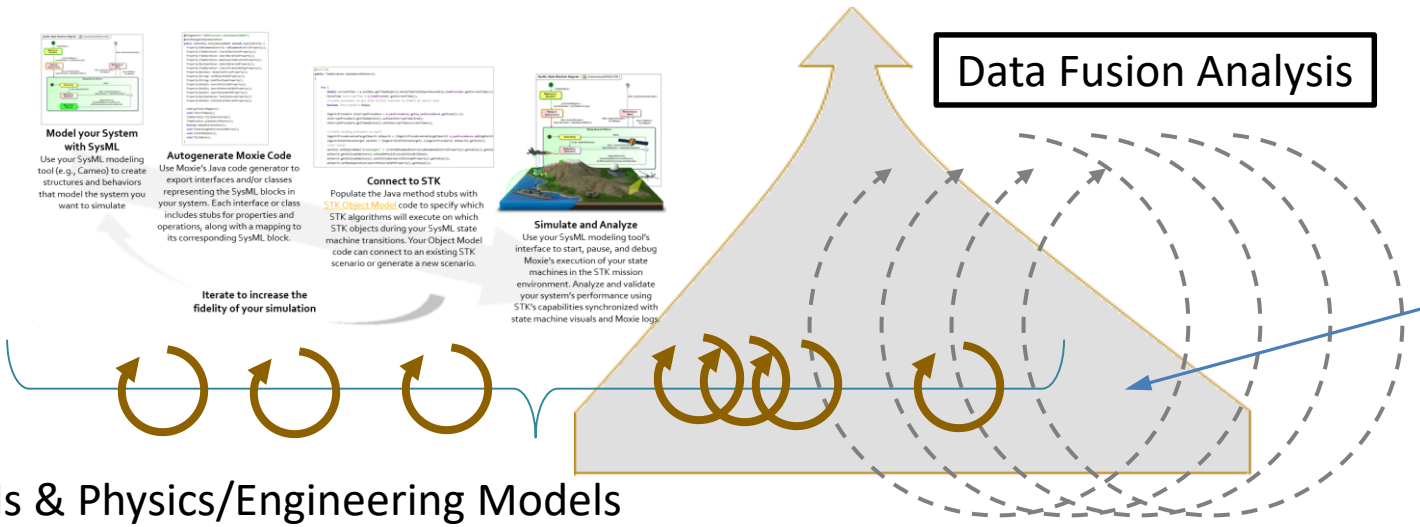
Execution Phase T&E Improvement Opportunity



Systems Engineering

T&E Execution

Systems Verification



SE Models & Physics/Engineering Models

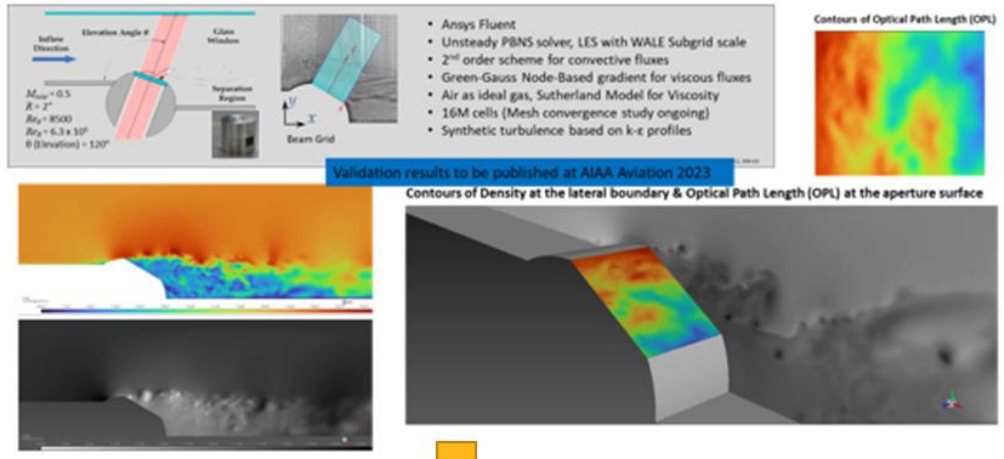
Opportunity to use models generated in the overall DE process into the T&E Execution process for test detailed planning, execution & data analysis

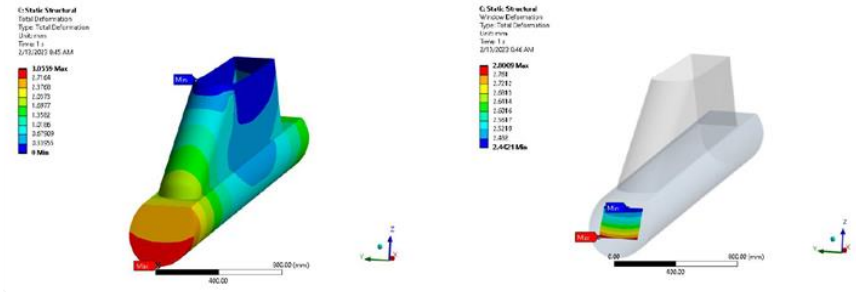
(model – test – model – test – model …)

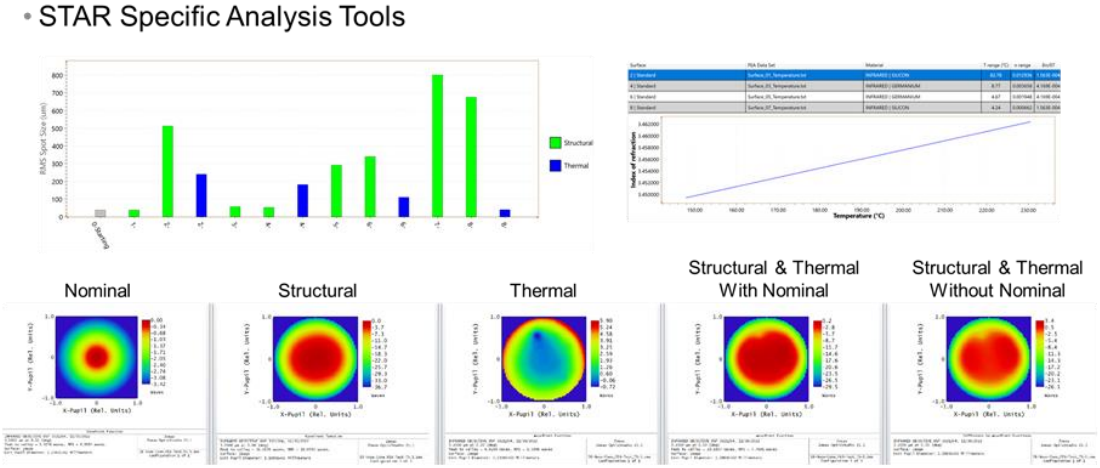
Model Readiness Level Progression

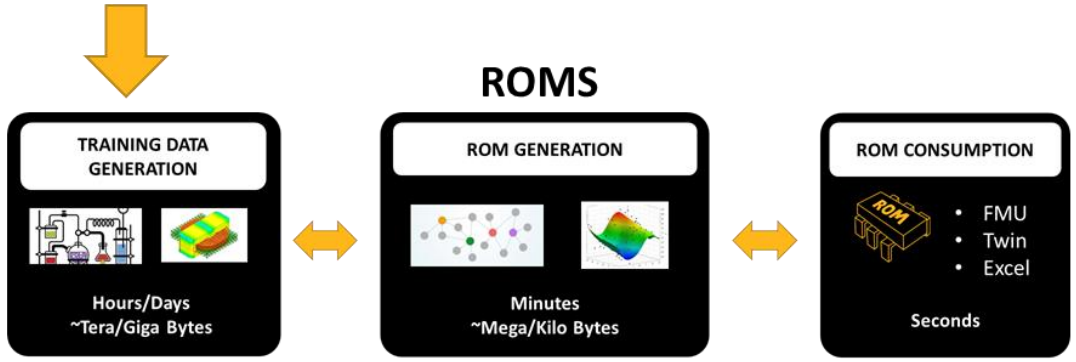
(All Depicted Data is Notional)

Test Data Informed Reduced Order Models as Dig Twins





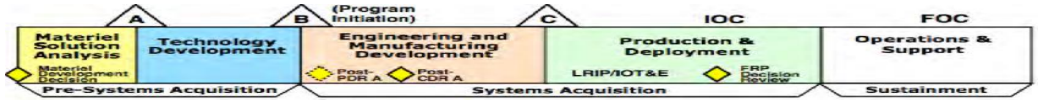




Ansys Advantage:
- ROMs built using a combination of statistical and physics-based machine learning techniques
- ROMs based on small datasets for engineering simulations

(All Depicted Data is Notional)

Digital Mission Engineering Vision



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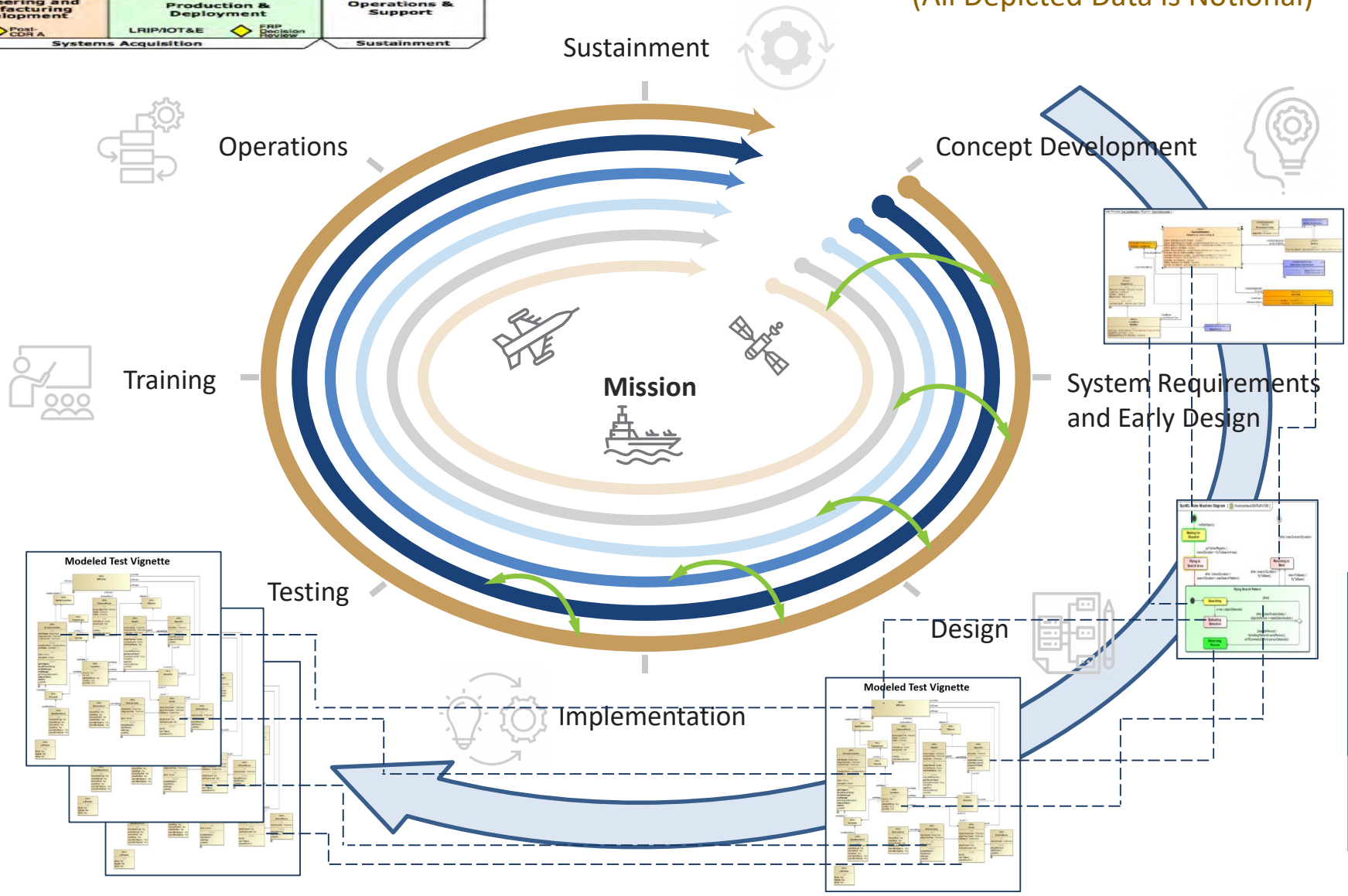
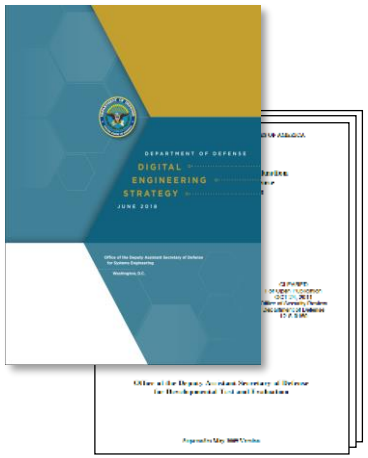
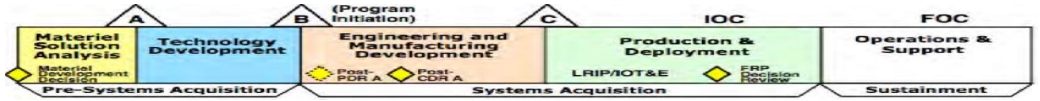
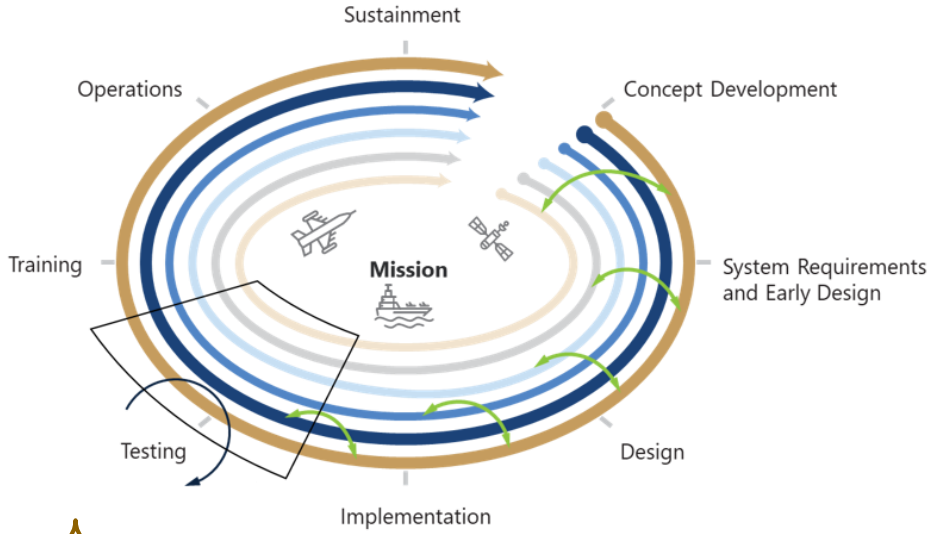




Execution Phase T&E Improvement Opportunity





(All Depicted Data is Notional)

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Engineering IPTs

Detailed Test Requirements

CTF / ITT / ITF

Test Point Narratives

Detailed Test Planning – Test Cards

Test Execution

Post-Flight Quick-Look

Verification

T&E Execution Phase Process – Challenges

(All Depicted Data is Notional)

Engineering IPTs

Detailed Test Requirements

CTF / ITT / ITF

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Verification

Increasingly Complex Systems

Understanding systems process knowledge in support of DOEs

Less than modern planning methods:
- **Planes-on-sticks**
- **Paper processes**

Low test-point density

High re-fly rates

Missed Test Points

“Big Data” problem Much goes unanalyzed

Delays in actionable information from analyses

Increasingly Systems Software Complexity

Anomaly evaluation and resolution - drags on test team personnel

“Ad-Hoc / Composable” Modeling - Definition

- Using COTS toolsets including function libraries and higher level physics-based engineering toolsets to achieve “Ad Hoc Modeling” in advancement of “Decision Support”
- Models are “Composed” from standard COTS tools on-demand and to meet a variety of evolving needs across multiple disciplines and use cases
- Models are assembled using those COTS capabilities together with various specifically developed models in support of the Digital Thread by using standard open plug-in interfaces within these toolsets.
- Models are evolved and quantified and validated with test data

Progression of “Composable” Modeling

(All Depicted Data is Notional)

Complex

Multi-domain, Multi-vehicle modeling

Multi-vehicle modeling

Detailed Subsystem modeling (physics-based modeling: comm/radar/EOIR links, ..)

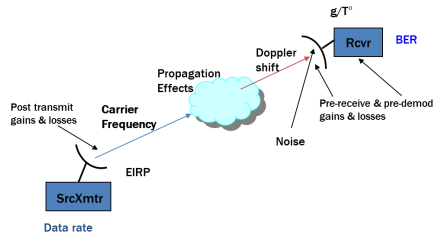
Simplified Subsystem modeling (FOVs, geometric constraints, ..)

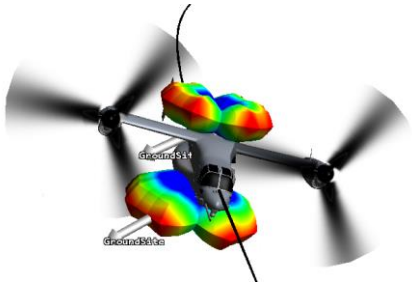
Detailed Vehicle Performance modeling

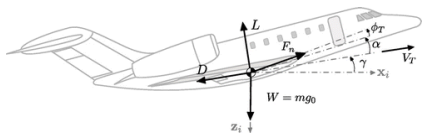
Simplified Vehicle Performance modeling

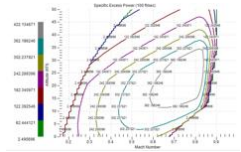
Dynamic Geometry and FOVs modeling

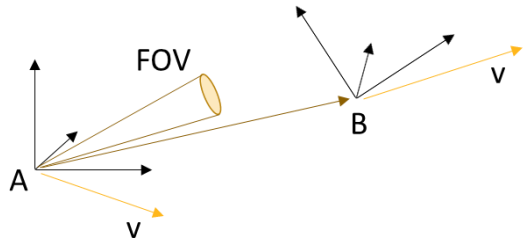
Simple











Progression of “Composable” Modeling

Fast / Composable

Long-lead Time / Significant Development Buildout

Complex

Simple

Multi-domain, Multi-vehicle modeling

Multi-vehicle modeling

Detailed Subsystem modeling (physics-based modeling: comm/radar/EOIR links, ..)

Simplified Subsystem modeling (FOVs, geometric constraints, ..)

Detailed Vehicle Performance modeling

Simplified Vehicle Performance modeling

Dynamic Geometry and FOVs modeling

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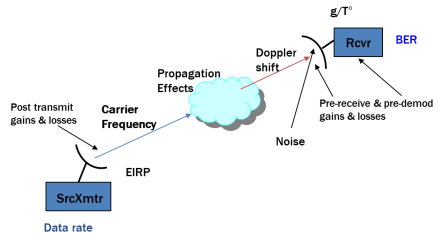
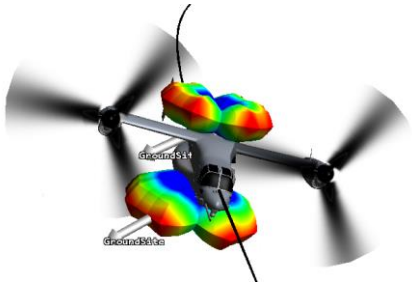
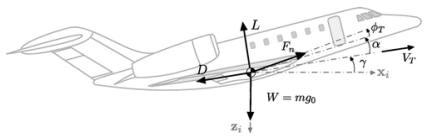
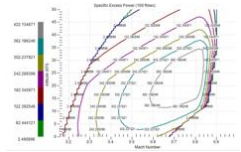
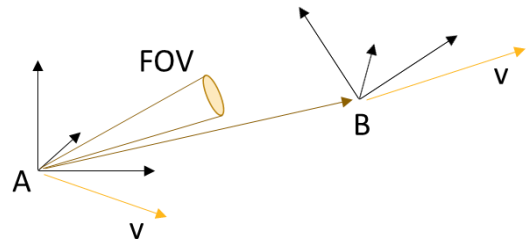






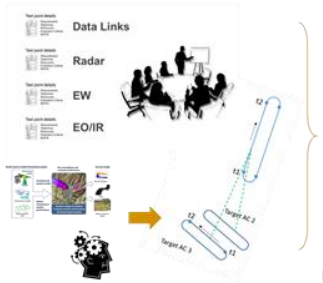




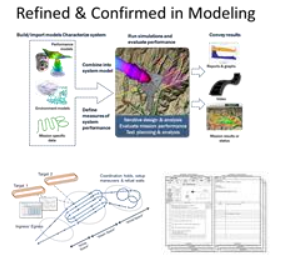
Test Ops Composable Modeling

- Efficiency of Test Team
- Efficiency & Effectiveness of Test Activity
- Communication among stakeholders
- Flight Safety

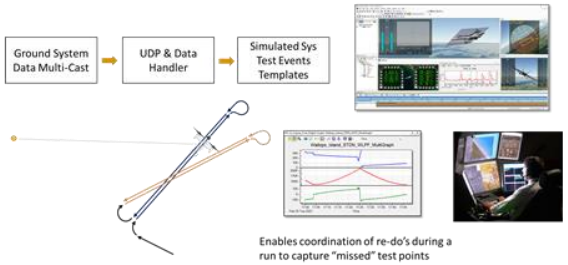
Test Point Narratives → **Detailed Test Planning – Test Cards** → **Test Execution** → **Post-Flight Quick-Look** → **Verification**



Test-Point Narratives



Increased Test-Point Density & Effectiveness



Enables coordination of re-do's during a run to capture "missed" test points

★ **Increased Test-Point Density**

★ **Improved Re-Fly Rate**

★ **Saved Test-Points**

★ **Faster and More Informative Quick-Looks**

★ **Quicker Feedback Loop with Planning, Engineering & Software Dev**

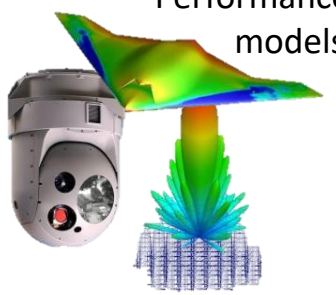
★ **Test personnel efficiency**

★ **Flight Safety**

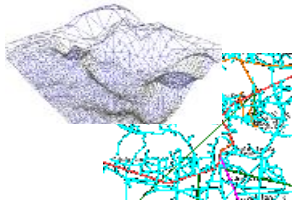
(All Depicted Data is Notional)

Composable Model Based T&E in Mission Context

Build/import models characterize system



Performance models



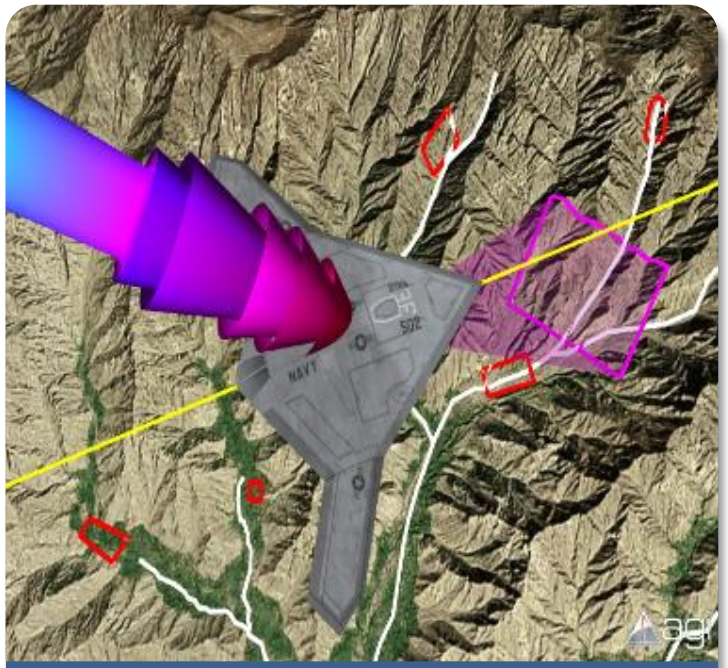
Environment models

Mission specific data

Combine into system model

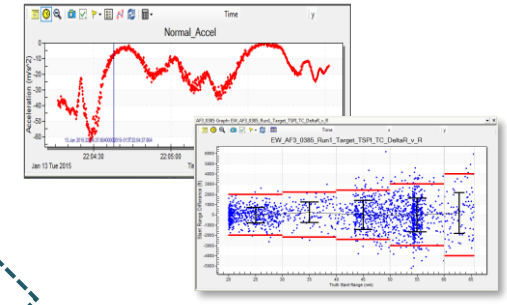
Define measures of system performance

Run simulations and evaluate performance

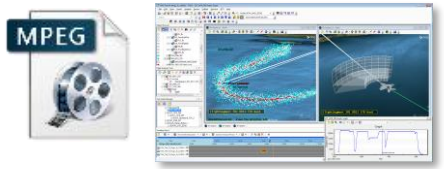


Iterative design & analysis
Evaluate mission performance
Test planning & analysis

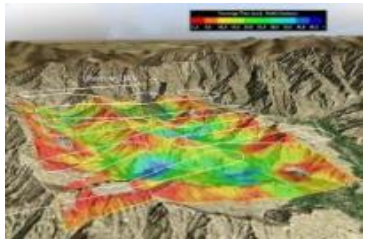
Assess & convey results



Reports & graphs



Audio/Video



Evaluate System Performance

Refine models based on test data results

(All Depicted Data is Notional)

Example Composable Modeling: Dynamic Link Analysis

(All Depicted Data is Notional)

- Transmit power & frequency
- Transmit angles
- Transmit antenna gains
- EIRP

Transmitter

- Propagation Losses
  - Rain
  - Absorption
  - Diffraction (terrain)
  - Diffraction (urban prop)
  - …

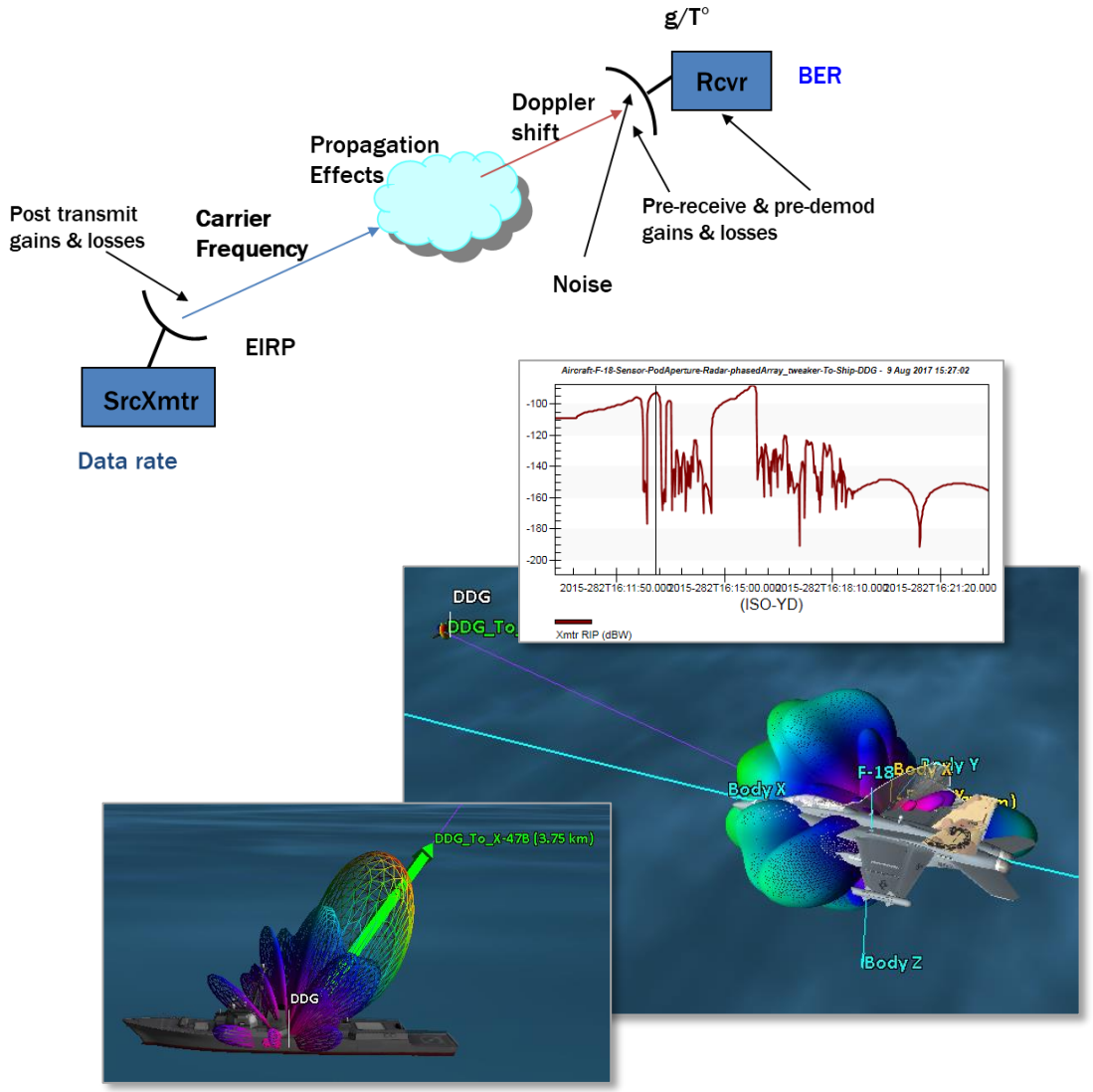
Channel

- Frequency Doppler effects
- Receive angles
- Receive frequency
- Receive antenna gains
- Received Isotropic Power
- Noise temperatures
  - Sun
  - Earth impingement
  - …

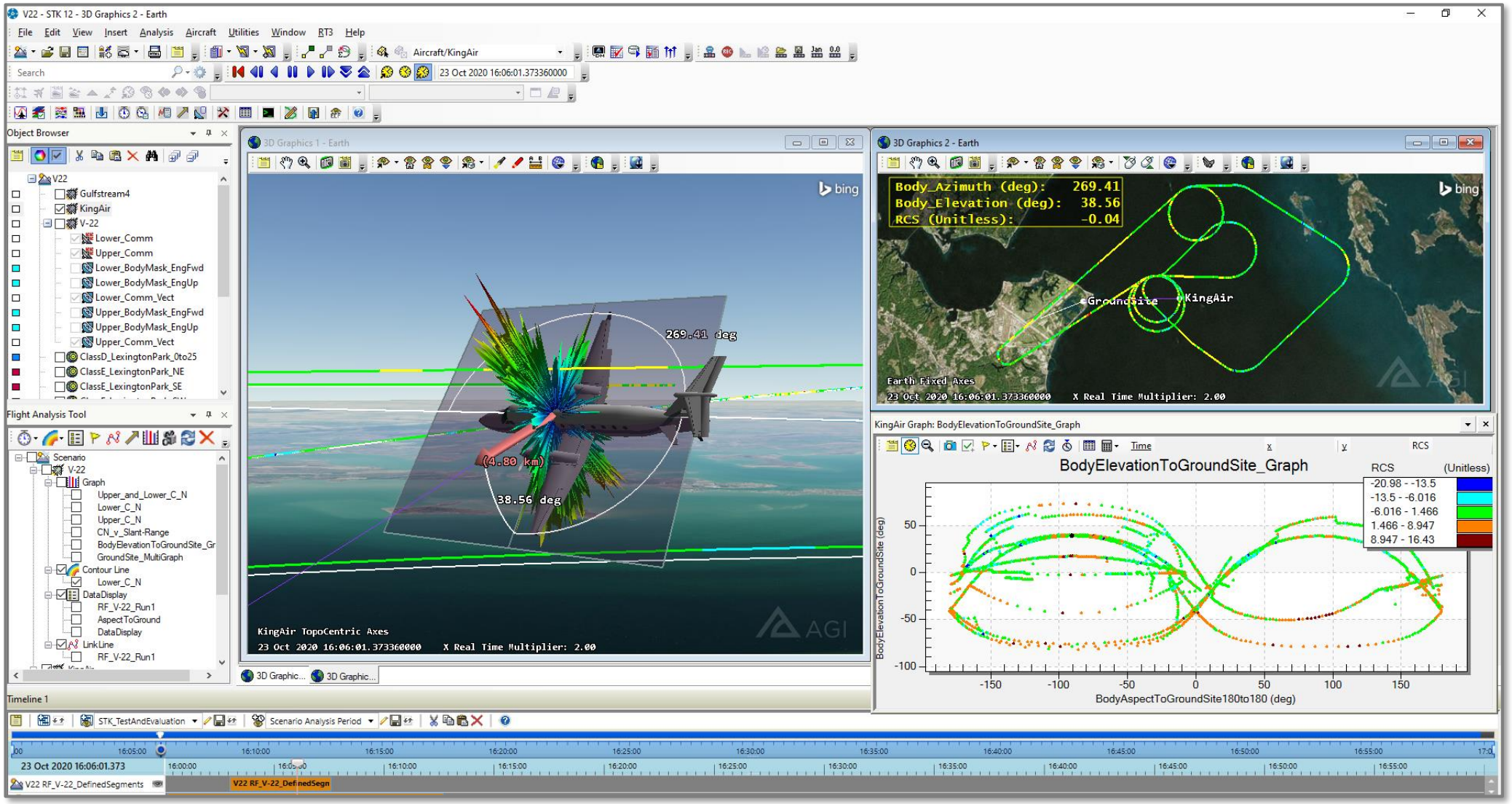
Receiver

- C/N, C/No, C/(N+I)
- Eb/No, Eb/(No+Io)
- BER …

System Performance

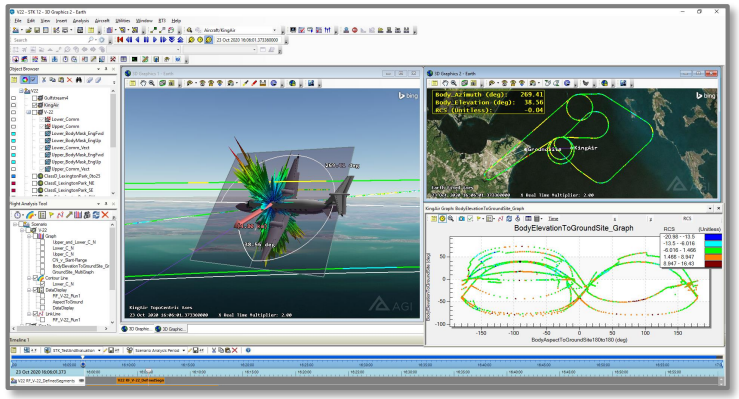


Example - Radar RCS Analysis In T&E Mission Space



(All Depicted Data is Notional)

Interactive Test-Point Narratives Design



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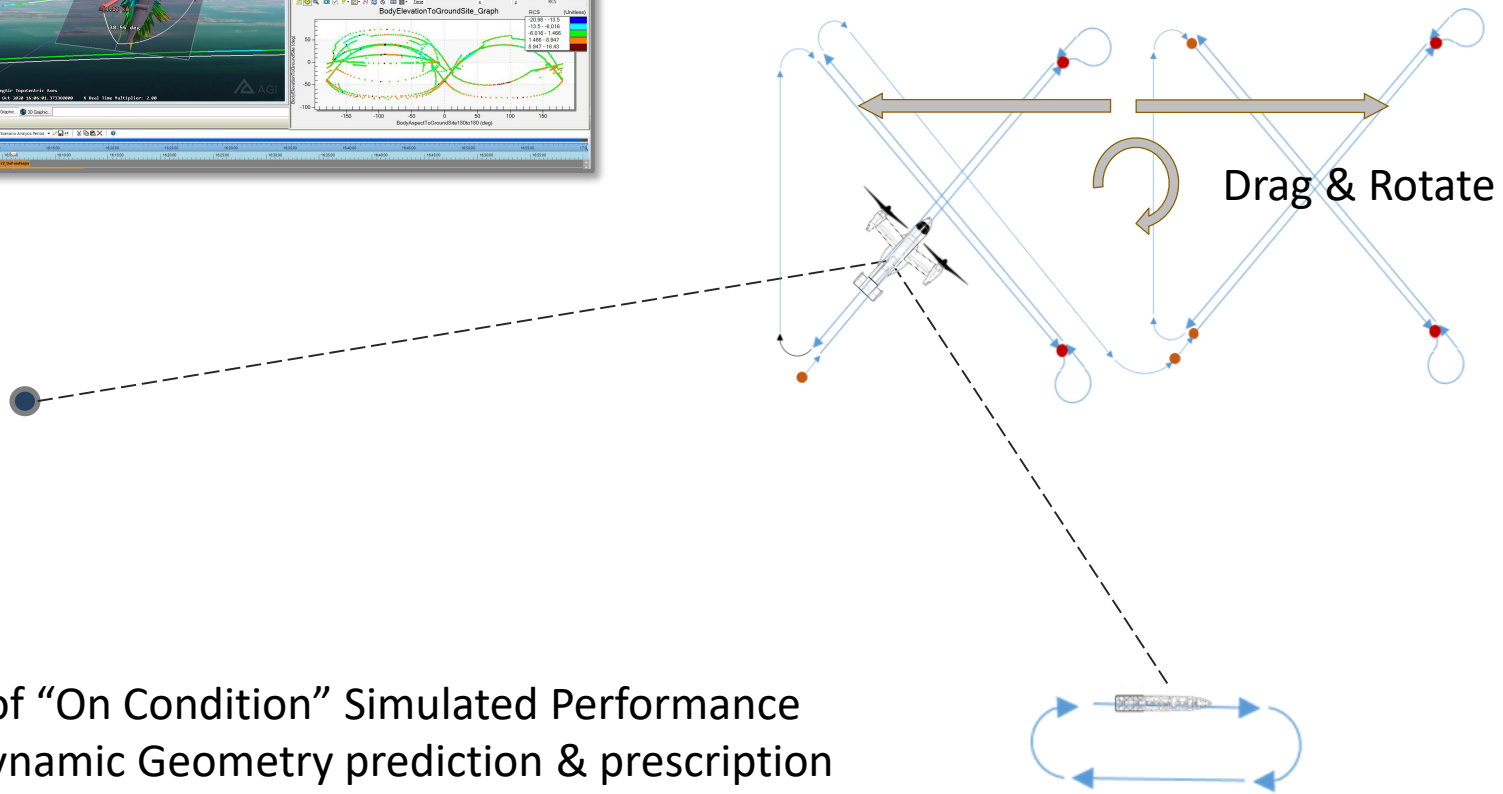
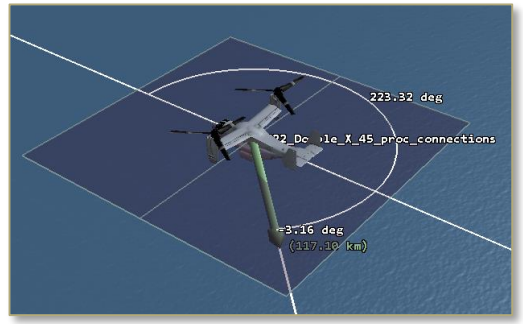
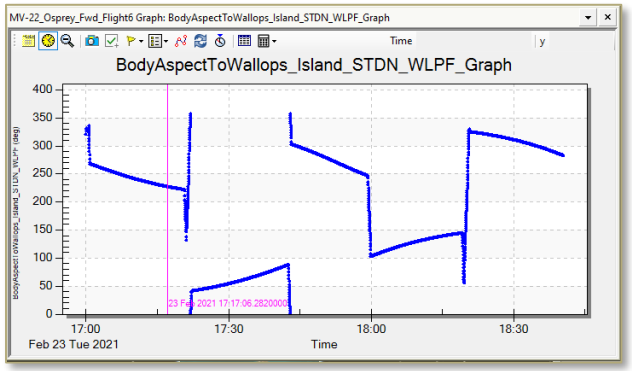




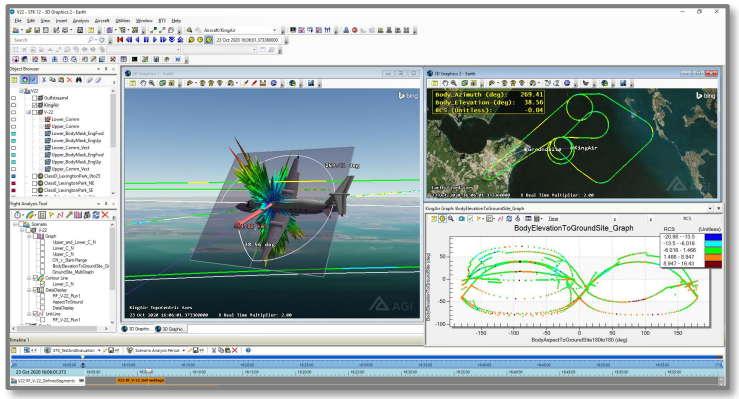
Assess Relevant Metrics



Test of “On Condition” Simulated Performance

- Dynamic Geometry prediction & prescription
- System Performance prediction & prescription

Interactive Test-Point Narratives Design



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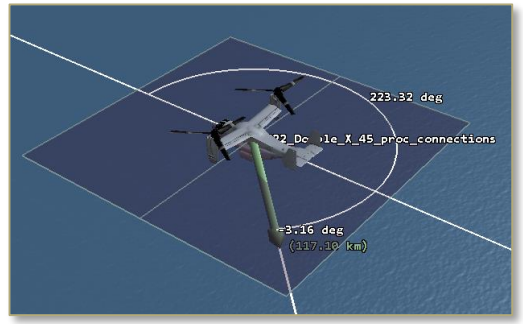
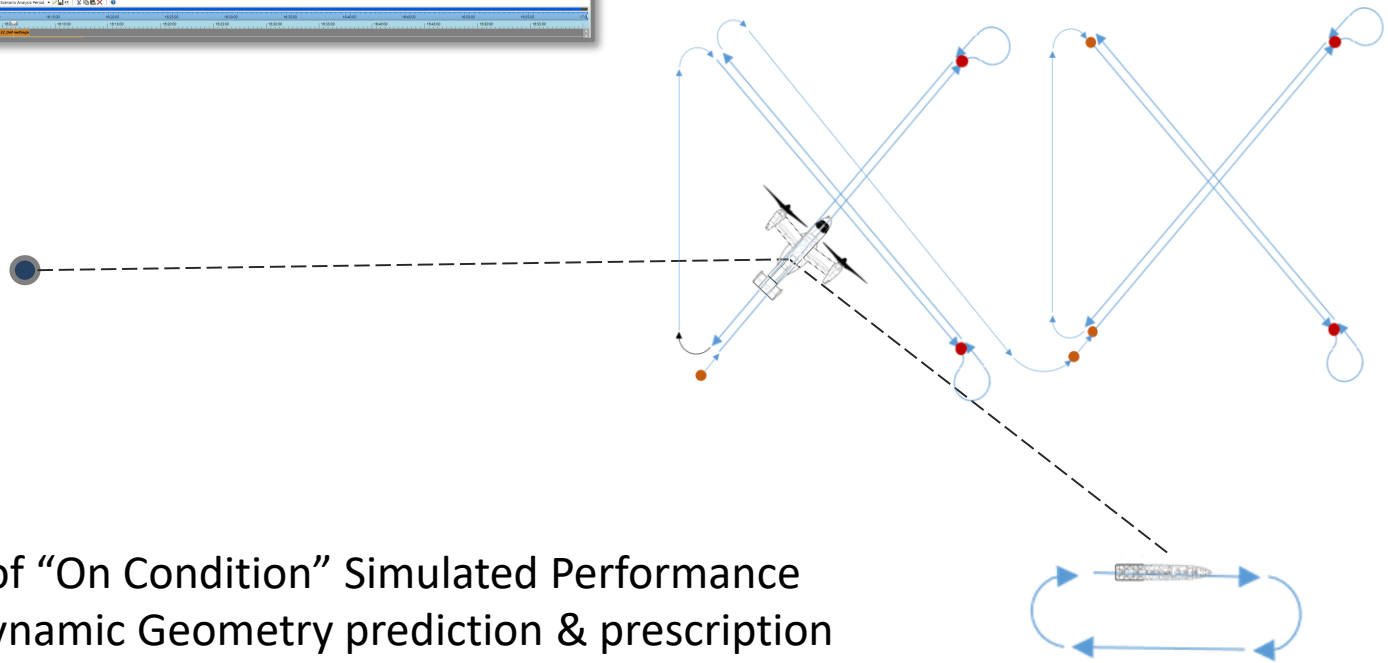
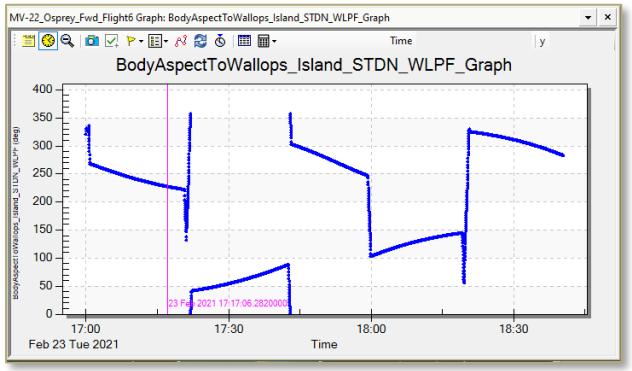




Assess Relevant Metrics



Test of “On Condition” Simulated Performance

- Dynamic Geometry prediction & prescription
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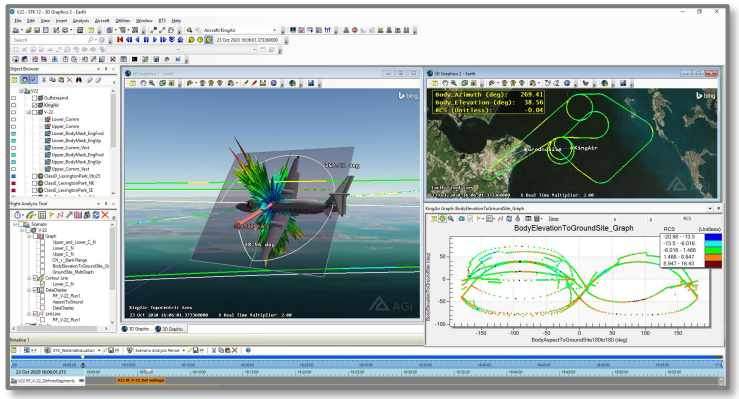
Interactive Test-Point Narratives Design



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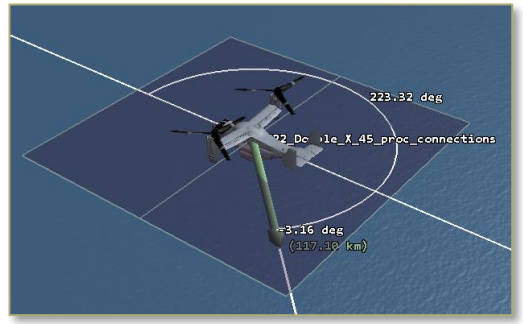
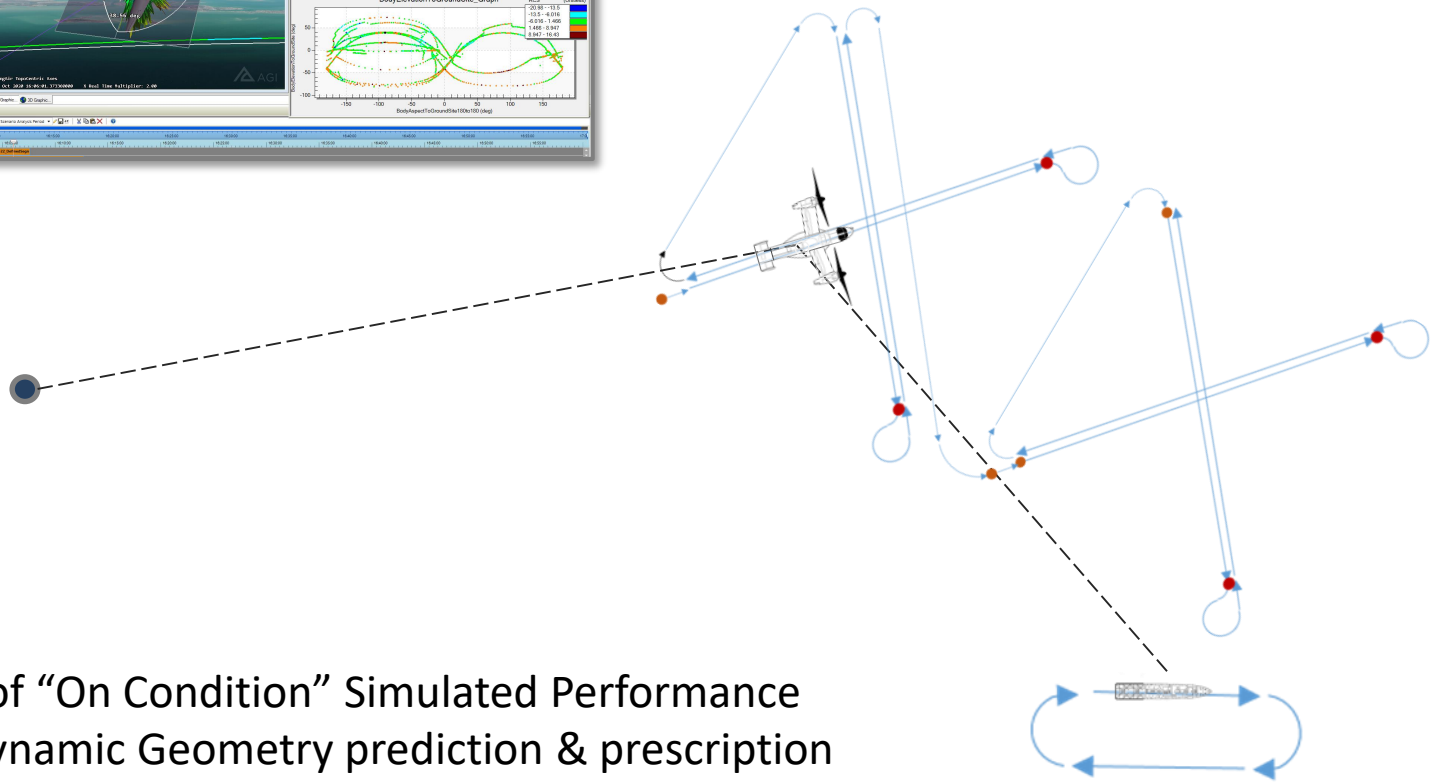
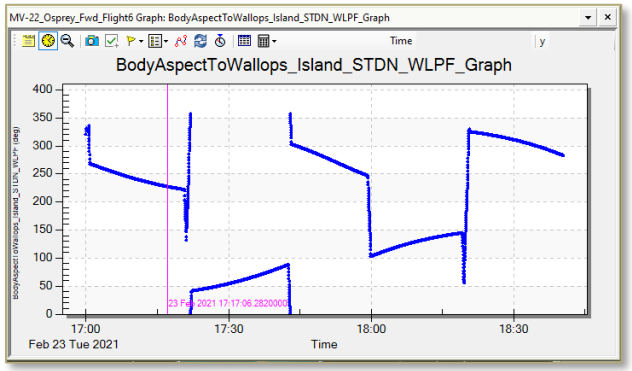




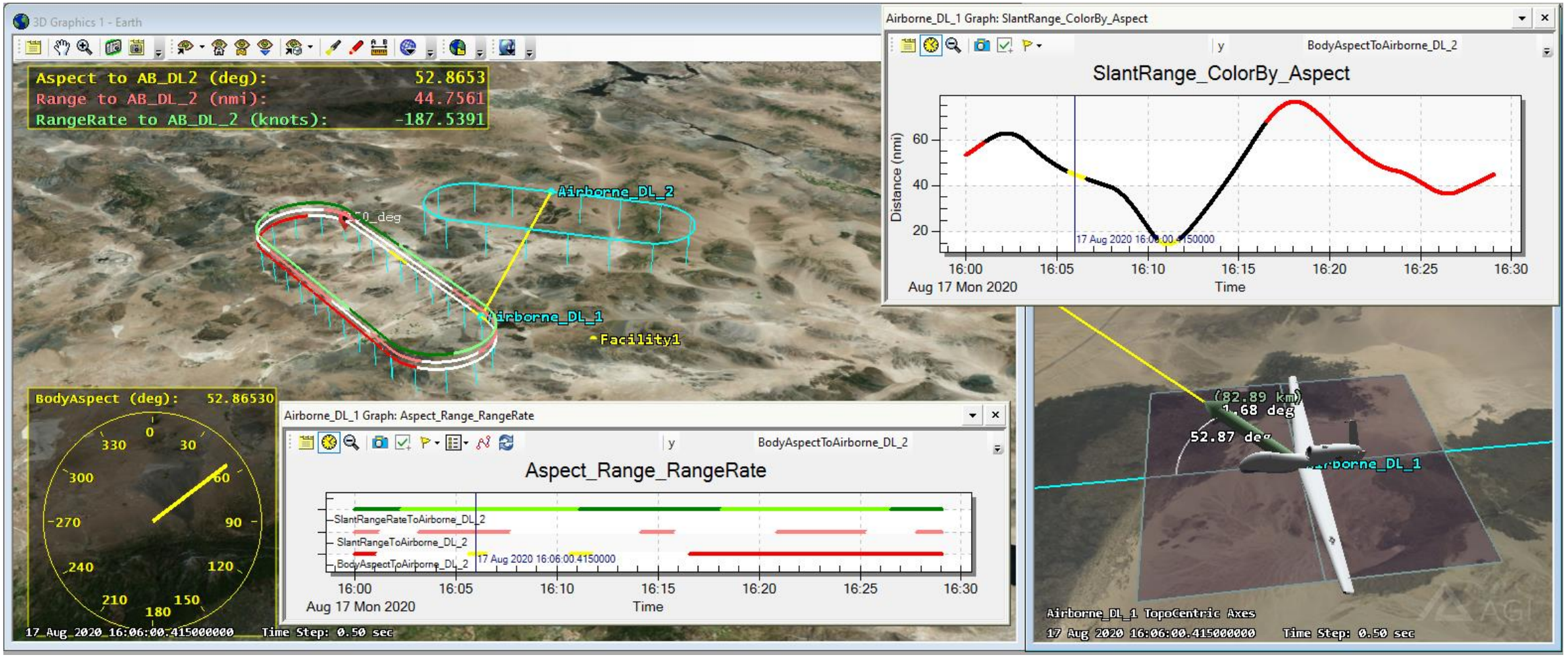
Assess Relevant Metrics



Test of “On Condition” Simulated Performance

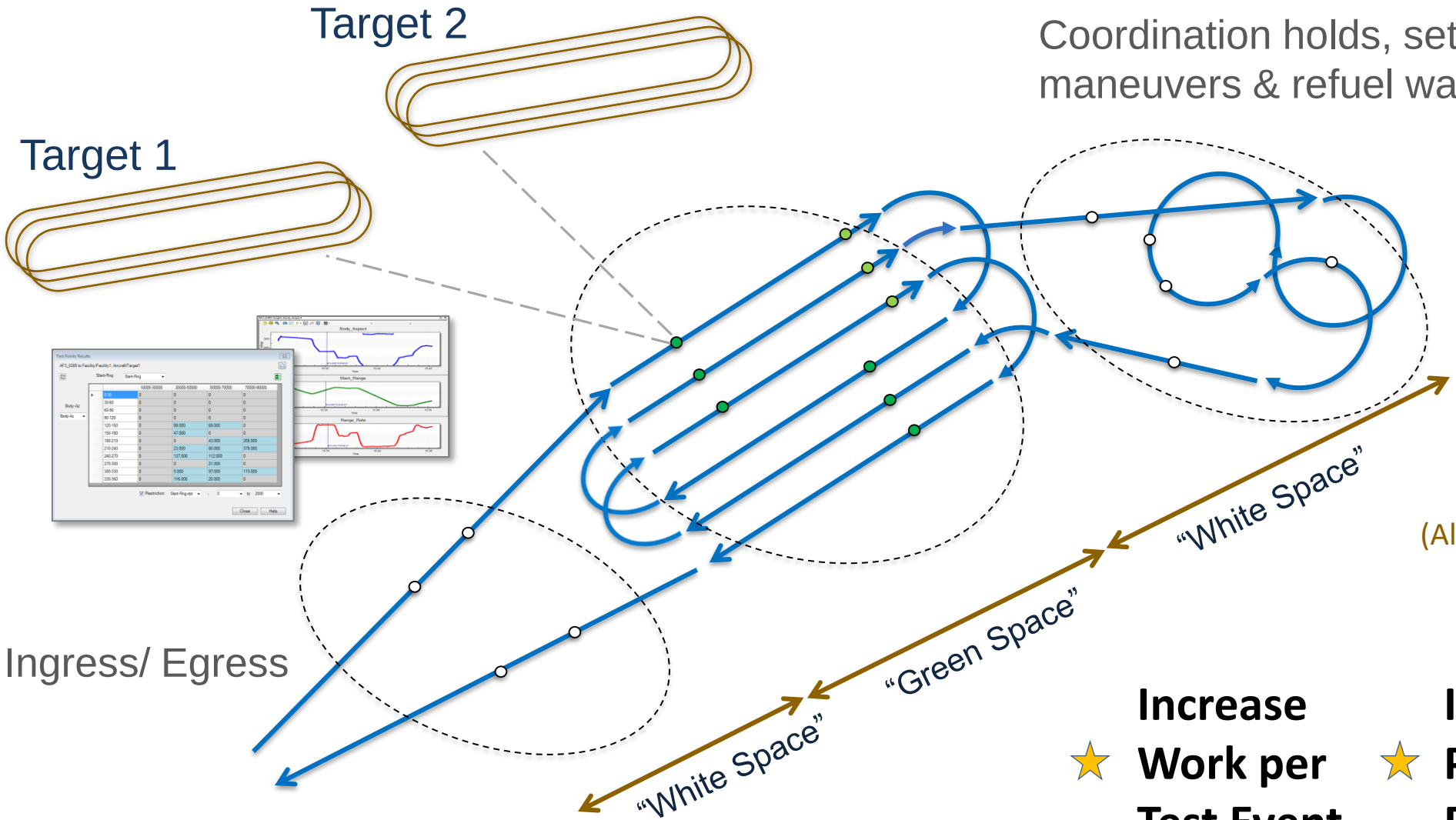
- Dynamic Geometry prediction & prescription
- System Performance prediction & prescription

Decision Support to Detailed Test Planning



(All Depicted Data is Notional)

Improved Efficiency & Effectiveness of Test Events

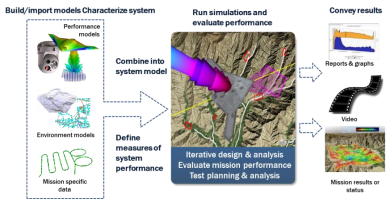


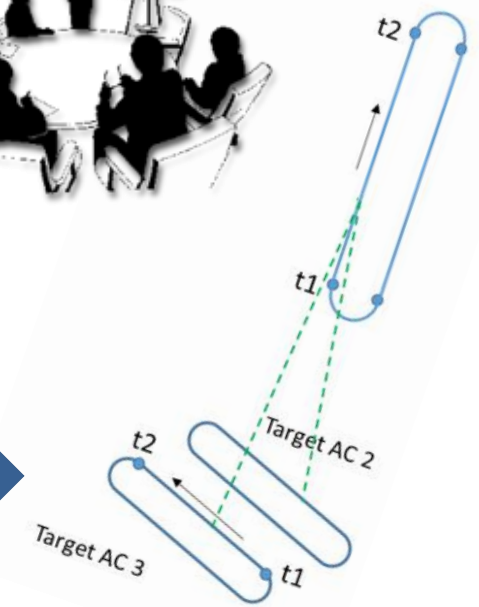
(All Depicted Data is Notional)

★ **Increase Work per Test Event**

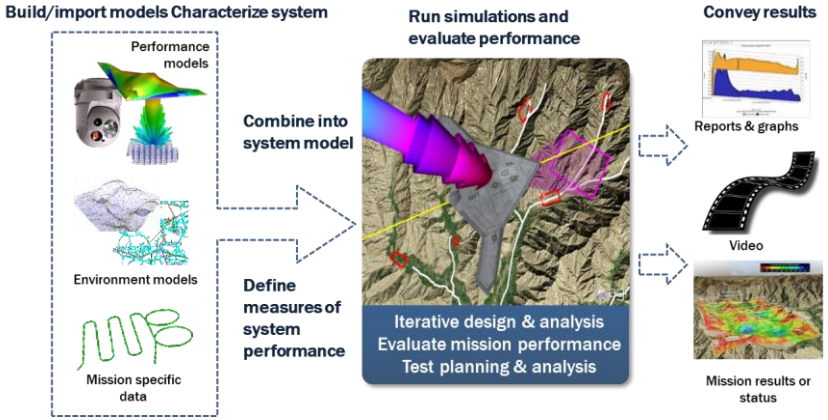
★ **Increase Test-Point Success Rate**

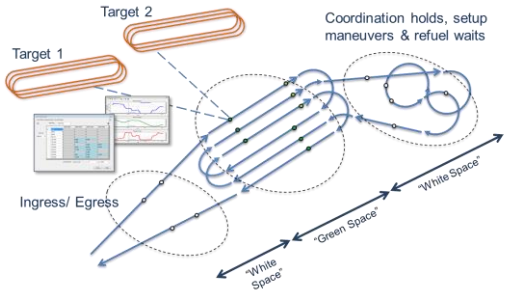
Impact on Planning Efficiency & Effectiveness





Refined & Confirmed in Modeling



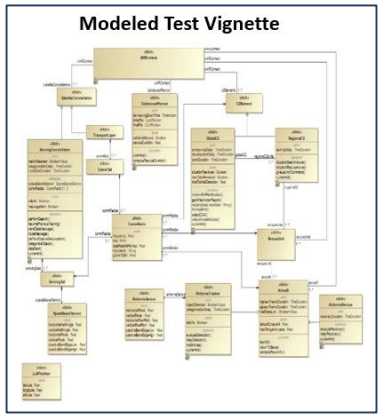


Test-Point Narratives

Increased Test-Point Density & Effectiveness

(All Depicted Data is Notional)

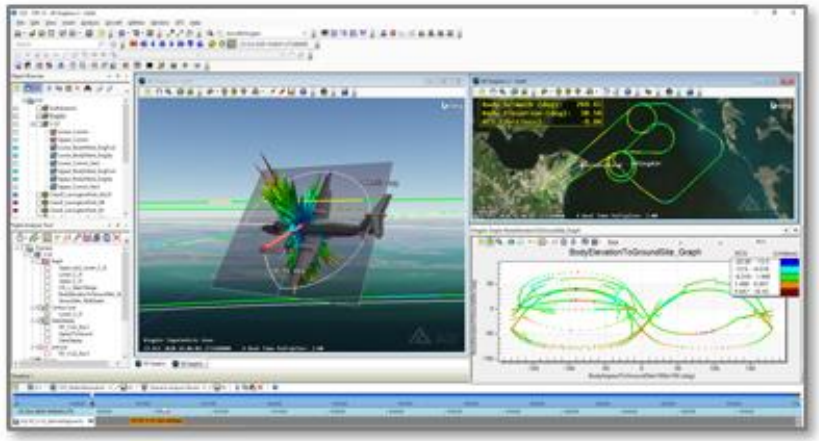
MBT&E Composed Detailed Test Planning Templates

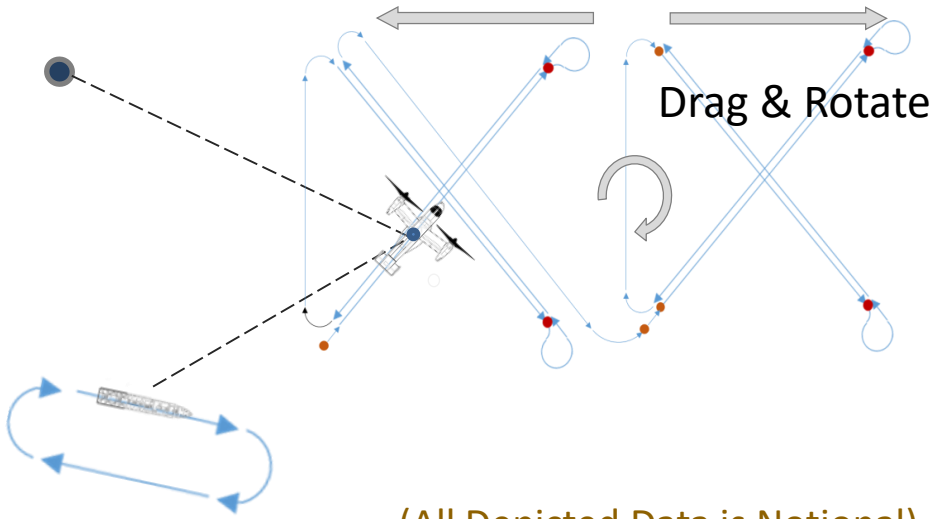


Location Specific Range Data — C2, Telemetry, Terrain, Airspaces, …

Aircraft Performance Model — 3DOF model, 6DOF model, Engine Performance

Mission Systems Model — Radar System Constraints, Operating Parameters, …



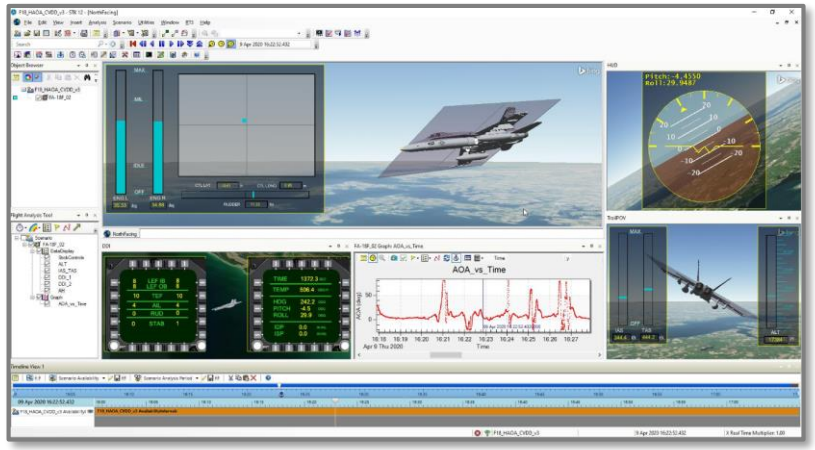


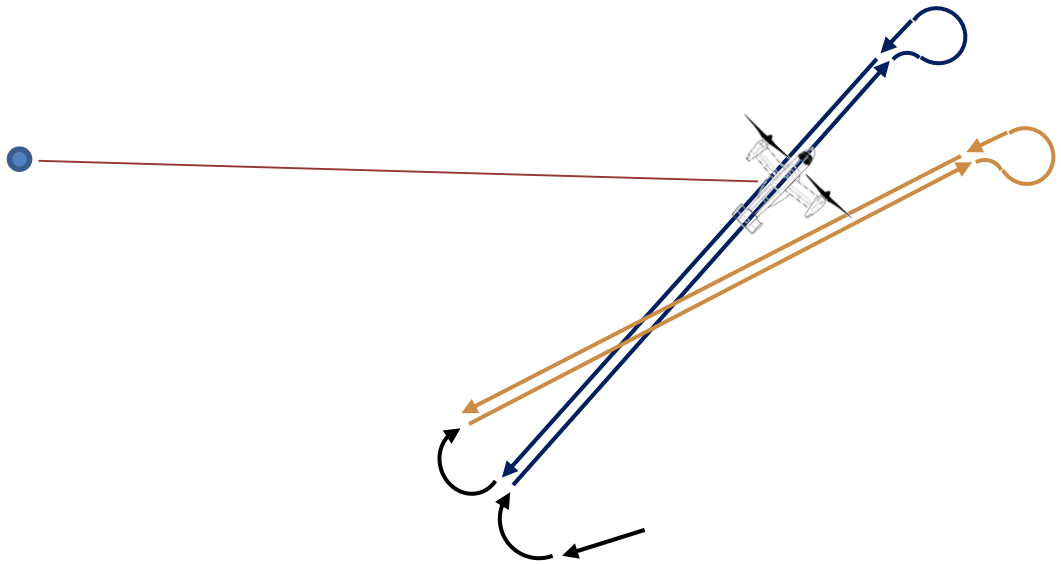
(All Depicted Data is Notional)

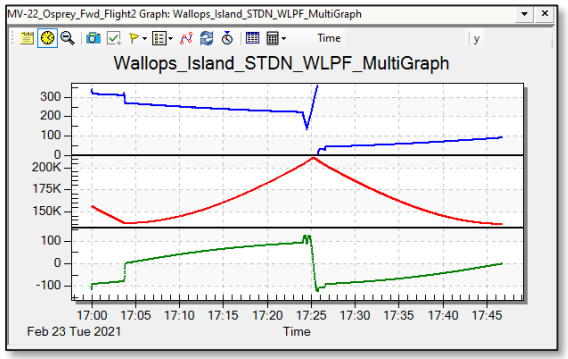
Real-Time Decision Support

Ground System Data Multi-Cast → UDP & Data Handler → Test Event Modeled Template

Real-time decision support





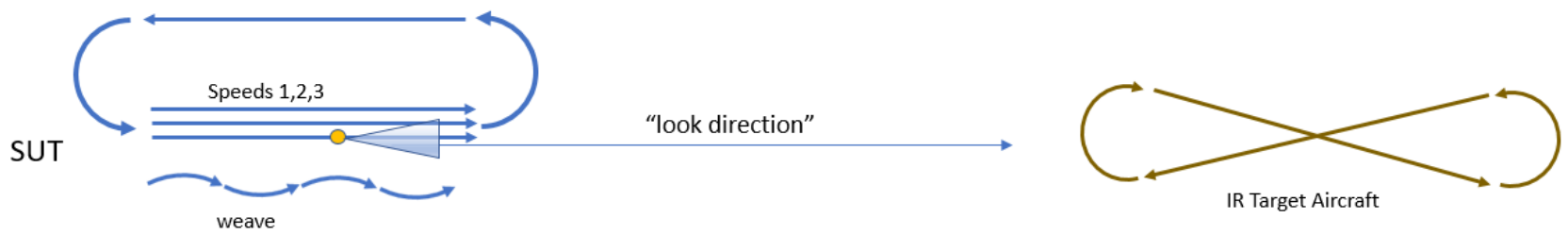


- ★ "Post-flight" anytime during test event
- ★ Enables coordination of re-do's during a run to capture "missed" test points

(All Depicted Data is Notional)

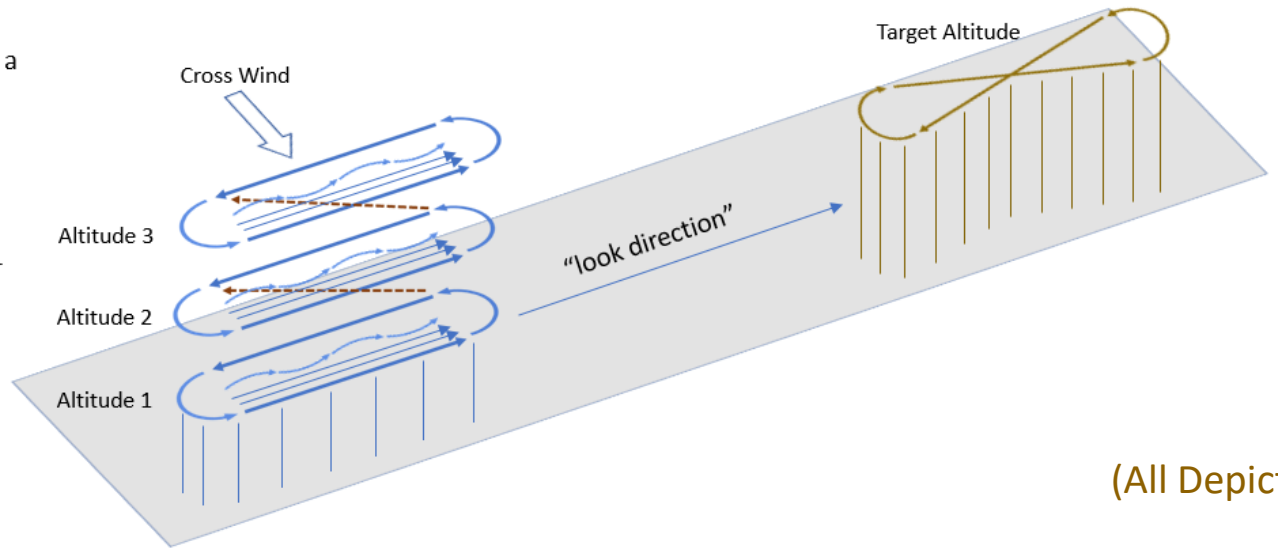
Notional Test Event Narrative Development

Notional IR Pod Test Vignette Narrative



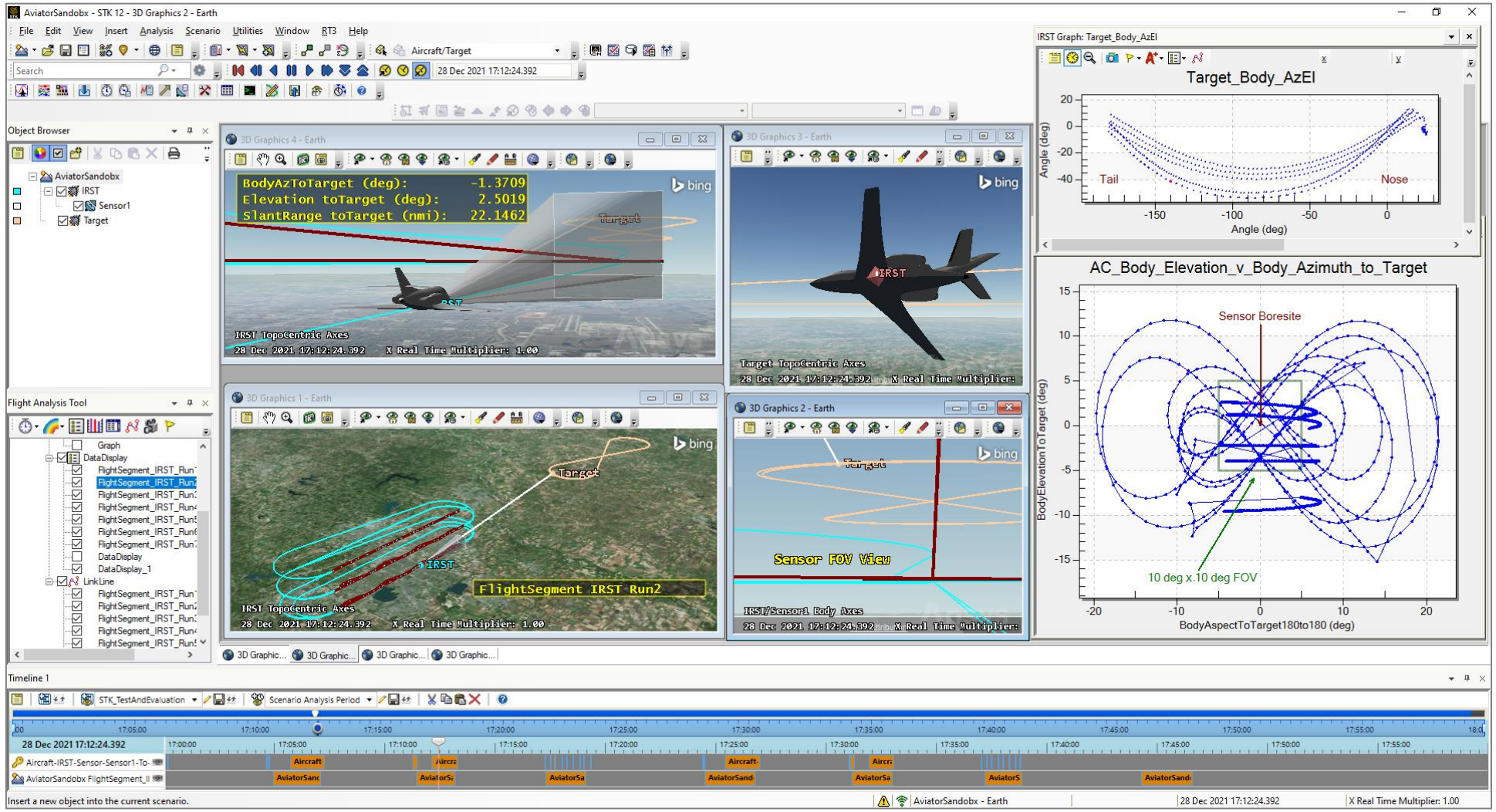
Repeat racetrack three times at each altitude with each cycle at a different speed in the direction to target.
Repeat one rev with a weave pattern

Cross wind added to affect side-slip



(All Depicted Data is Notional)

Example: Test Requirements Evaluation

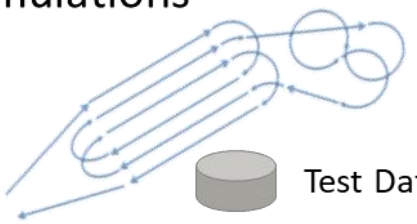


(All Depicted Data is Notional)

Post-Test Analysis & Verification

(All Depicted Data is Notional)

- Open Air Flight Tests
- T&E Labs Results
- Simulations



Test Data

Data to Simulated Objects Mappings

Typical Project Test Data Database with Metrics names index

0101 HDF

CSV

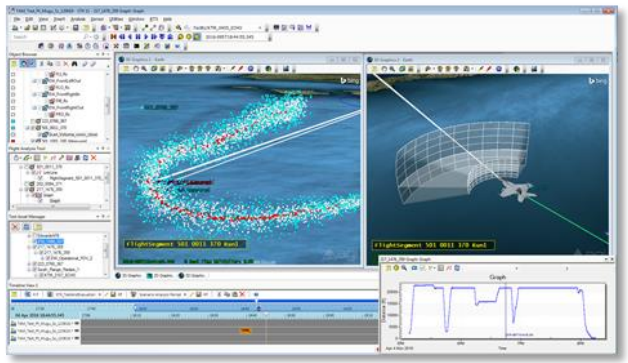
0101 .MAT

XLS

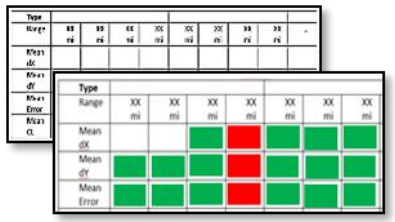
Data Importer

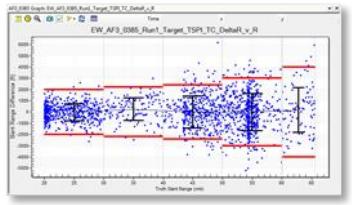
- Vehicles
  - .e, .a, covariance
- Vectors
- Scalars
- Sensor Volumes
- Tracks (pos, cov)
- ATC MTOs

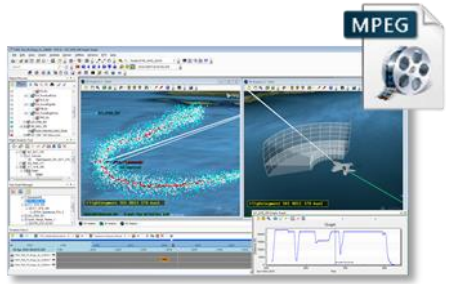
Modeled Elements



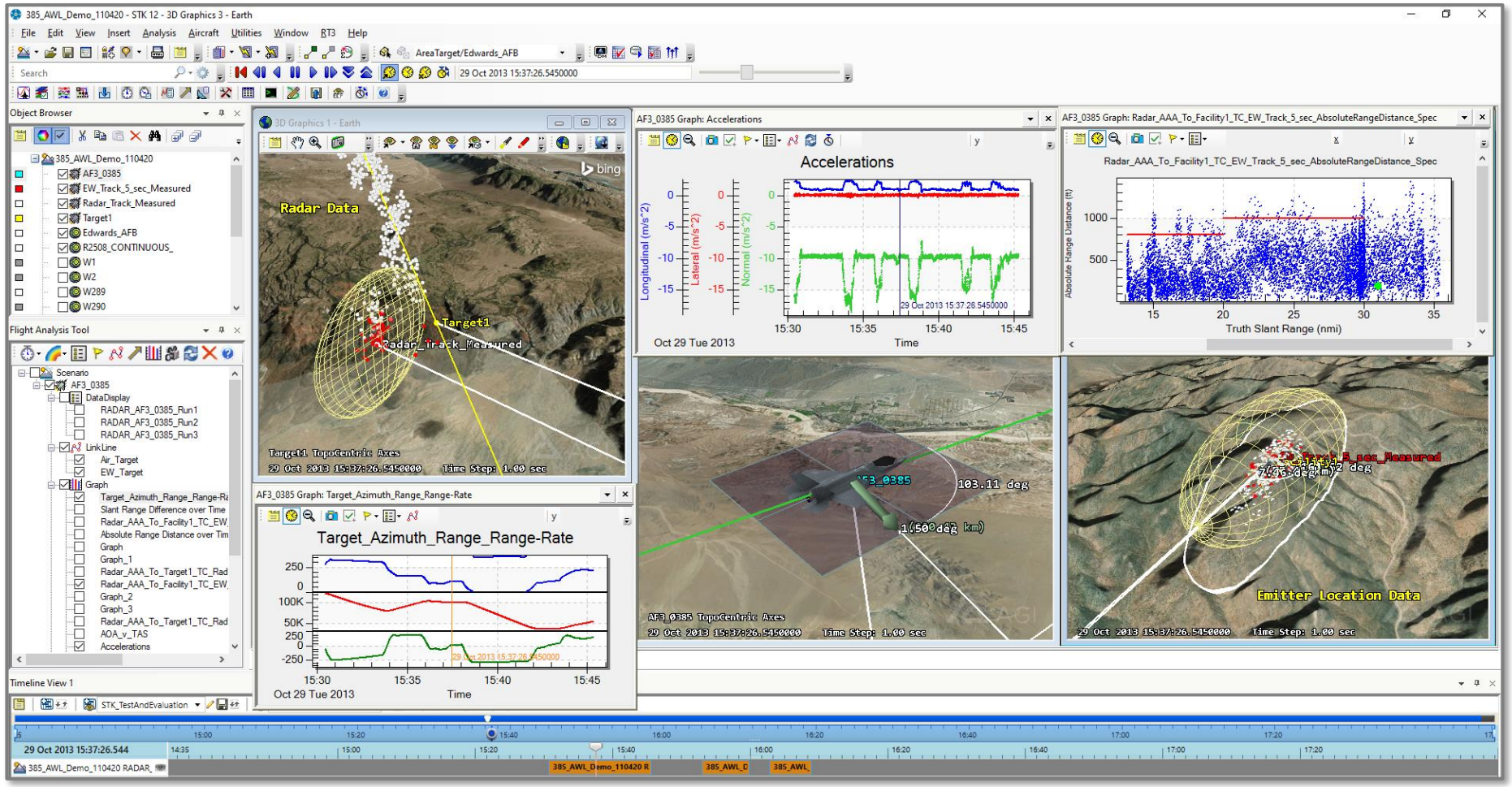
- Quick-look
- Flight reconstruction
- Track analysis
- Verification products
- Visualizations & Animations







More Inciteful Post-Flight Quick Looks



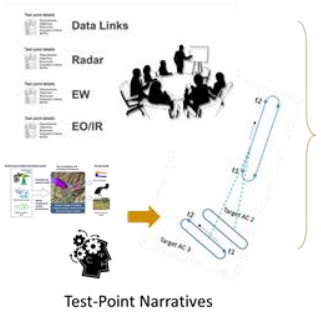
- “Richer” post-flight quick looks
- Immediate post-flight decision support
- Means to communicate key issues among various discipline stakeholders

(All Depicted Data is Notional)

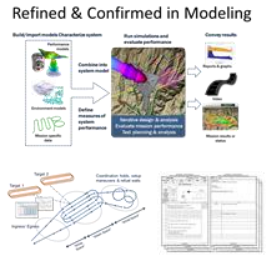
Benefits of Composable Modeling

- Efficiency of Test Team
- Efficiency & Effectiveness of Test Activity
- Communication among stakeholders
- Flight Safety

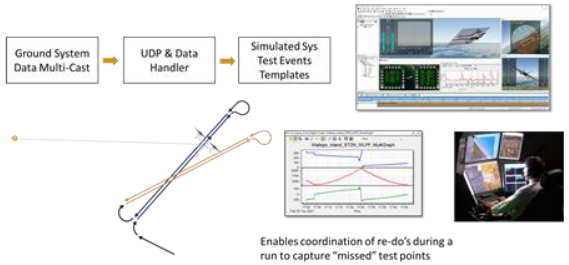
Test Point Narratives → **Detailed Test Planning – Test Cards** → **Test Execution** → **Post-Flight Quick-Look** → **Verification**



Test-Point Narratives



Increased Test-Point Density & Effectiveness



Enables coordination of re-do's during a run to capture "missed" test points

★ Increased Test-Point Density

★ Improved Re-Fly Rate

★ Saved Test-Points

★ Faster and More Informative Quick-Looks

★ Quicker Feedback Loop with Planning, Engineering & Software Dev

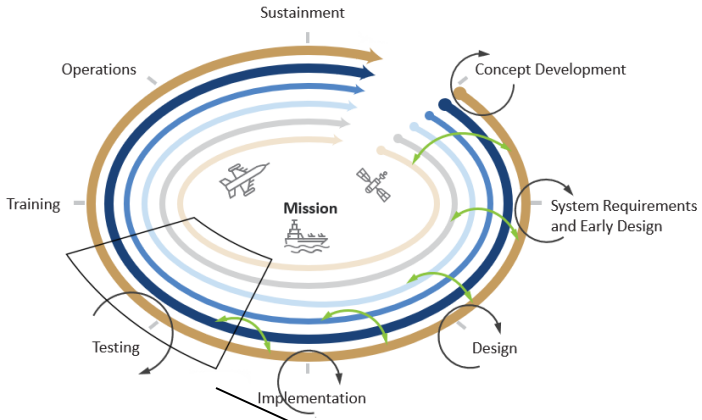
★ Test personnel efficiency

★ Flight Safety

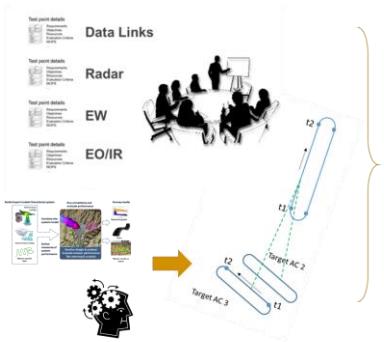
(All Depicted Data is Notional)

Application Throughout Program Life Cycle

(All Depicted Data is Notional)

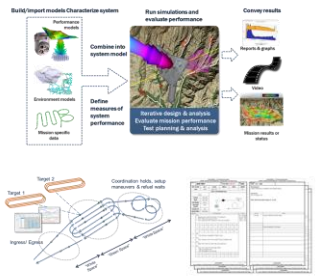


Test Designs → **Live Systems Flight Tests** → Post Analysis



Test-Point Narratives

Refined & Confirmed in Modeling



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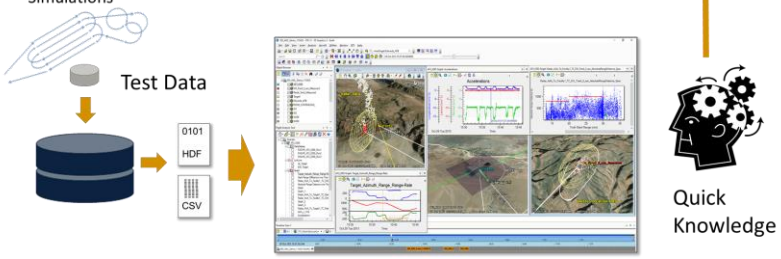
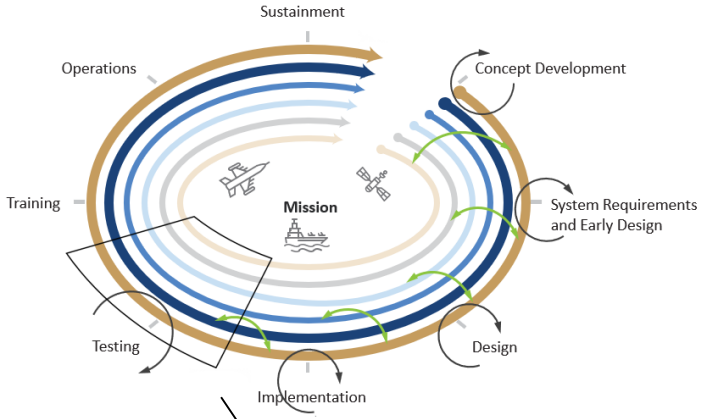
- Simulations

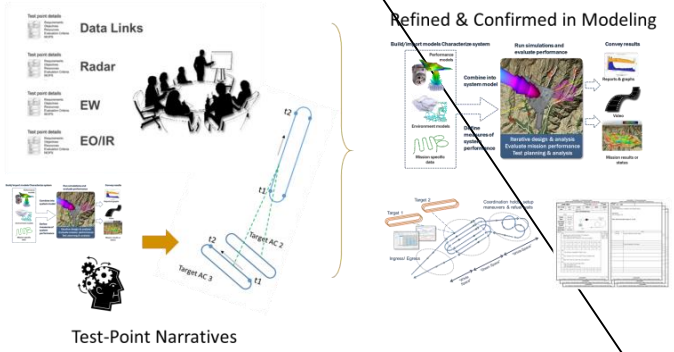


Quick Knowledge

Application Throughout Program Life Cycle

(All Depicted Data is Notional)



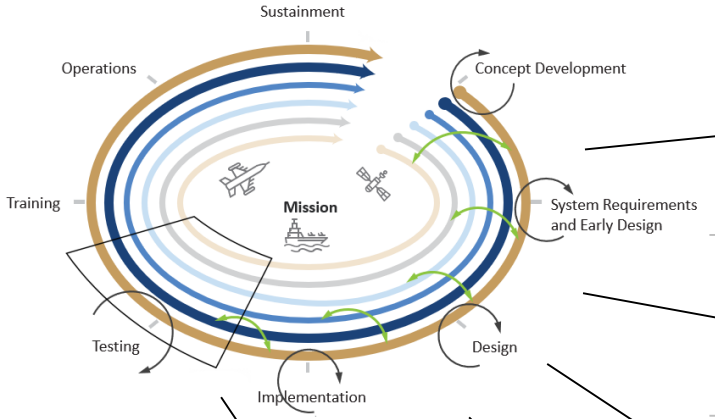


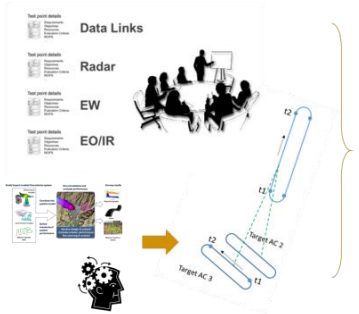
Test Designs → **Live Systems Flight Tests** → Post Analysis

Flight

Application Throughout Program Life Cycle

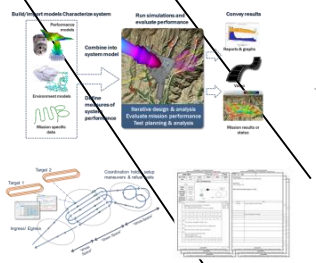
(All Depicted Data is Notional)





Test-Point Narratives

Refined & Confirmed in Modeling



Test Designs	**AOA M&S Simulations**	Post Analysis	Sim
Test Designs	**Systems Design M&S Simulations**	Post Analysis	Sim
Test Designs	**Component HWIL Lab Test**	Post Analysis	Lab
Test Designs	**Full System SIL – LVC – Lab Test**	Post Analysis	Lab
Test Designs	**Sys on Surrogate Platforms Tests**	Post Analysis	Flight
Test Designs	**Live Systems Flight Tests**	Post Analysis	Flight

Concluding Remarks

- Modern COTS composable physics-based engineering tools are available and quickly configurable for ad hoc use to great effect
- Application to “Execution Phase Test” can occur long before full lifecycle application of Digital Engineering in major programs
- Can provide a dramatic effect on efficiency and effectiveness of test execution planning and analysis operations
- Provides for T&E workforce development in advance and in preparation of full DE transformation

27th Annual Systems & Mission Engineering Conference

Oct 28-31, 2024

MBT&E Instructed Composable Modeling Supporting T&E Execution Phase Planning & Analysis

GOVERNMENT INITIATIVES (AGI)

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