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Software for Space, Defense & Intelligence

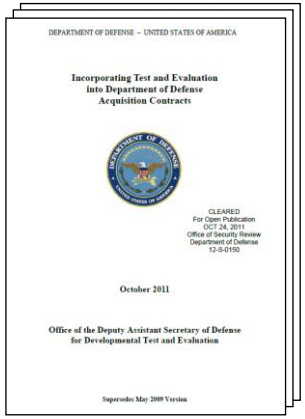
ITEA Conference - 2013

Leveraging M&S Tools for Rigorous Test Designs

Nov 12, 2013

DOD, AT&L, DTE, DOT&E Policy Directives

- **Current mandates from offices of: DOT&E & DT&E/TRMC**
  - Smarter Test Planning methods - Scientific Test and Analysis Techniques (STAT)
    - Design of Experiments
    - Other M&S and Statistical based methods
  - DAG directed use of M&S in T&E
  - Initiatives to push OT and DT considerations to the beginning stages of systems requirements development
  - Initiatives to perform OT as early in the DT cycle as possible
  - TRMC initiative - Identify high-payoff areas for potential savings


DEPARTMENT OF DEFENSE – UNITED STATES OF AMERICA

Incorporating Test and Evaluation into Department of Defense Acquisition Contracts

CLEARED
For Open Publication
OCT 24, 2011
Office of Security Review
Department of Defense
12-S-0150

October 2011

Office of the Deputy Assistant Secretary of Defense for Developmental Test and Evaluation

Supersedes May 2009 Version

DoDI 5000.2

DoDI5000.2; Enclosure 5

- **E5.1** - The PM, in concert with the user and test and evaluation communities, shall coordinate developmental test and evaluation (DT&E), operational test and evaluation (OT&E), LFT&E, family-of-systems interoperability testing, information assurance testing, and modeling and simulation (M&S) activities, into an efficient continuum, closely integrated with requirements definition and systems design and development. The T&E strategy shall provide information about risk and risk mitigation, provide empirical data to validate models and simulations, evaluate technical performance and system maturity, and determine whether systems are operationally effective, suitable, and survivable against the threat detailed in the System Threat Assessment.
- Adequate time and resources shall be planned to support pre-test predictions and post-test reconciliation of models and test results, for all major test events.
- **E5.3.1** - Projects that undergo a Milestone A decision shall have a T&E strategy that shall primarily address M&S, including identifying and managing the associated risk, and that shall evaluate system concepts against mission requirements.
- **E5.4.7** - Appropriate use of accredited models and simulation shall support DT&E, IOT&E, and LFT&E.

DAG – Chap 9 – T&E

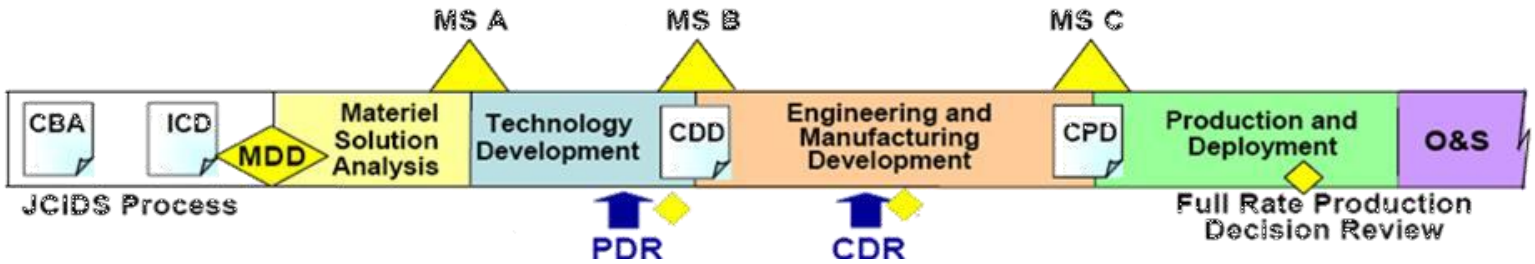
- **From Defense Acquisition Guidebook – Chapter 9 – Test & Evaluation – May 2010**
  - For T&E, the appropriate application of M&S is an essential tool in achieving both an effective and efficient T&E program.
  - T&E is conducted in a continuum of live, virtual, and constructive environments.
  - DoD Components have guidelines for use of M&S in acquisition, especially T&E. These guidelines are intended to supplement other such resources.
  - The program manager should have an M&S subgroup to the T&E Working-level Integrated Product Team (T&E WIPT) that develops the program's M&S strategy that should be documented in the program's Systems Engineering Plan and the Test and Evaluation Strategy/ Test and Evaluation Master Plan. Some DoD components require planning for M&S to be documented in a separate M&S Support Plan.
  - This M&S strategy will be the basis for program investments in M&S.
  - M&S should be planned for utility across the program's life cycle, modified and updated as required to ensure utility as well as applicability to all increments of an evolutionary acquisition strategy.
  - A program's T&E strategy should leverage the advantages of M&S.
  - M&S planning should address which of many possible uses of M&S the program plans to execute in support of T&E.
  - Models and simulations can be used in planning to identify high-payoff areas in which to apply scarce test resources.
  - Rehearsals using M&S can help identify cost effective test scenarios and reduce risk of failure.
  - During conduct of tests, M&S might provide adequate surrogates to provide stimulation when it is too impractical or too costly to use real world assets. This impracticality is particularly likely for capability testing or testing a system that is part of a system-of-systems, or for hazardous/dangerous tests or in extreme environments, or for testing the system's supportability.
  - M&S can be used in post-test analysis to help provide insight, and for interpolation or extrapolation of results to untested conditions.

DOT&E TEMP Guidebook

DOT&E TEMP Guidebook – Feb 27, 2012

- M&S for Test Planning, Pretest Predictions, and Evaluation - Guidance
  - The Modeling and Simulation (M&S) sections should address how M&S will be employed in the overall test strategy and how the M&S will be verified, validated and accredited (VV&A). Specifically, the TEMP should list any M&S expected to be used, the intended use, any data requirements, the test objectives to be addressed and/or how test scenarios will be supplemented with M&S, the planned VV&A effort, and who will conduct the VV&A effort (ref. DoDI 5000.61). The TEMP should list any specific test events required for VV&A of the M&S. The resources for the specific test events will be included in Part IV.
  - M&S is used throughout developmental, operational and live fire testing. M&S can support evaluation of requirements, trade studies, test planning, pre-test predictions, evaluation of system performance, and other uses. It includes a broad set of tools including spreadsheet models, high-fidelity digital models, and hardware and computer in the loop facilities.
  - M&S for Test Planning and Prediction
    - M&S is frequently used in test planning and pre-test predictions. If M&S will be used as a basis for decisions regarding test scope or test conditions, describe how it will be used. Which tests will have pre-test predictions? Which pre-test predictions will be based on M&S?
  - M&S for Evaluation
    - Another common intended use is that M&S can support the evaluation of system performance. The TEMP should describe how M&S will be used as a basis for evaluating any important system metrics and/or make significant contributions to the assessment of any Critical Operational Issues. Will M&S be used to supplement, interpolate, or extrapolate results from live testing? Briefly summarize the degree of reliance on M&S. Which evaluation issues will be addressed through M&S? Explain why M&S is being used (e.g., safety restrictions preclude testing).

Potential STAT in the Execution Phase



Planning

Test Planning

- Gross system trades
- Detailed system trades
- Process knowledge
- Selection of factors
- Sensitivity of factors
- Design of Experiments
- Other statistical methods

Execution

Detailed Test Planning

- Test-point requirements
- Test-point resources
- Route planning
- Sequencing and choreographing vehicles and resources

Test Execution

Post Test Analysis & Verification

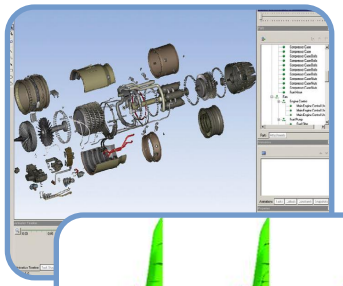
- Quick-look reconstruction
- Measures of performance assessment
- Test-point attainment verification
- Post-test data package visualization supplement

Execution Phase Challenges

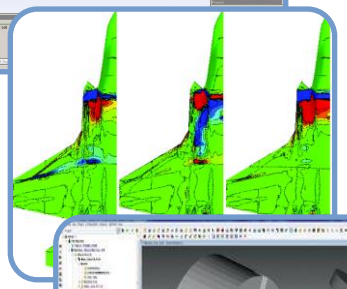
- Increasing complexity of mission systems
- Increasing mission software complexity
- Budget constraints (living with overruns to date)
- Low test-point density ?
- High re-fly rates ?
- Challenge of achieving test-point parallelization
- Challenge of communicating capability attainment along with test-point completion
- Post-test facing ever increasing data quantity
- Verification complexity

T&E Compared to Other Eng Disciplines

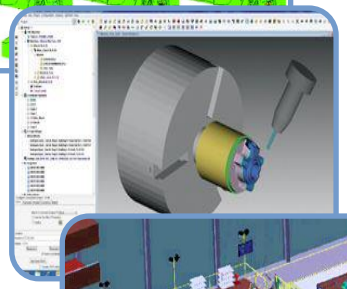
- **Product life-cycle & engineering disciplines taking advantage of well established computer aided engineering (CAE) methods**



Design



Analysis



Manufacturing

Assembly

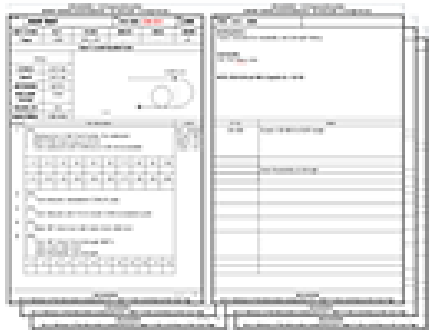
Training

Operations

Maintenance

T&E Execution Phase Detailed Planning Tools

- **Great opportunity in the T&E discipline to reap similar benefits by using CAE-like methods in test-event design, execution & post-flight analysis**



- **Traditional methods**
  - Excel
  - PowerPoint
  - Word
  - Custom MATLAB
  - “Planes-on-sticks”
  - “Flying wrist watches”

T&E Execution Phase Detailed Planning Tools

- **"Planes-on-a-stick" is a common method for detailed mission systems test plan route design**

Detailed Test Event Planning Considerations

- **Available aircraft & condition of systems**
- **Readiness of software block version**
- **Sequencing of subsystem tests for parallelization**
  - Modes, targets, emitters, integrated operation, …
- **Choreographing of multiple aircraft tests**
  - Aircraft, targets, emitters, operating conditions
- **Sequencing to minimize fuel usage and tanker use**

Detailed Test Event Planning – closer look

Test Plans

Test-point details

Requirements
Objectives
Resources
Evaluation Criteria
MOPS
…

Test Cards

Test point details
Requirements
Objectives
Resources
Evaluation Criteria
MOPS
…

Test point details
Requirements
Objectives
Resources
Evaluation Criteria
MOPS
…

Test point details
Requirements
Objectives
Resources
Evaluation Criteria
MOPS
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Test point details
Requirements
Objectives
Resources
Evaluation Criteria
MOPS
…

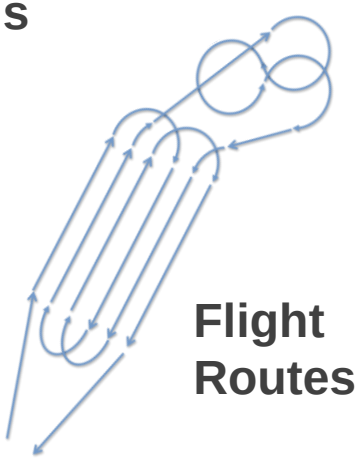
Data Links

Radar

EW

EO/IR

Mission Deck Test Cards



Flight Routes

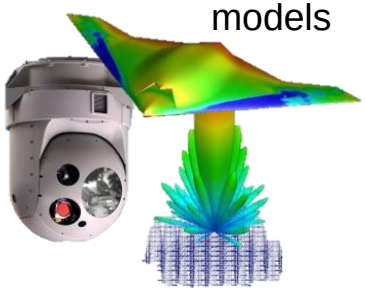
How can we:

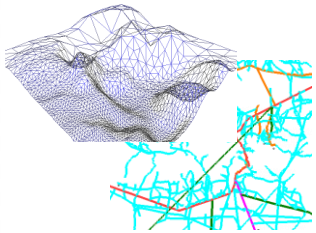
- Ensure test-point success?
- Fly more test-points per flight?
- Reduce planning cycle time?
- React quickly to evaluate anomalies?
- Capitalize on “white-space” effectively?
- Streamline communications?
- Reduce program test costs?

M&S for Interactive Detailed Test Design

Build/import models
Characterize system

Performance models





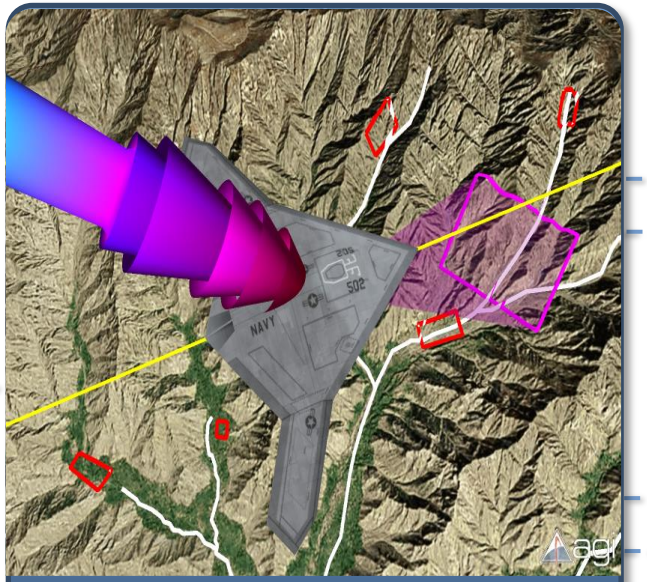
Environment models

Mission specific data

Combine into system model

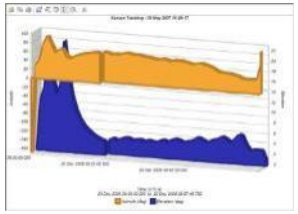
Define measures of mission effectiveness

Run simulations and evaluate performance

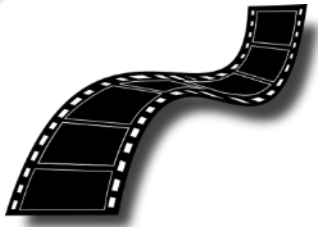


Iterative design & analysis
Evaluate mission performance
Test Planning

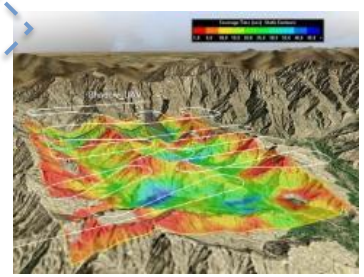
Convey results



Reports & graphs



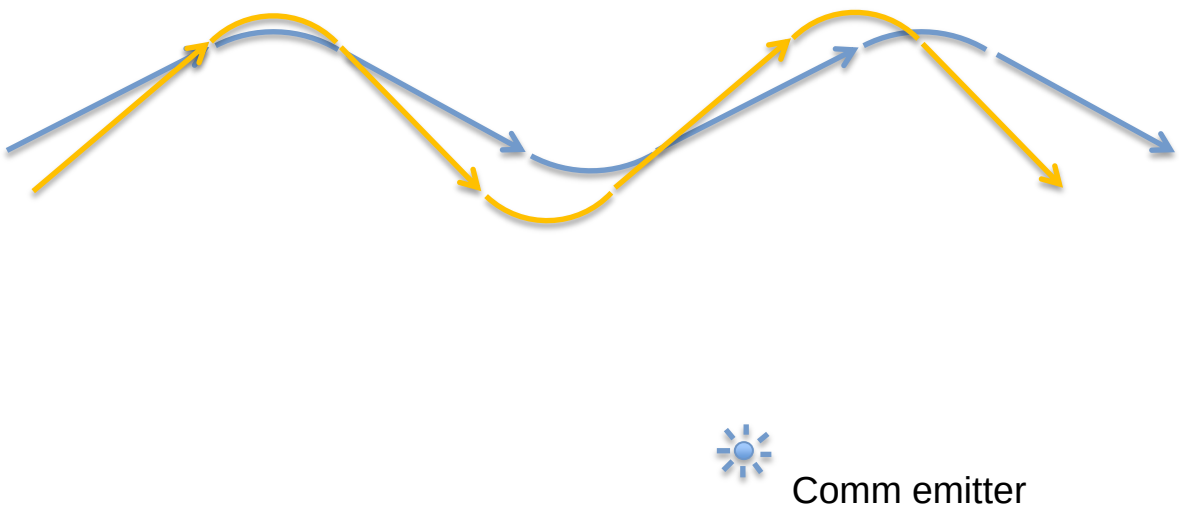
Video



Mission results or status

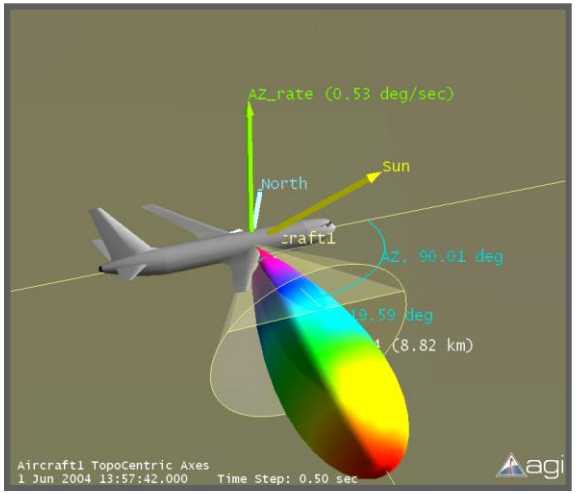
Test Event Route Assessment

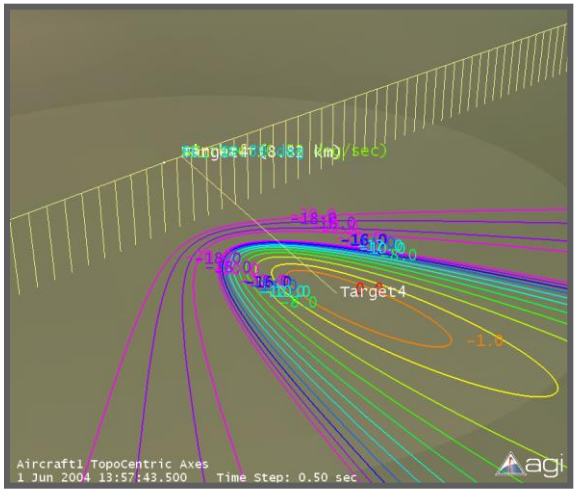
- **Which route is “better” ?**



Predictive Computation

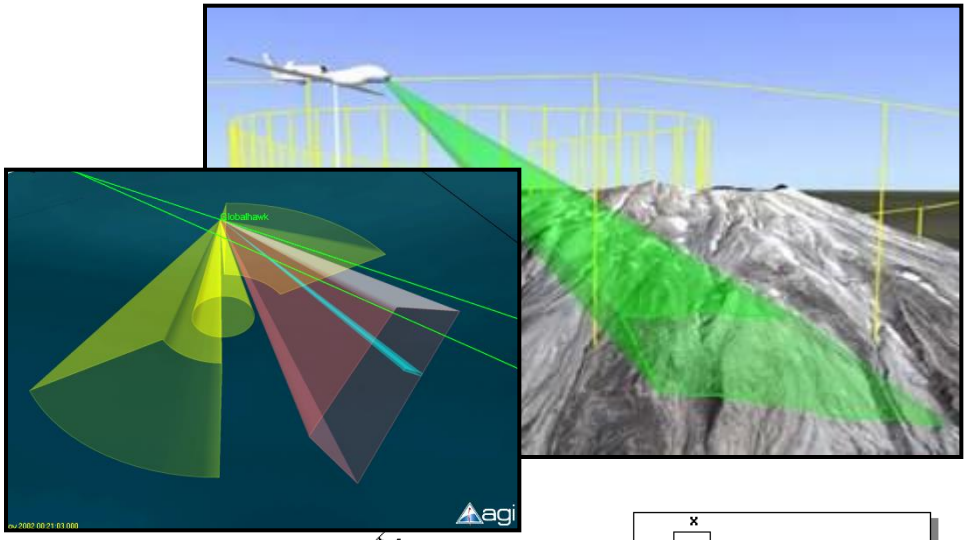
- **Determine values of, and "constraint" satisfaction time periods that meet mission objectives**
  - Geometric
  - Proximity
  - Pointing
  - Lighting
  - Line-of-sight atmospheric conditions
  - Inter-object geometry
  - Comm link quality, Jamming values
  - Radar performance measures
  - Terrain vertical profile
  - GPS DOP and Nav accuracy prediction

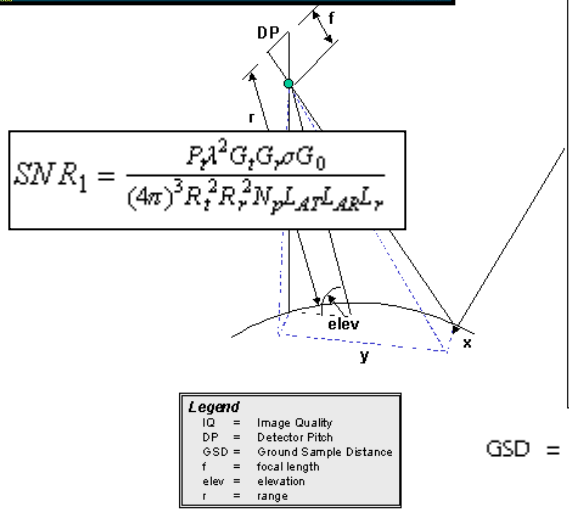


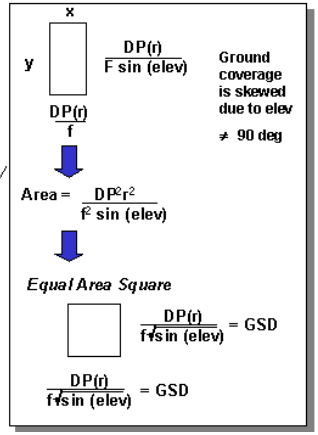


Virtual Sensors Modeling

- **What can your systems see?**
  - Dynamic environment
  - Number/type of platforms
  - Number/type of sensors
  - Target constraints
    - Terrain
    - RCS
- **Complex detection**
  - Visual
  - IR (GSD)
  - RF
  - Search/Track Radar
  - Synthetic Aperture Radar (SAR)
  - GMTI (flexible constraints)
- **Use the right sensor for the mission**



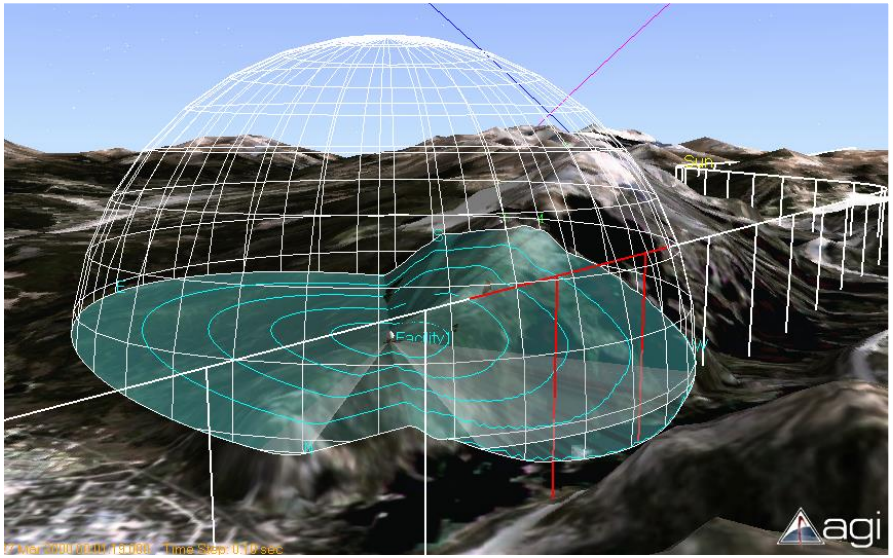


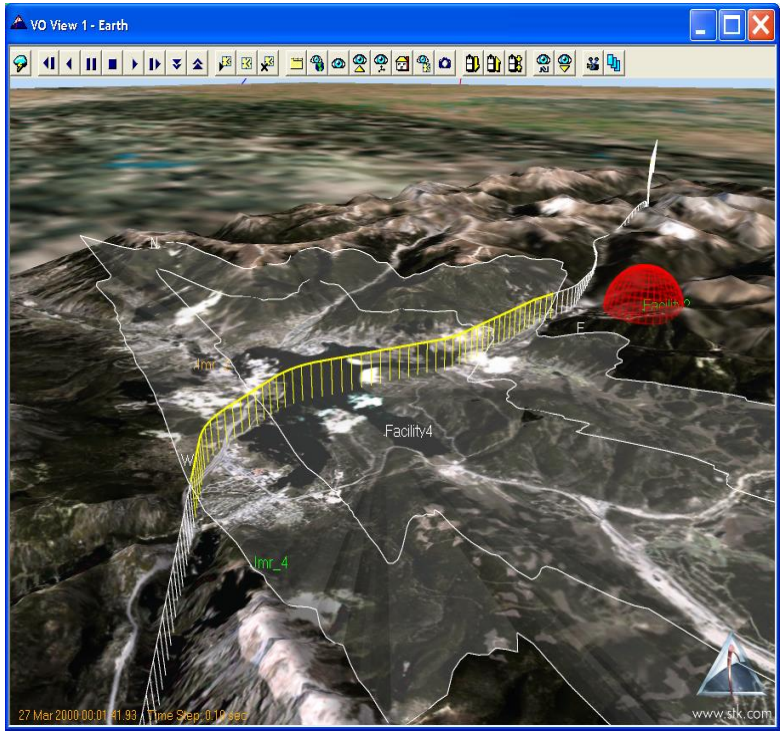


$$GSD = \frac{(\text{detector pitch})(\text{range})}{(\text{focal length})\sqrt{\sin(\text{elevation})}}$$

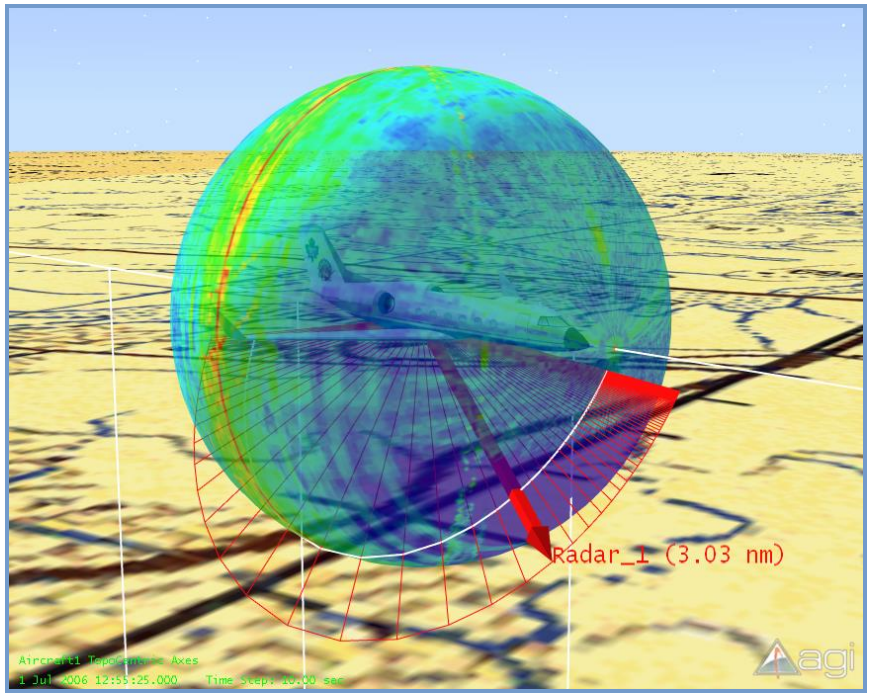
Terrain analysis

- **AzEl Terrain masking (to range, to altitude)**
  - Colorize flight paths within view of detection mask

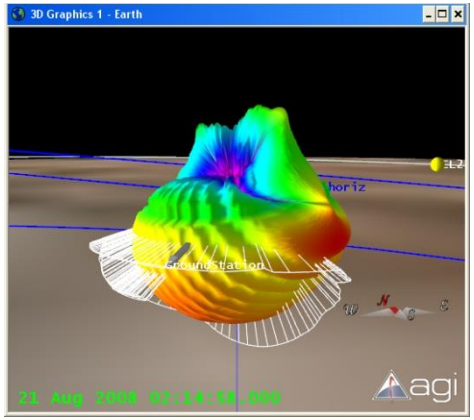




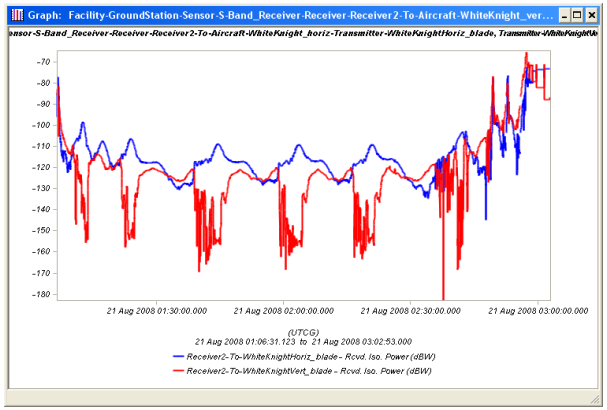
Radar to RCS signature planning



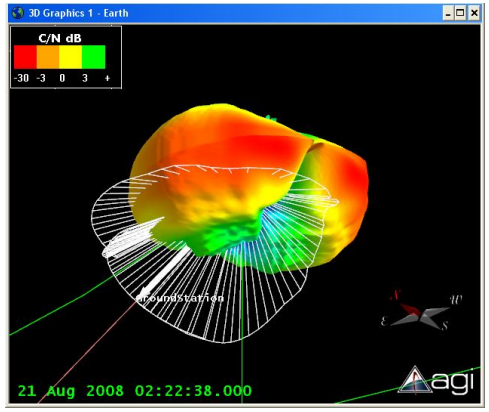
Communications Link Modeling



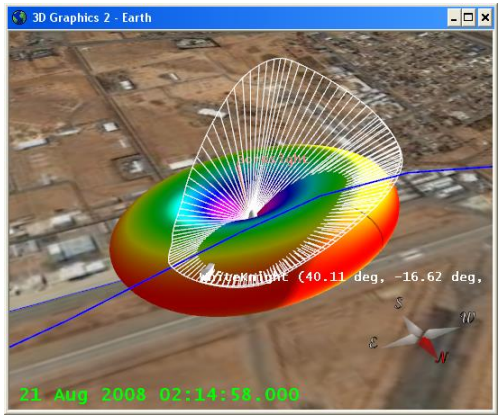
Horizontal Polarization



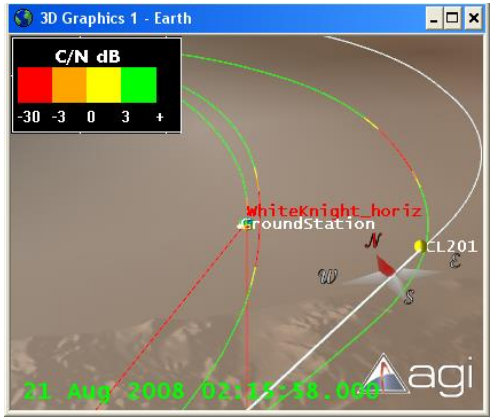
C/N Plot – Horiz & Vert



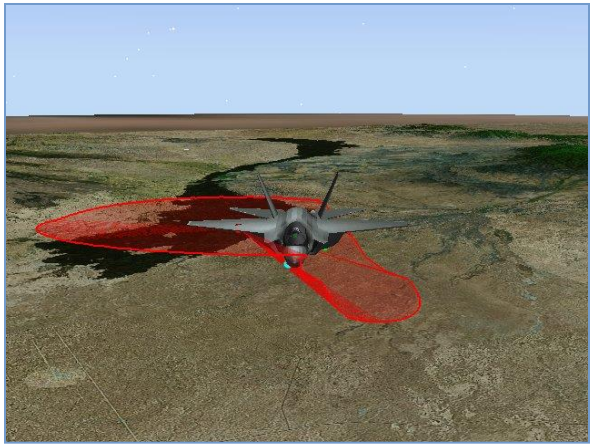
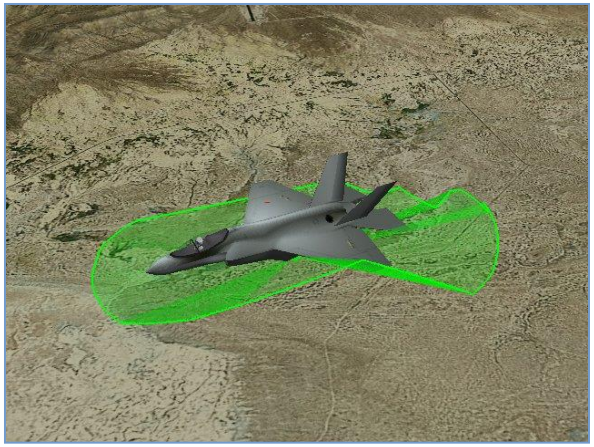
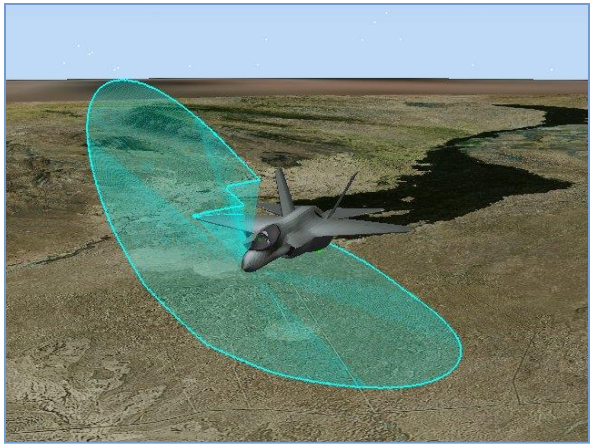
Vertical Polarization

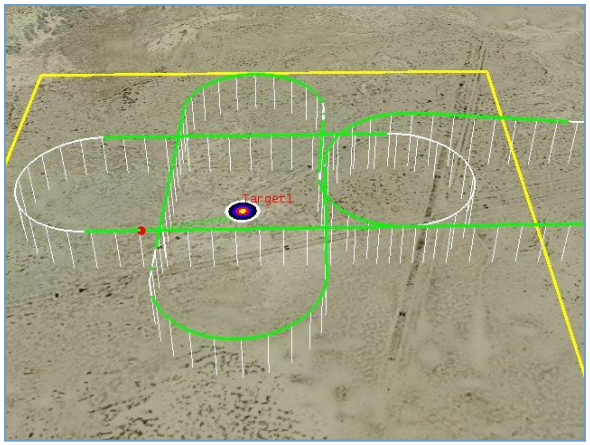


Ground Omni



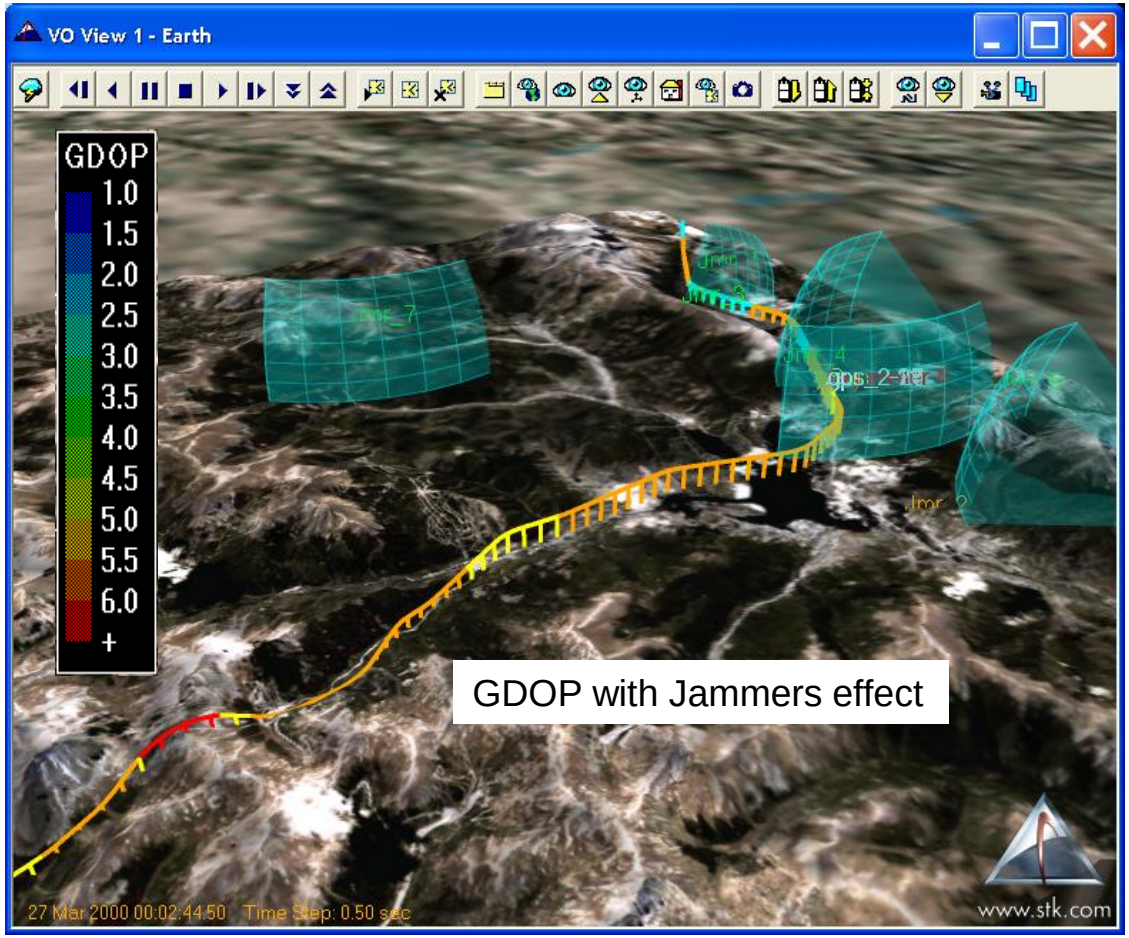
Payload/Sensors Design

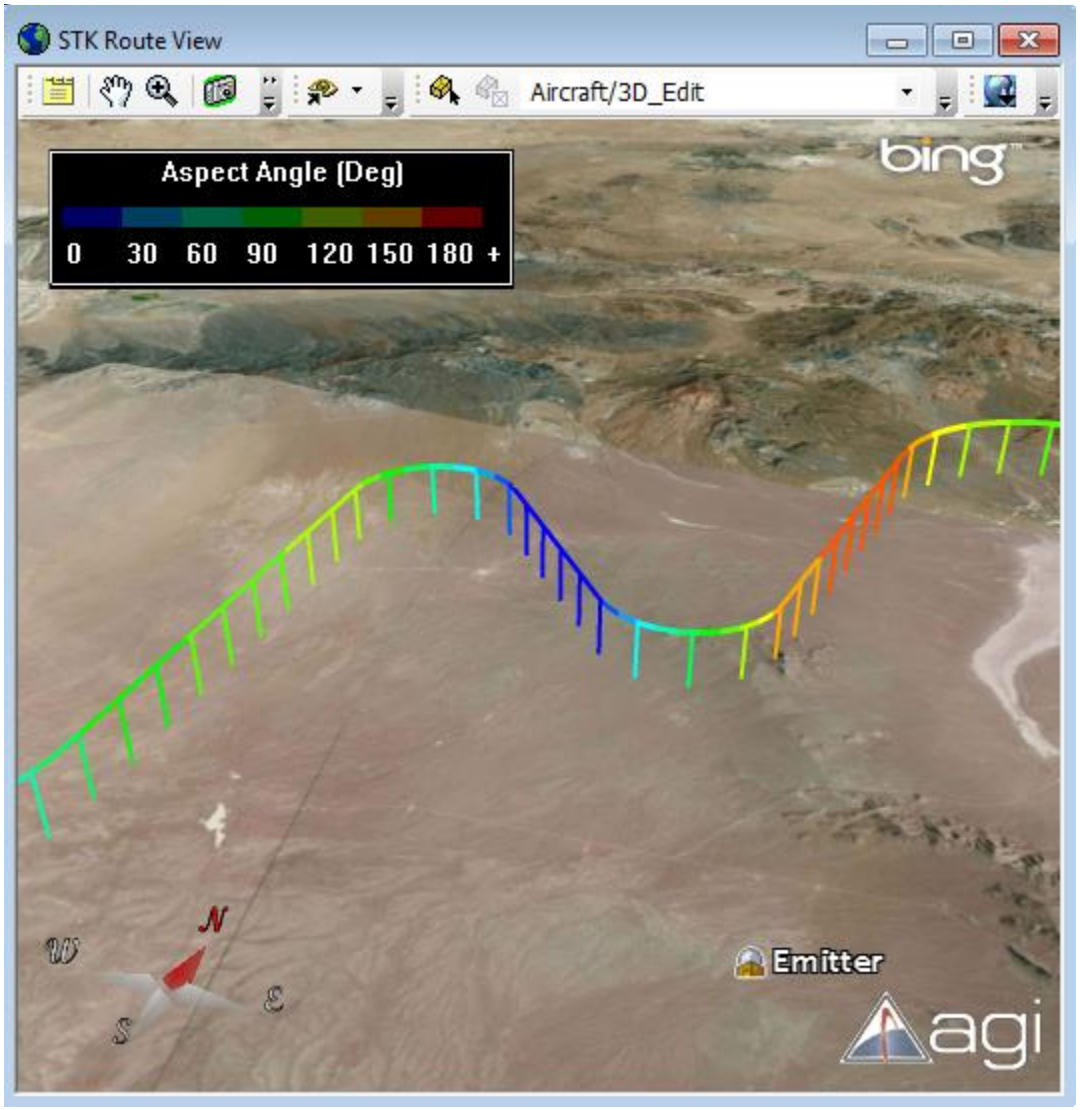
Test Event Route Assessment

- **Colorized flight paths based on simulated results**
  - Inter-visibility conditions
  - Sensor conditions
  - GPS navigation accuracy
  - Proximity conditions
  - Radar performance
  - Comm link conditions
  - Flight performance conditions
  - Fuel remaining

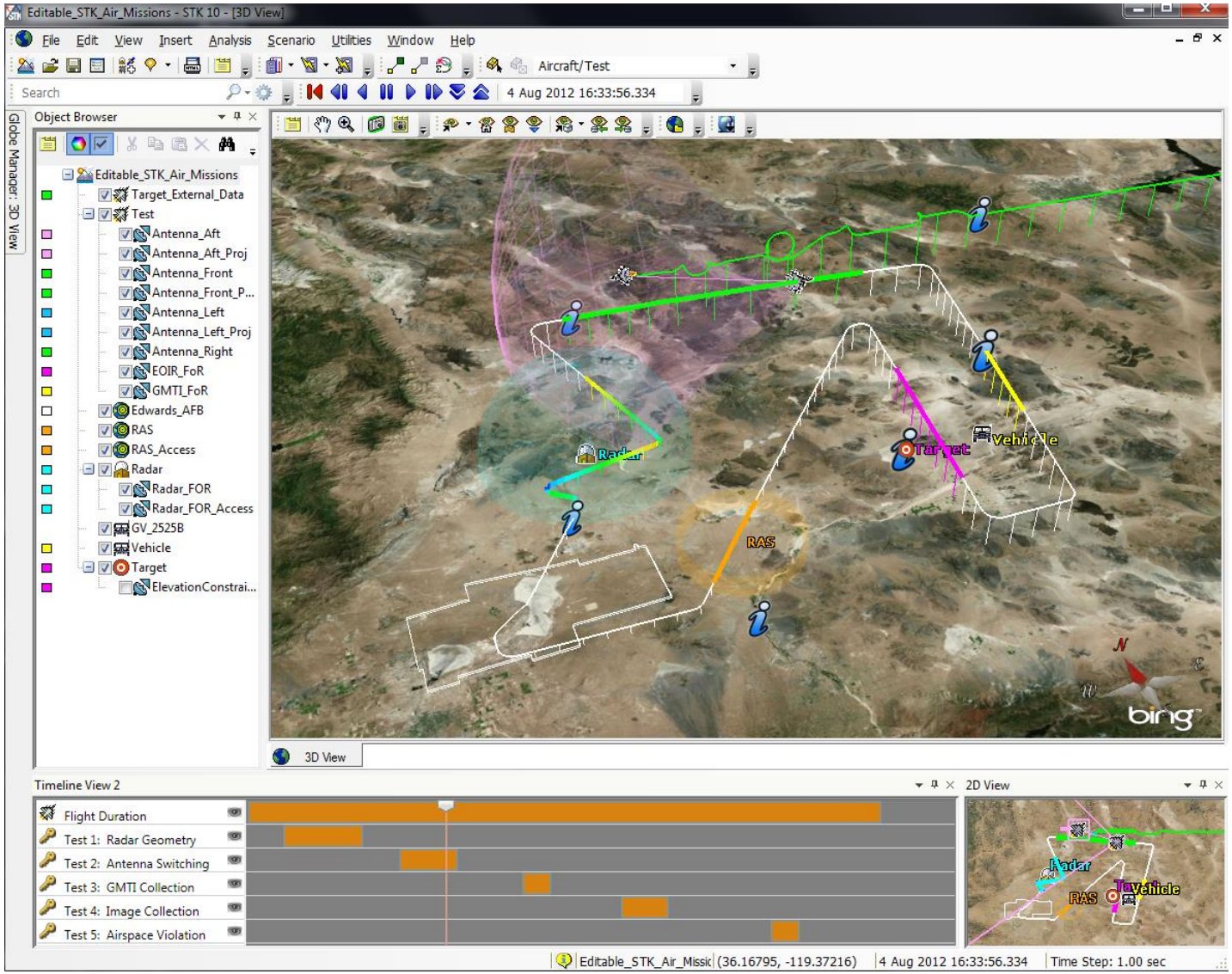


Test Event Route Assessment

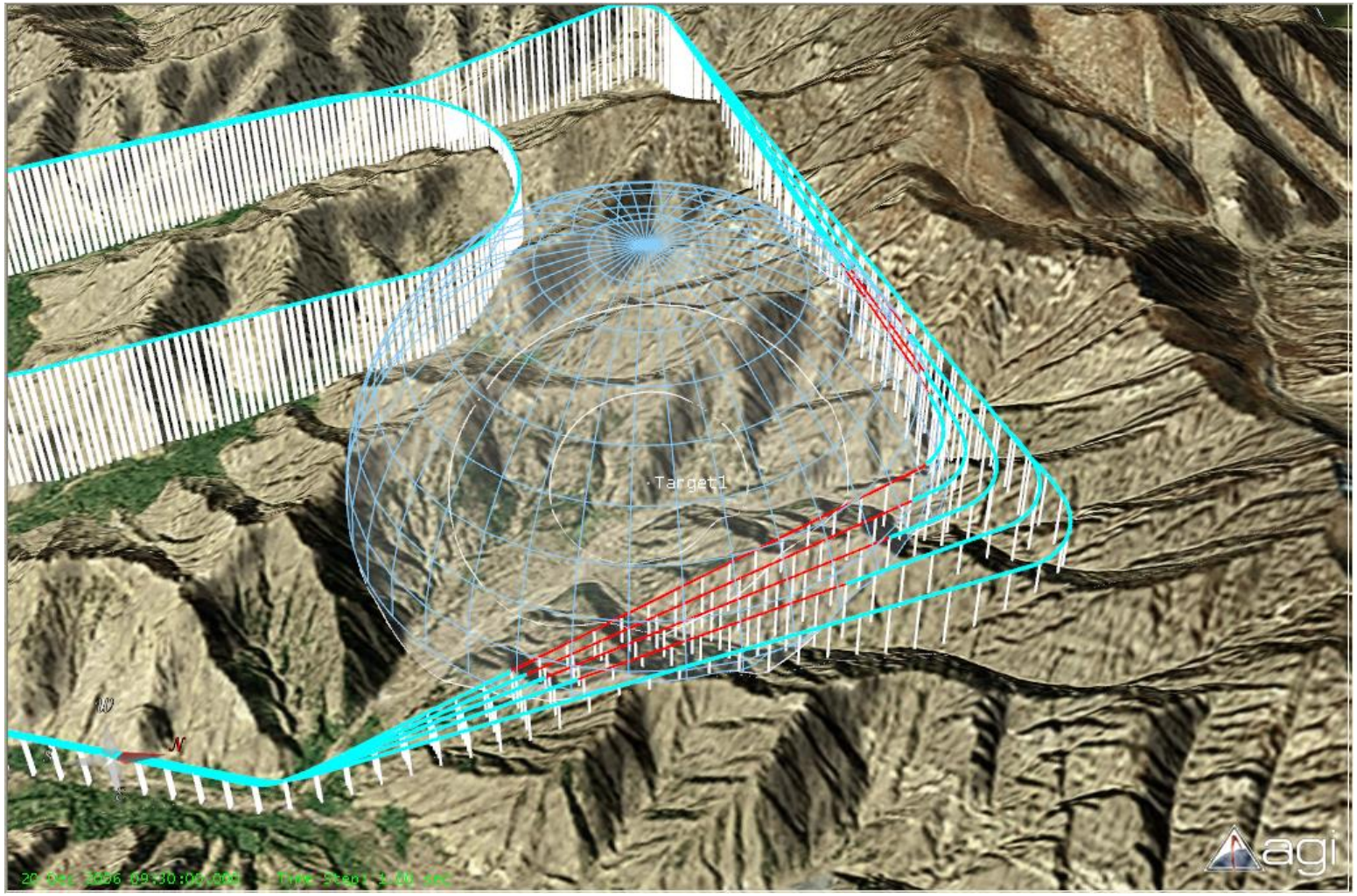
- **Interactive route design**
  - Fuel remaining
  - Aspect angle
  - Comm performance
  - Telemetry assurance
  - Dynamic geometry
  - Lighting directionality
  - RF directionality
  - Safety of flight
  - Multi-ship choreographing
  - Number of test-points



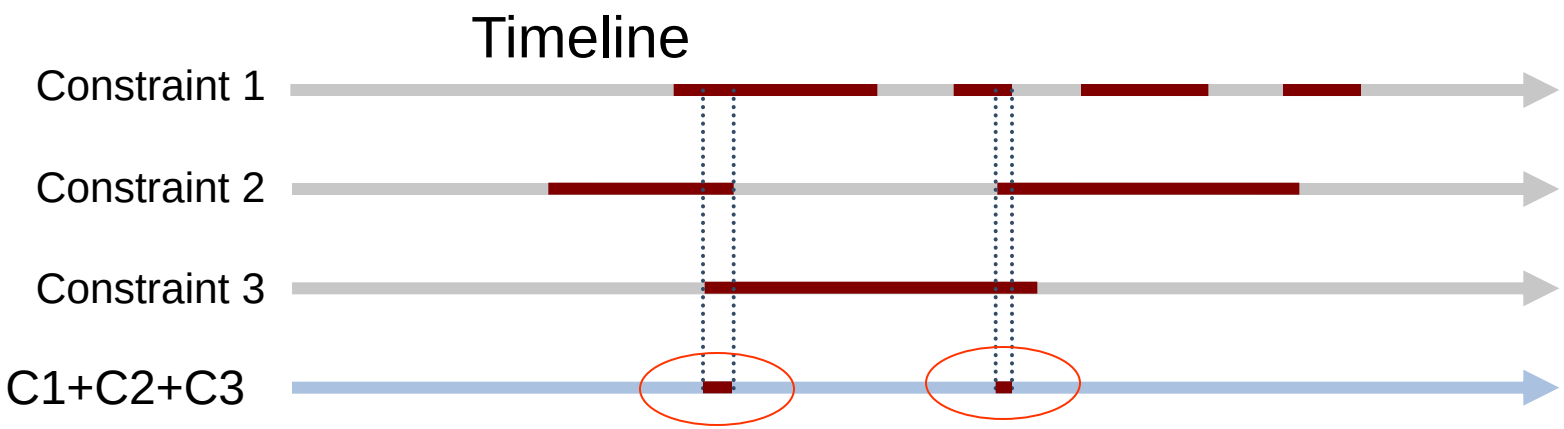
Demonstration – Interactive Route Design



Route Design / Optimization

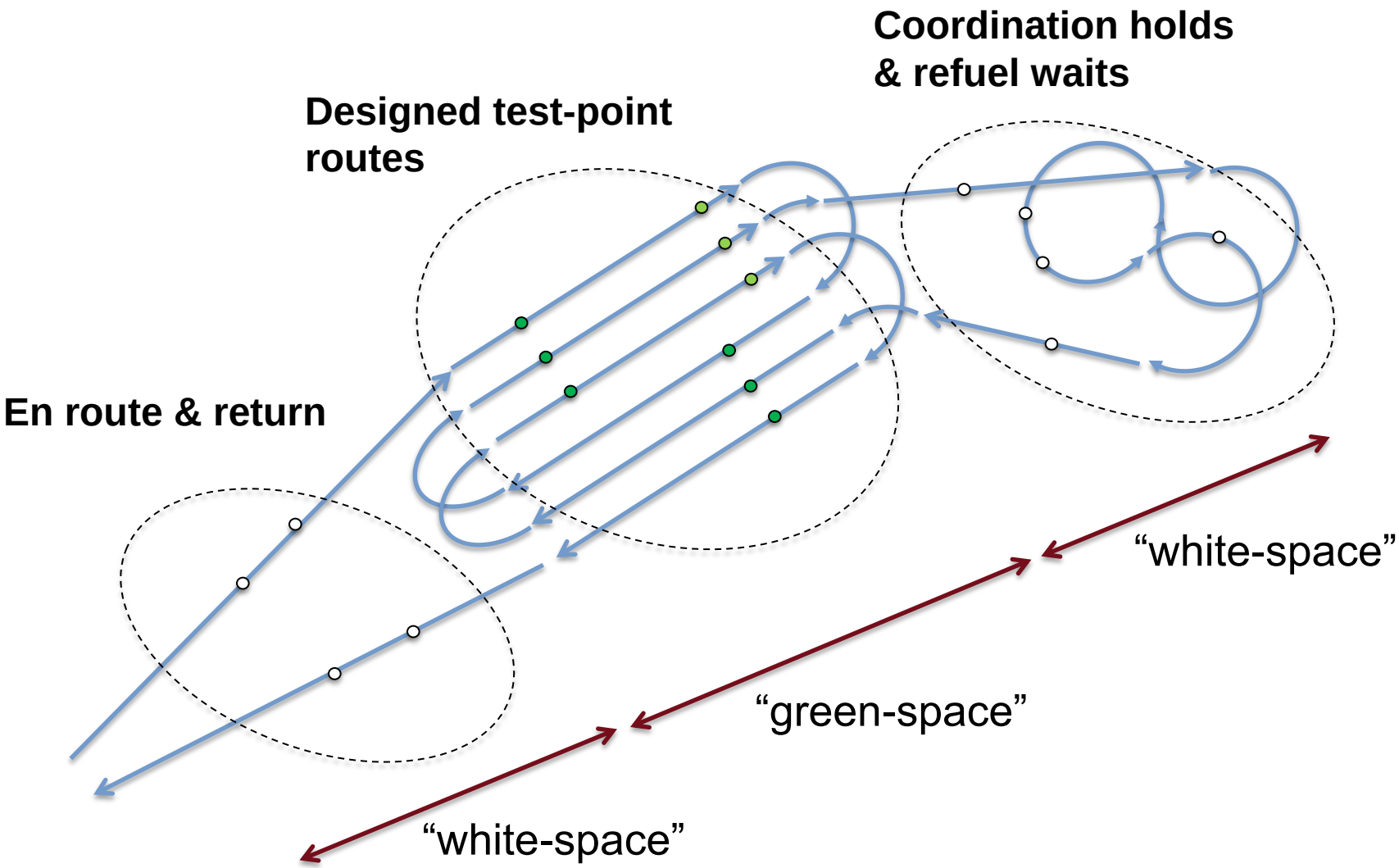


Multi-Constraint Prediction



- **Determination of "multi-constraint" satisfaction times**

Increasing Test-point Density per Flight

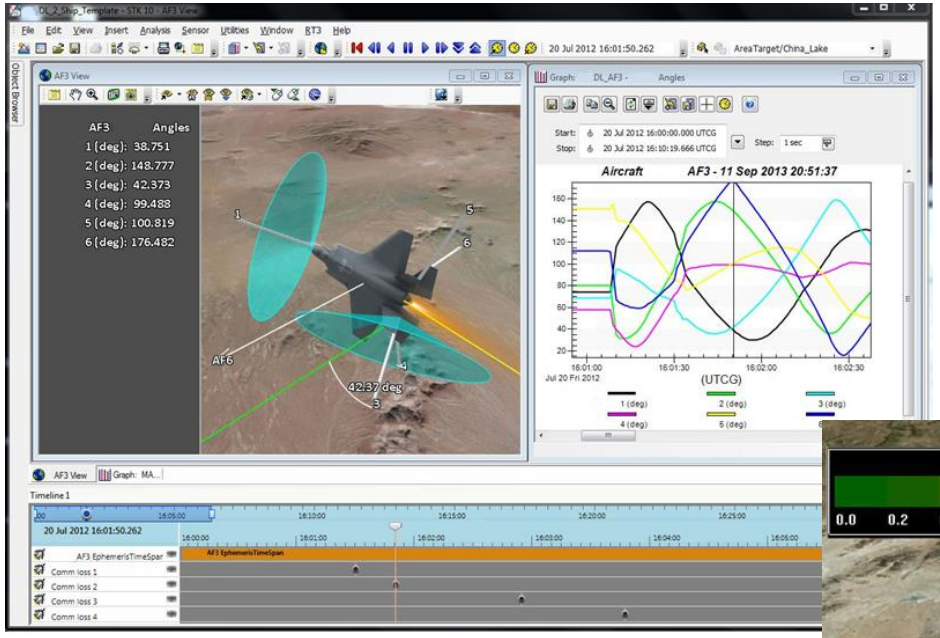


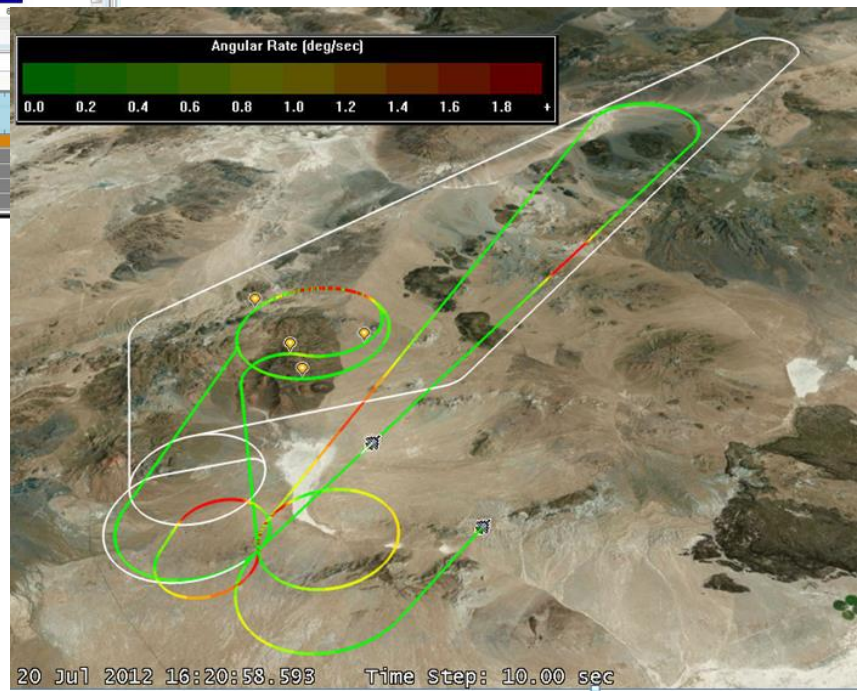
Post-Flight Analysis

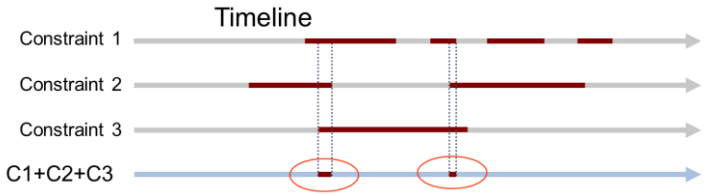
- **Quick import of telemetry data**
- **Colorized routes based on:**
  - Various operating parameters
  - Various performance parameters
  - AGI generated analytical parameters
  - Events
- **Markers on routes or ground (static and time-based)**
- **Supplemental composable routes to assess variations on effectiveness**
- **Analytically derived supplemental visual aides**
  - Vectors, angles, range lines, head-up data displays, parameter graphs
- **Flight playback (quick forward/reverse scroll)**

Post-Flight Analysis

All notional depictions on this slide







How? - When? - How Hard? - How much? - Why?

- How do you do this?
- Is it too late for my program to do this?
- How much time does this take?
- How detailed do my models need to be?
- What is the implementation cost?
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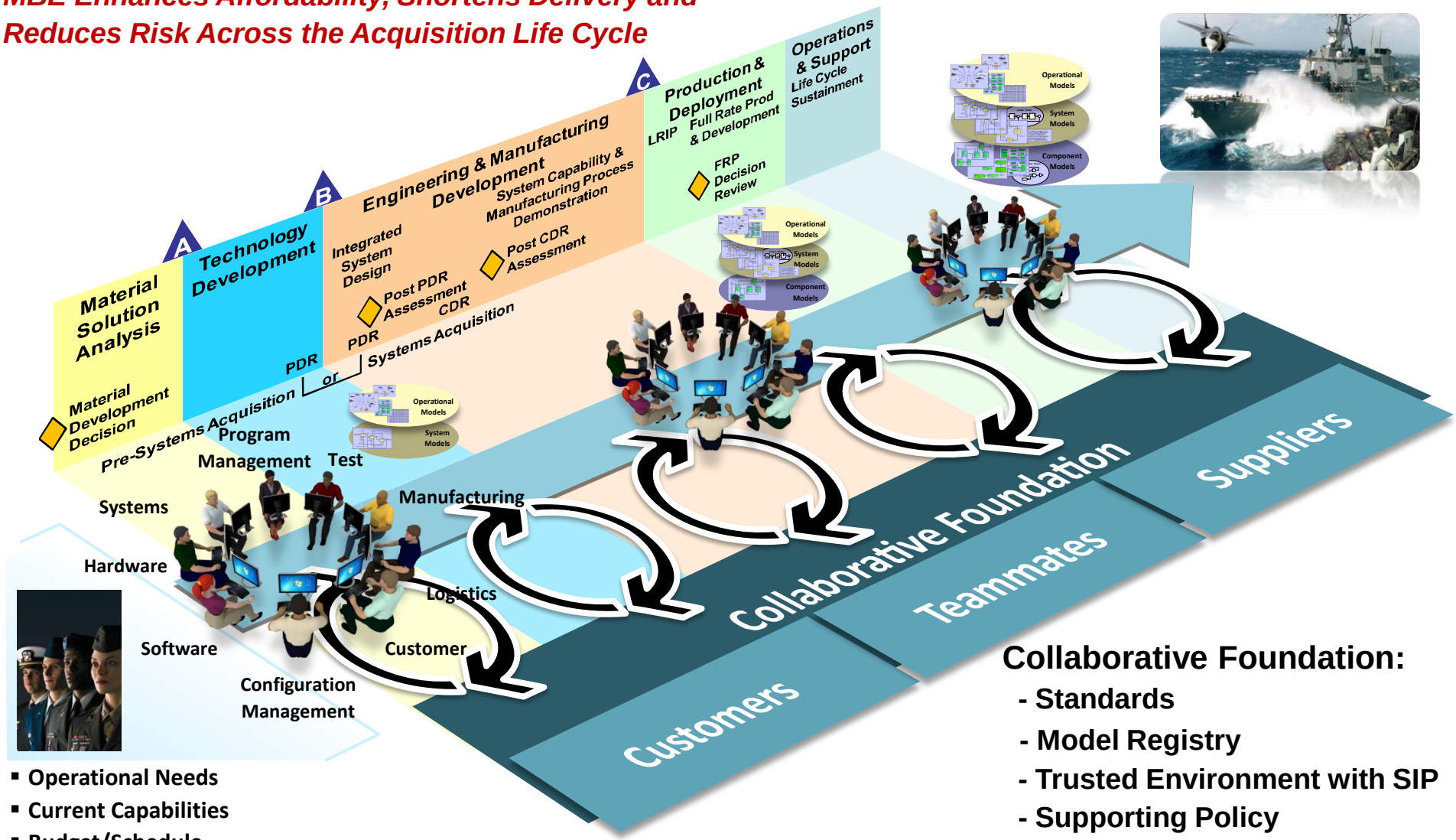
MBE To-Be State

MBE Enhances Affordability, Shortens Delivery and Reduces Risk Across the Acquisition Life Cycle

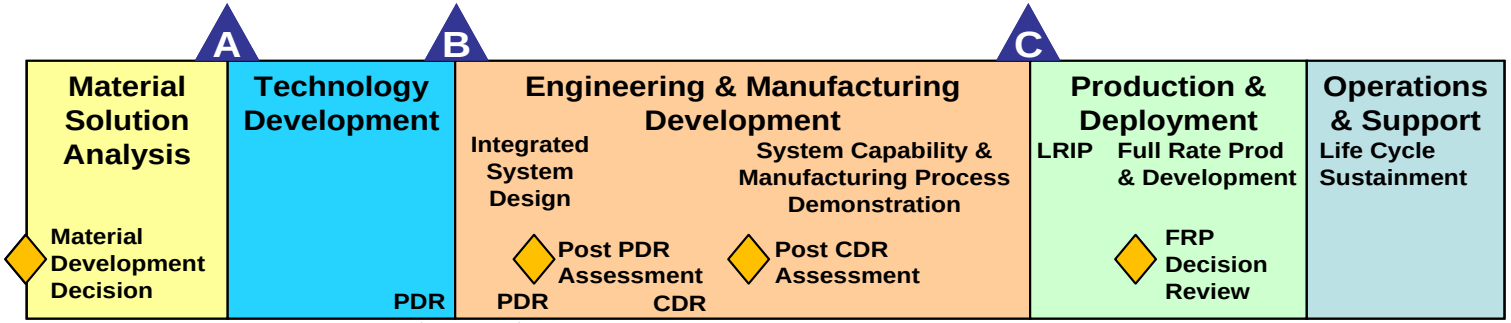


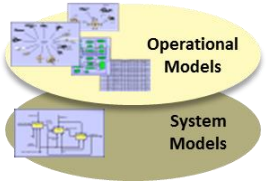
- Operational Needs
- Current Capabilities
- Budget/Schedule

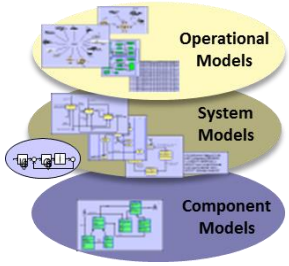
Collaborative Foundation:

- Standards
- Model Registry
- Trusted Environment with SIP
- Supporting Policy

MBE Initiation & Evolution – (When?)





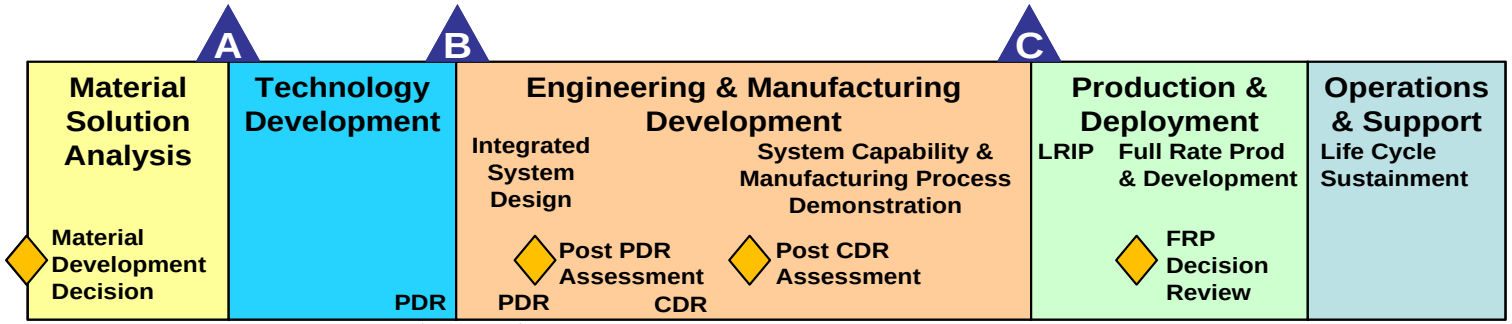


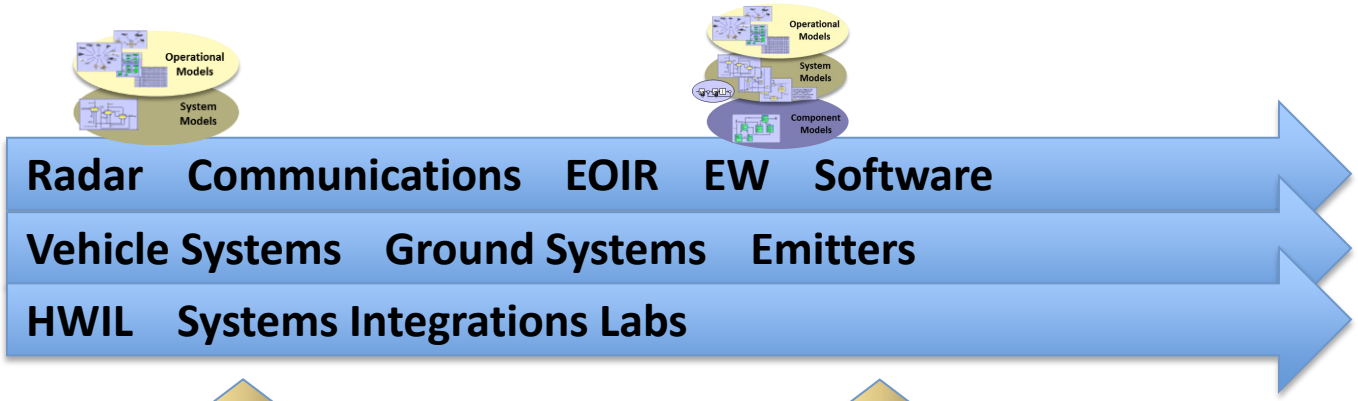
Radar Communications EOIR EW Software

Vehicle Systems Ground Systems Emitters

HWIL Systems Integrations Labs

MBE Initiation & Evolution – (When?)





MBE planned early and carried through to T&E

Systems modeling specific to T&E Execution Phase

Virtual Modeling benefit potential in T&E Timeline – (How Much)

Develop Test Plan

- Test scenario development
- Timing of test events
- Gross system trades
- Detailed system trades
- Determine objectives – given & derived
- Determine essential elements of analysis and MOEs
- Identification of variables for control and measurement
- Gross trades of schedule of objectives
- Design of Experiments

Test-Event Design

- Selection of test points for specific objectives
- Flight plan design to match test point goals
- Coordination of test resources
  - Multiple aircraft
  - Multiple sensors
  - Air & ground
- Design & planning of specific test
- Scheduling
- Planning & analysis of infrastructural items
  - Telemetry systems
  - Test range radars
  - Comm systems
- Pre-flight briefing material production – animations, snap shots, event schedules

Event Rehearsal

- Use of pre-flight briefing materials
- Nominal test scenario run through
- Scheduling check
- Coordination of test resources
- Quick reaction test plan modifications

Pre-Test Re-Plan

- Pre-test adaption to last minutes changes
- Flexibility to bring up nominal test plan in M&S environment and quickly make changes
  - Airspace changes impact assessment & adaption
  - Wind direction impact assessment & adaption
  - Weather conditions changes impact assessment & adaption
- Provides a means to allow for changes with low impact to test objectives achievement

Test Execution

- Test event situational awareness tools
- Real-time visualization of test event
  - On-board aircraft
  - Local to test range
  - Remote to contractor facility or customer facility
- Monitoring of test points achievement versus nominal plan
- Quick reaction to real-time changes in actual flight paths versus planned nominal and impact on test points and objectives
- Real-time re-planning to adapt to changes and to execute secondary objectives and test points
- Remote real-time SA of test events and participation in real-time re-plans

Post-Test Analysis

- Rapid production of "quick-look"
  - Actual flight path –vs– nominal
  - Actual test points achieved comparison to plan
  - Visualization of test geometry history correlated with collected test data
- M&S supplement to actual test results
  - Use of STEP process approach to validate M&S models as part of the feedback loop within the test series
  - Test point trade space extrapolation
  - Variations of parameters to aid in the design of next test event
- Post test briefing material production
  - Animation of entire test event
  - Specific test point geometry depictions and animations

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T&E Tool Kit Formulation Example – (How?)

Program Test Requirements

- Air Veh performance description
- Physical 3D model
- sensor attach points
- xmtr and rcvr attach points
- Radar spec's description
- EOIR sensors specs
- Comm antenna's specs
- Comm & sensor operating constraints
- Telemetry descriptions
- Data descriptions
- Sensor operating modes & constraints
- Ground handling comm needs
- Typical flight paths (takeoff to op alt)
- Operating flight paths, and comm needs
- Multi-use of sensors and resource loading
- Active sensor targeting CONOPS
- Operating procedures wrt wind conditions
- Payload & bus loading & constraints
- Imaging modes relative resource loading
- Sensor use rules –vs- flight conditions

M&S Configurations

<u>STK objects:</u>
Vehicle model
Solid model
Sensors
Antennas

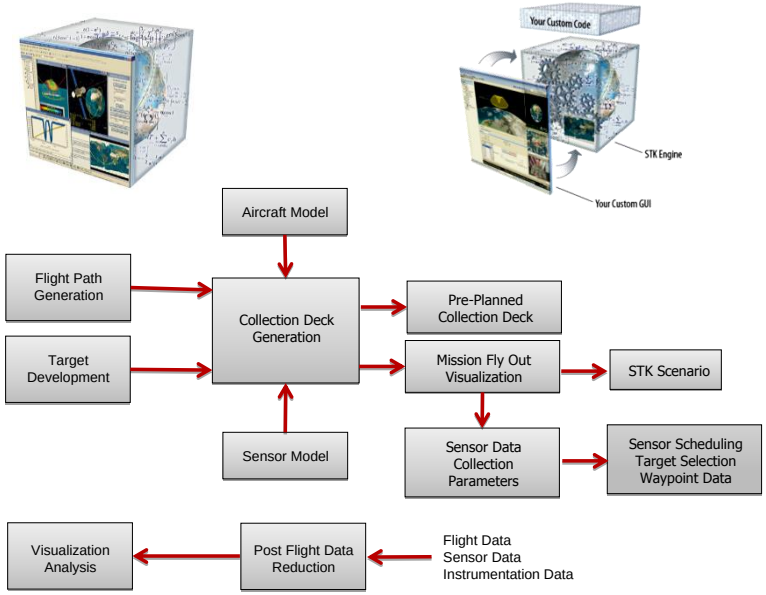
AMM changes

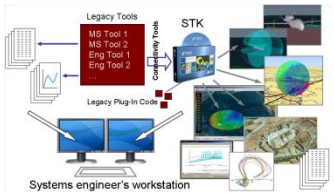
STK data readers

STK system trades

<u>Custom work-flow UIs:</u>
Target scheduling
Comm link assessment
Test points assessment
…

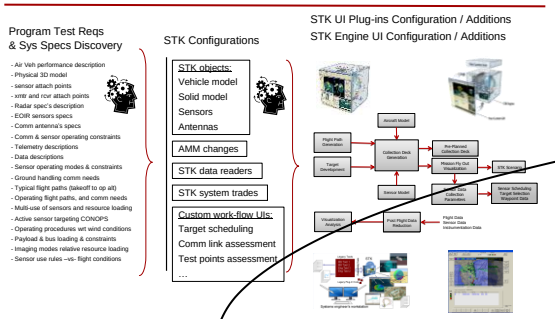
Specifically Configured M&S Tool Set for T&E Execution





Program Specific Implementation – (How?)

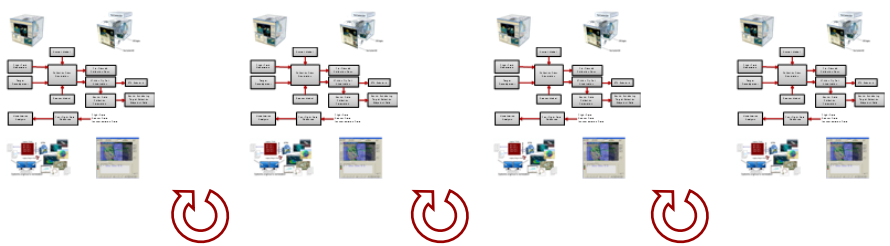
MBE Development for Test Planning



Design/Planning Tool Development

- **STK Configuration**
- **System/Subsystem Characterization**
- **Workflow Specific UI Development**
- **Implementation & Iterative Improvement**

Test Series

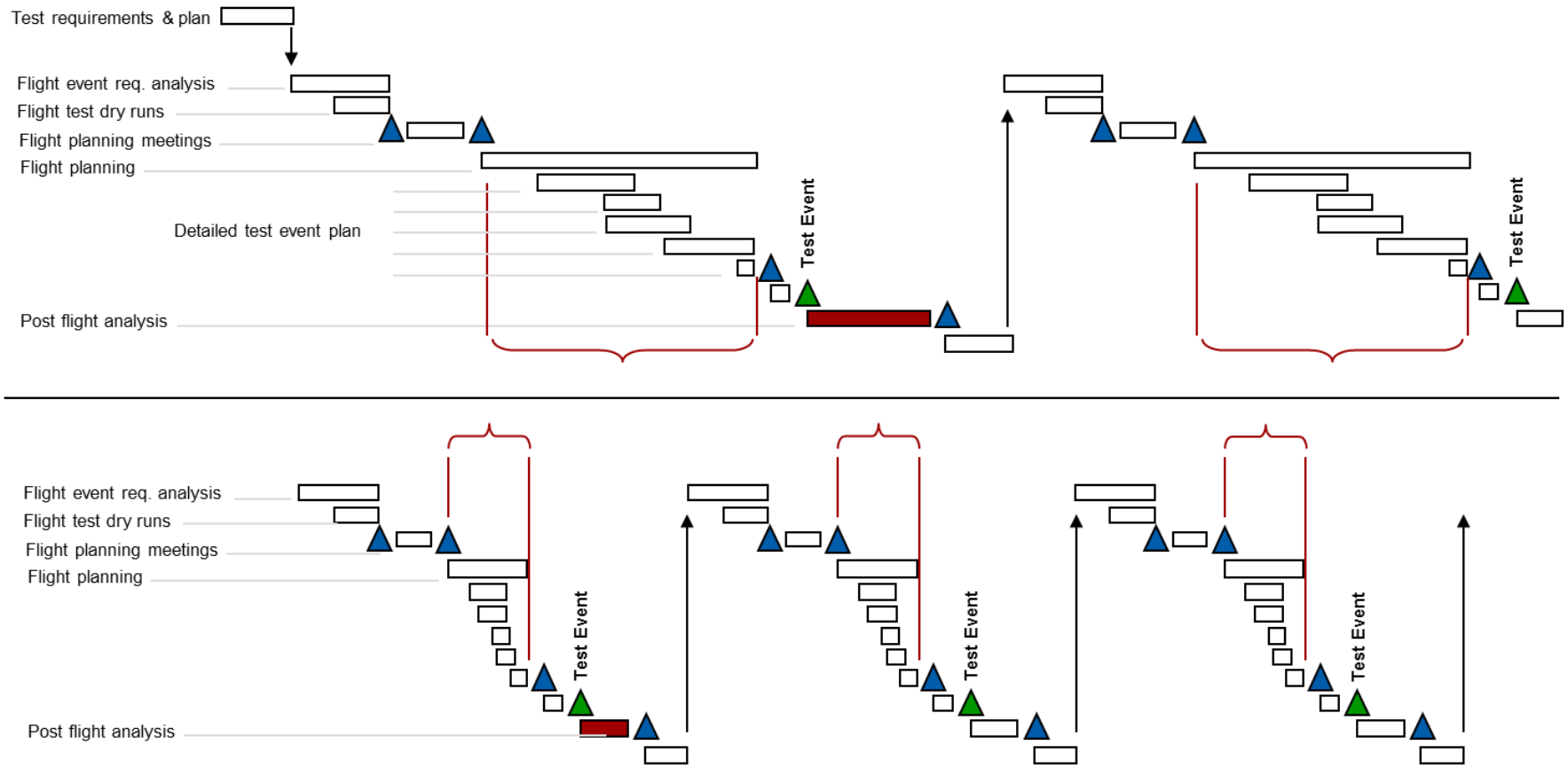


Toolset and process Improvement Iterations

People
Tools
Process
Methods
Metrics

Knowledge DB

Shortened Test Cycles – (Why?)



Summary of Proven ROI Potential – (Why?)

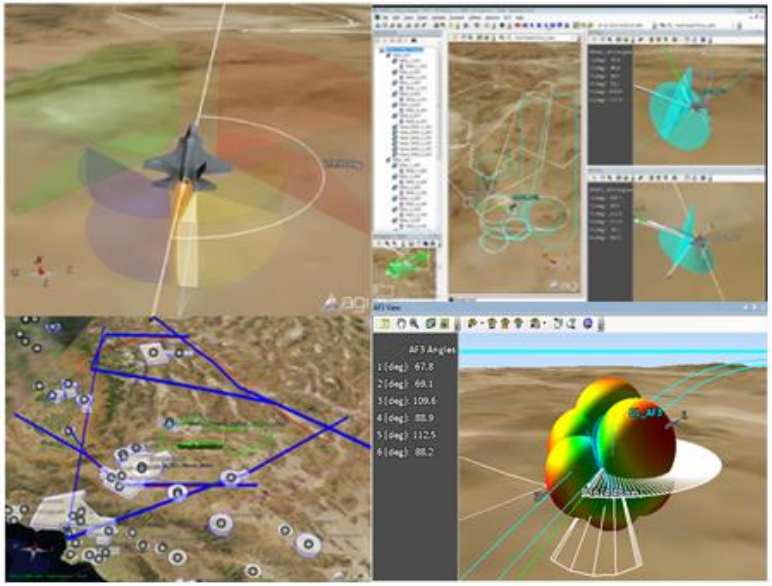
- **Efficiency of Test Force operations**
  - Reduced time for test-force process elements **$$**
    - Test-plan process, test-card development process, post-test process
  - Shortened and more effective meetings, pre-flight reviews, etc. **$**
- **Effectiveness and efficiency of test flights**
  - Improved robustness of test-card designs – validation against test plan objectives **$**
  - Increased number of test-points per flight **$$$$$**
  - Improved scheduling of refuel operations **$$**
  - Positive overall test-force flight schedule impact **$$**
  - Enabling the complicated choreographing of four-ship flights **$$$**
- **Communications within the program and with customer**
  - Illustration of complex concepts and issues at all stages of the execution T&E lifecycle **$**
  - Enable greater collaboration **$$**
  - Shortened and more effective meetings, pre-flight reviews, etc. **$$**
  - Positive impact to test-point sign-off activities
- **Flight safety**
  - Rich material enabling added insight to pre-flight briefings
  - Robust treatment of multi-ship flight choreographing and event scheduling

F-35 Flight Testing - Case Study

All notional depictions on this slide

Problem: Flight test planning is largely manual, relying on talent and intuition of experienced engineers.

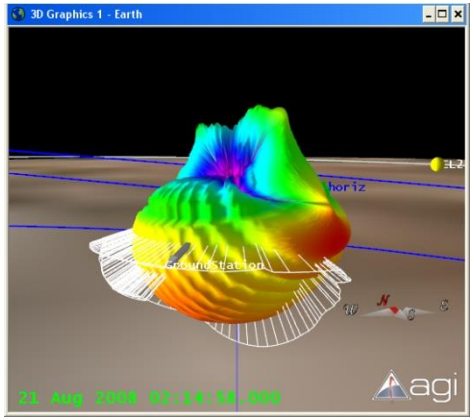
Solution: Use STK MS&A Environment to improve flight test efficiency, effectiveness and repeatability.



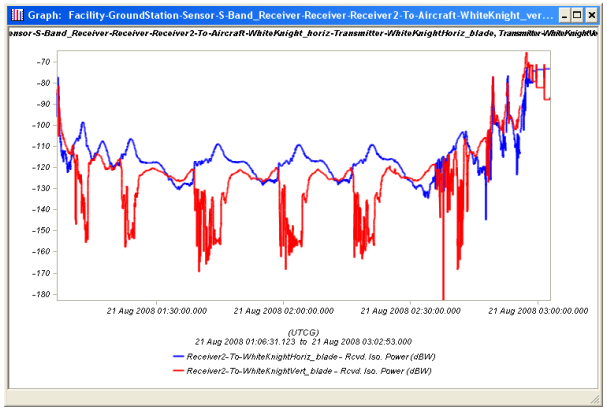
Outcome: Proof-of-Concept demonstrated improved flight test plans, designs and analysis for mission systems testing.

Accelerated & optimized test planning,
Increased flexibility in test event execution and
Faster post-test analysis

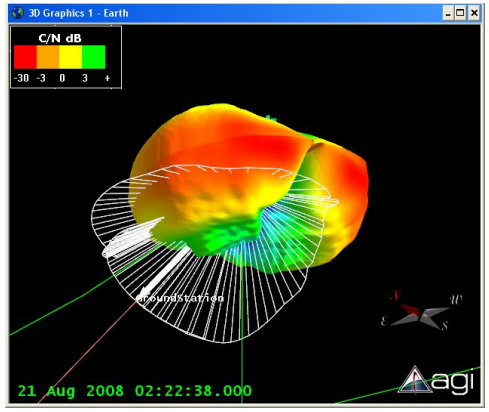
Communications Link Modeling - Demo



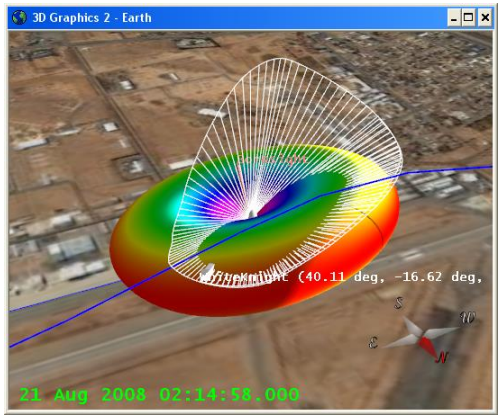
Horizontal Polarization



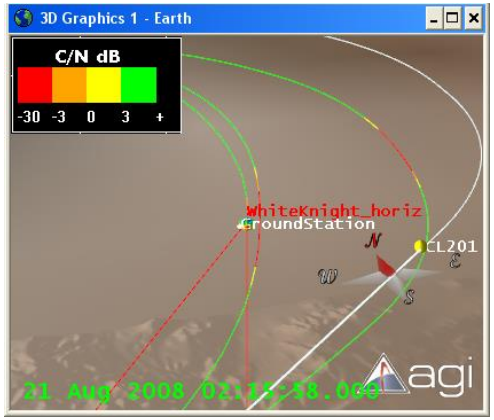
C/N Plot – Horiz & Vert



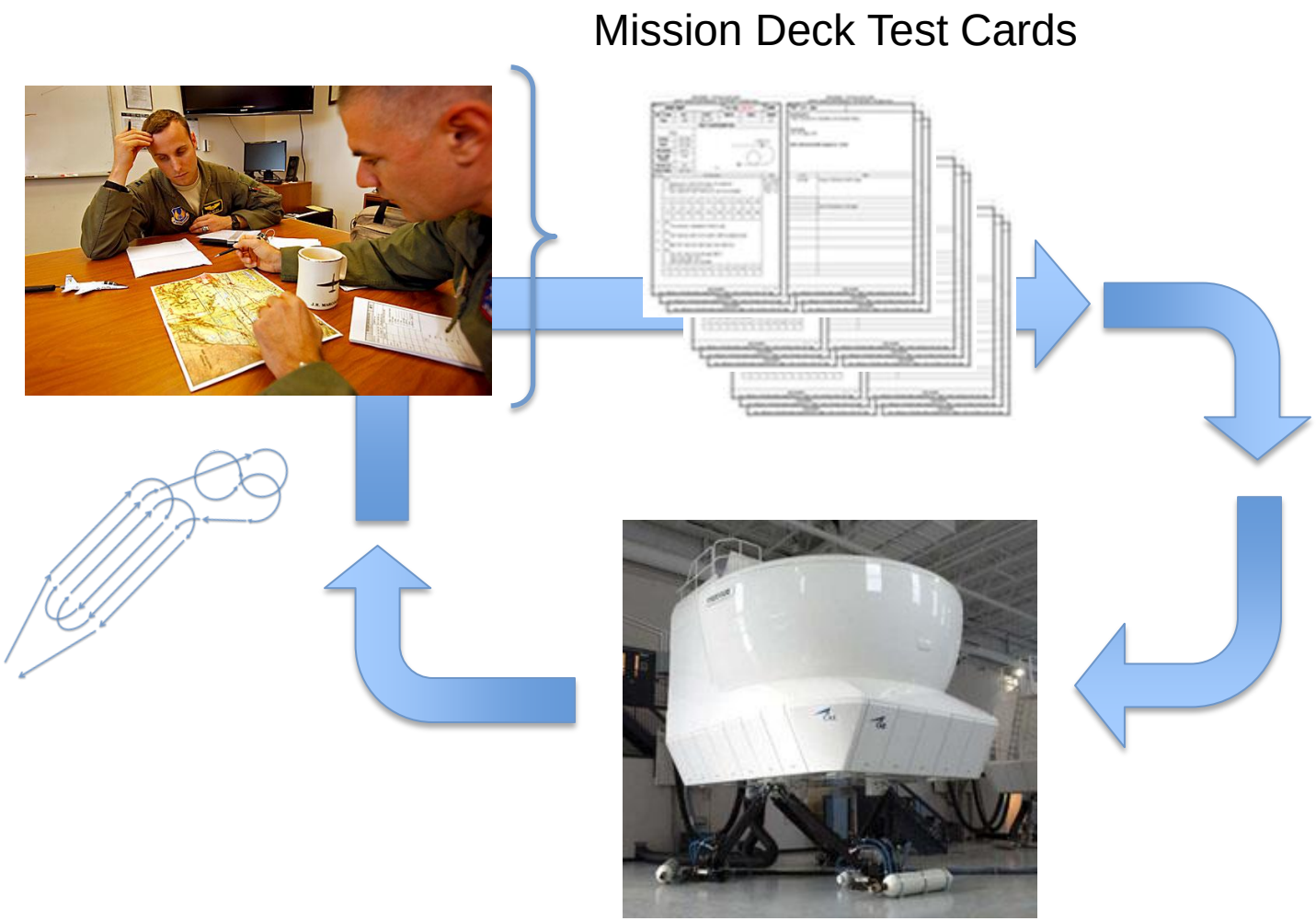
Vertical Polarization



Ground Omni

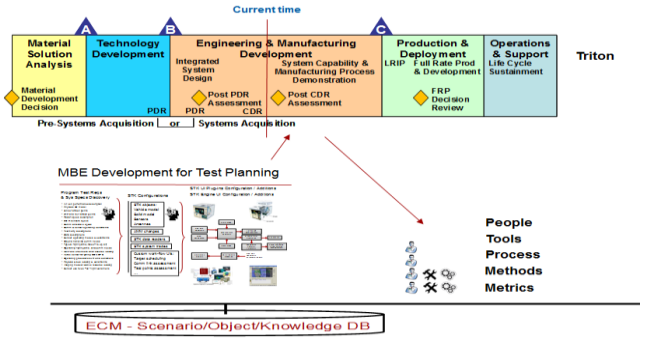


Optimizing Simulator Time – (Why?)



New Metrics Factored into Test Plan Cost & Schedule Forecast – (Why?)

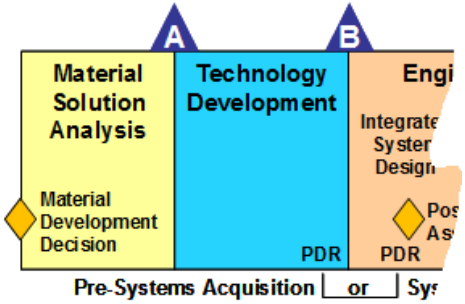
Execution Phase Program

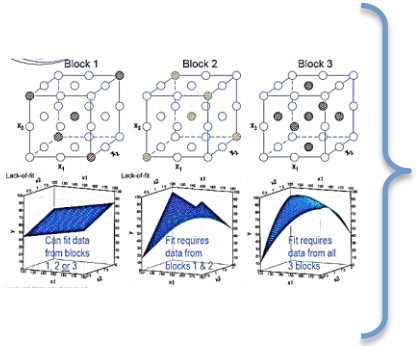


New improved metrics

- Test-points per flight
- Re-flight rate
- Practitioner's efficiency

New Start Program



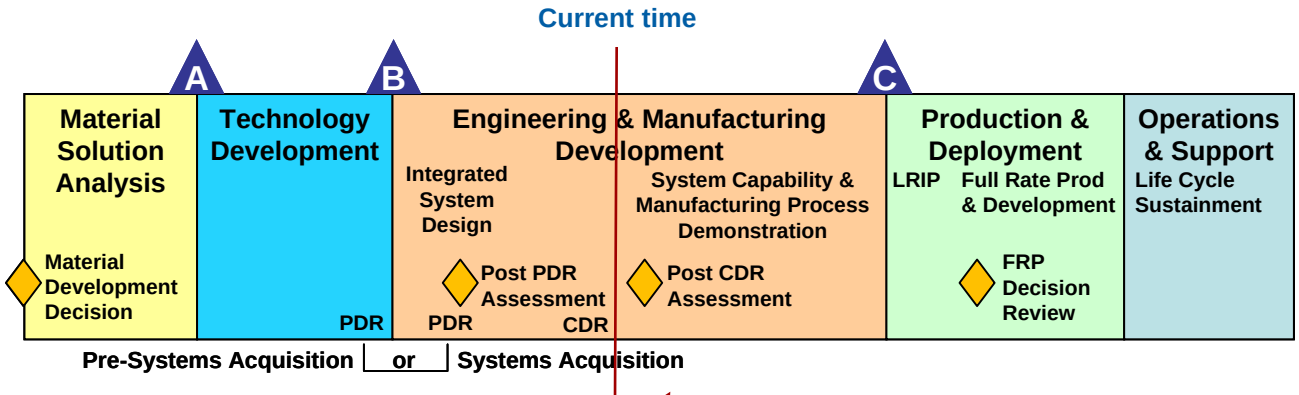


STAT/DOE yields "right sized" Test Plan

New metrics factored in to plan

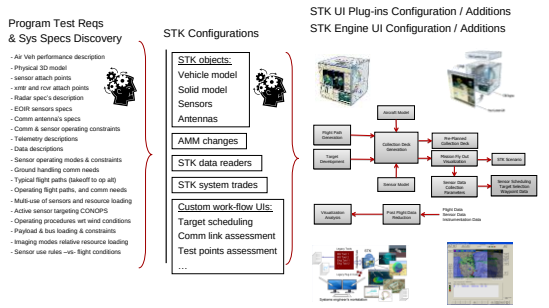
Improved Cost & Schedule Forecast

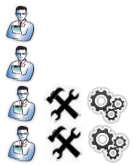
MBE for T&E Initiation & Evolution



Program "ABC"

MBE Development for Test Planning

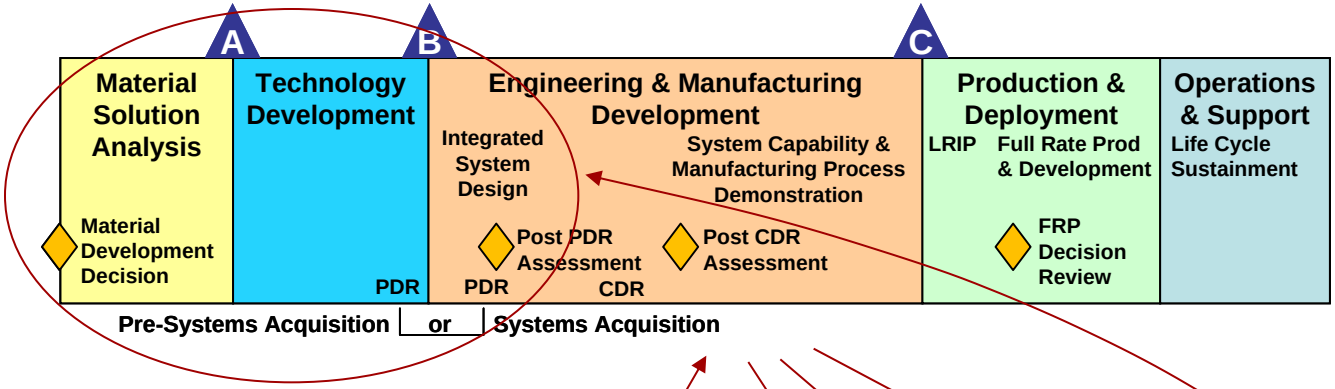




People
Tools
Process
Methods
Metrics

Knowledge DB

MBE for T&E Initiation & Evolution



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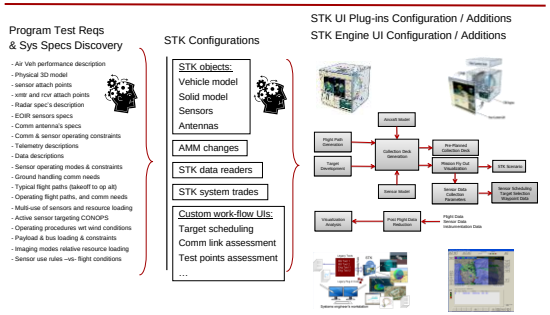
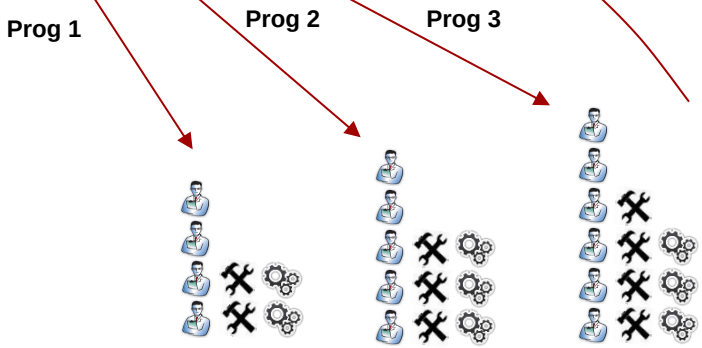




People
Tools
Process
Methods
Metrics

Knowledge DB

Re-usable Modeling Elements

Rev 1 – additions - designed based on “Program 1” requirements

- Targets manipulation & visualization ----------
- GIS, DAFIF, airspace manipulation & visualization -------
- Mission profile route creation and modification ----------
- Target scheduling ----------
- Sensor operation planning & optimization ----------
- Post-flight test point assessment & visualization ----------

Rev 1.2 additions – derived from “Program 2” requirements

- Communications link assessment ----------
- Real-time telemetry importer ----------
- Real-time test point & objectives assessment ----------
- Real-time situational awareness, visualization ----------
- Real-time systems performance assessment ----------
- Weather & winds assessment & incorporation ----------
- Import/export to PFPS & AMPS ----------

Rev 1.3 additions – derived from “Program 3” requirements

- Flight termination assessment ----------
- Camera geometry assessment & visualization ----------
- GPS Nav performance assessment & visualization -------

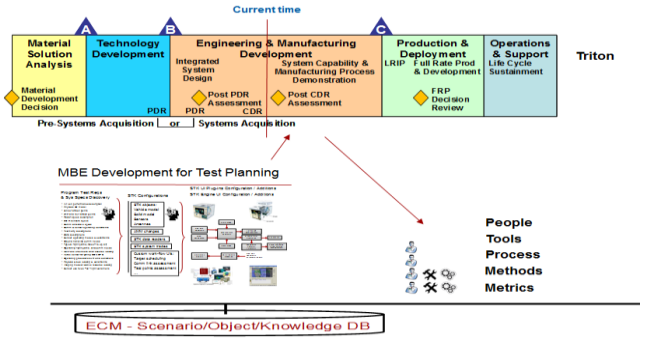
Prog 1

Prog 2

Prog 3

New Metrics Factored into Test Plan Cost & Schedule Forecast – (Why?)

Execution Phase Program



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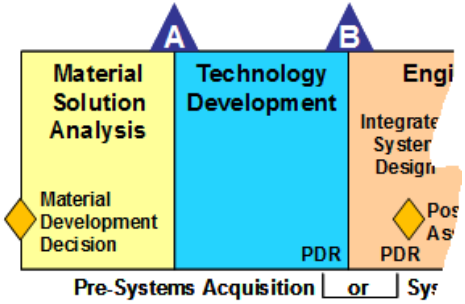

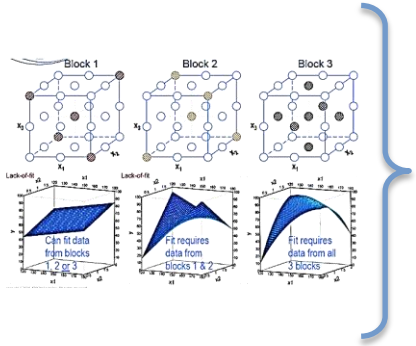

STAT/DOE yields "right sized" Test Plan

New metrics factored in to plan

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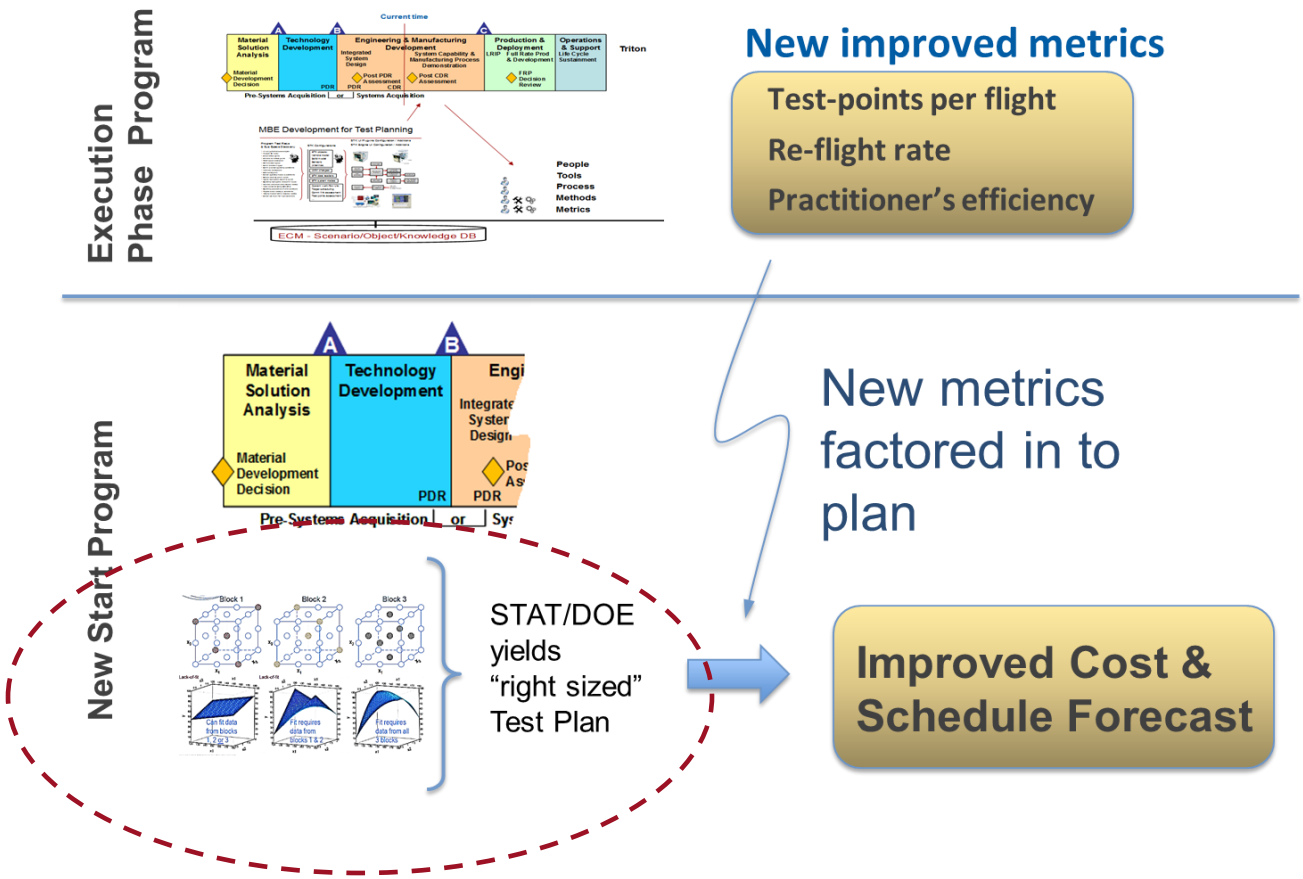
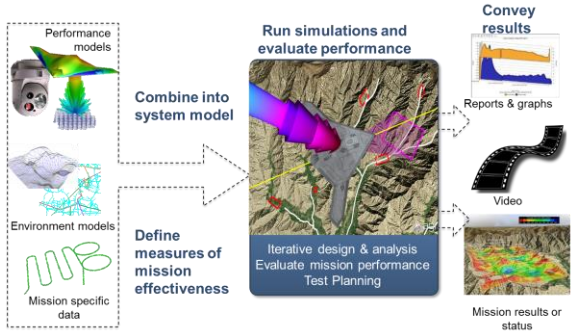
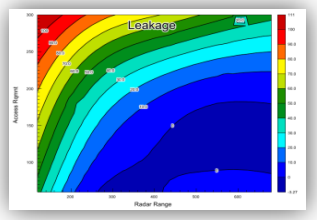
Support for DOE Test Planning

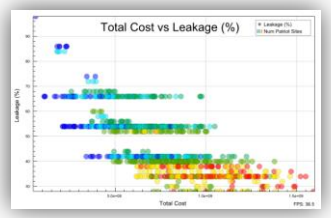


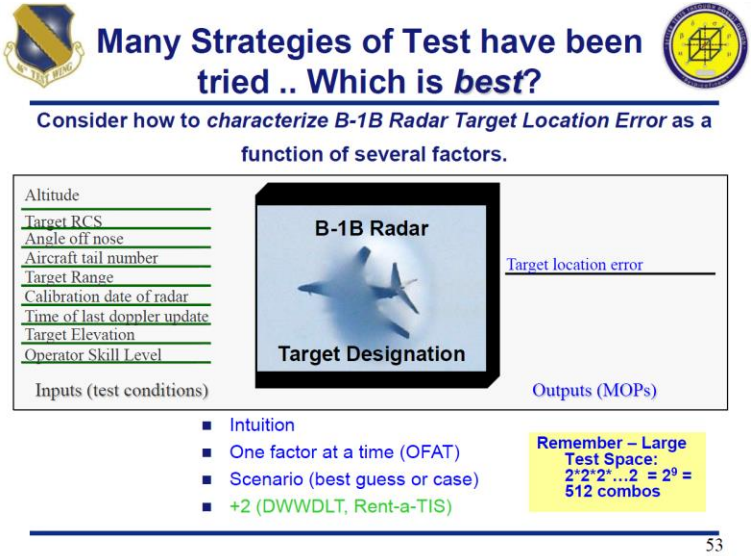
- **So how does this help me with my overall test planning?**

Test Planning Support





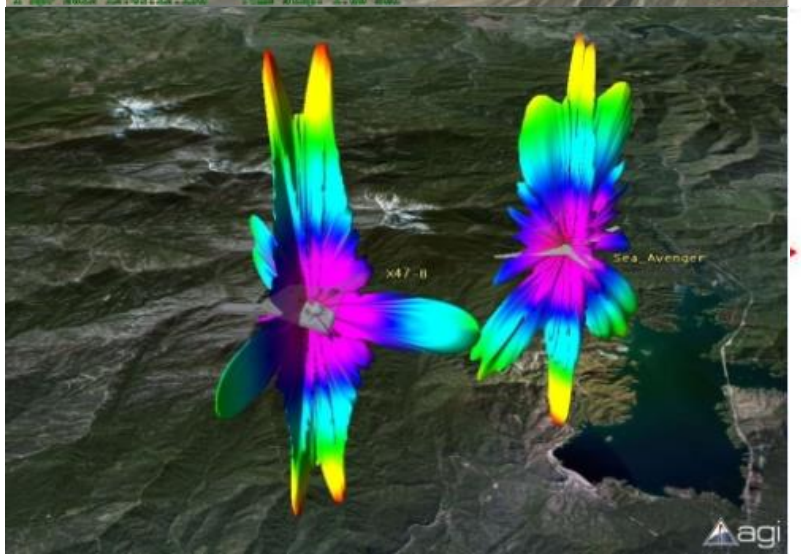


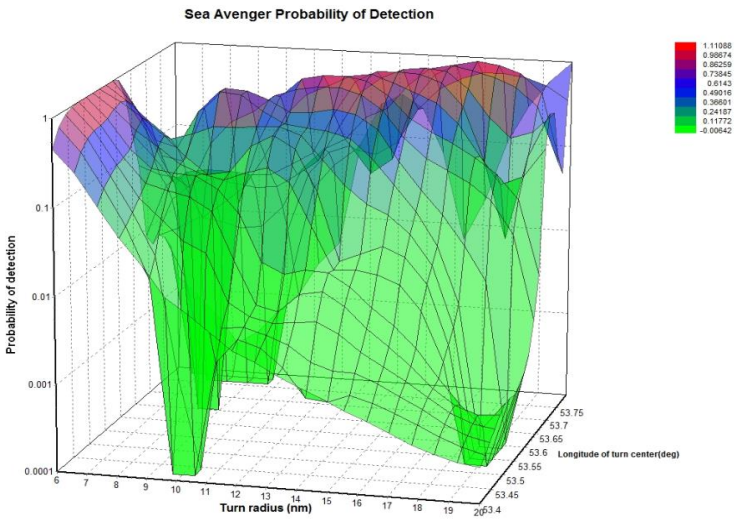


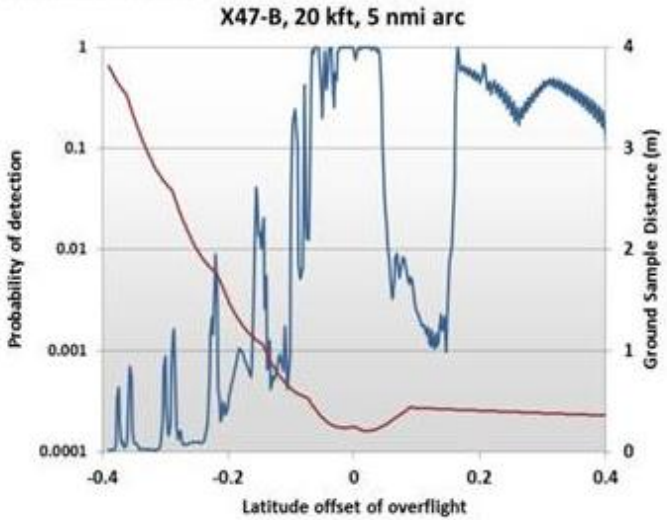
Ref: Gregory Hutto

- **The M&S tools provide an easy way to assess the inter-relationship and sensitivities of factors to assist in choosing factor sets and setting up effective DOEs**

Process Knowledge Evaluation





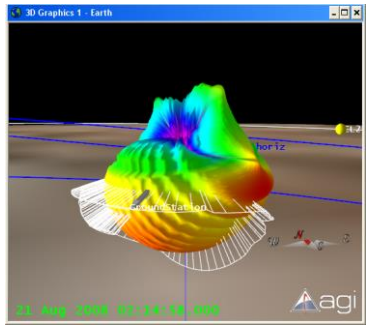


M&S for T&E Execution Phase – Summary

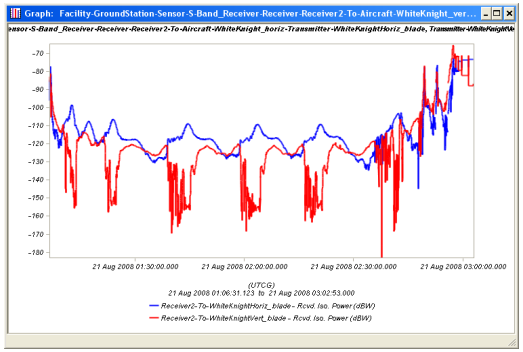
- Nimble M&S can be effectively used in test execution
- Methods can usually be applied at any point in the cycle given the significant ROI potential
- Benefits attained with requisite level model fidelity
- COTS tools can enable and accelerate implementation
- New methods and metrics can be applied to improve future programs
- Nimble M&S can feed effective STAT/DOE methods

Example Use Cases

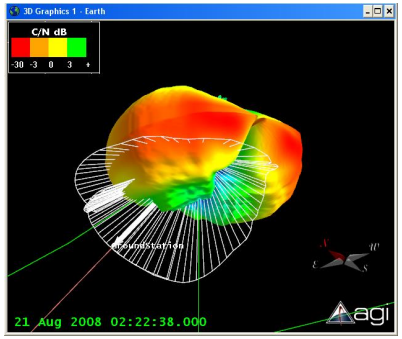
CHLOE Test Planning & Com Link Modeling



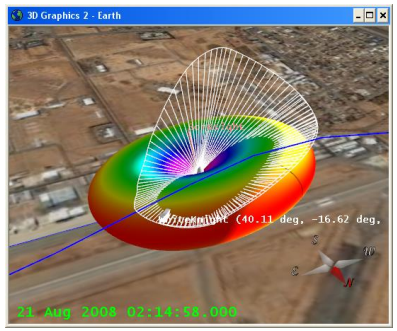
Horizontal Polarization



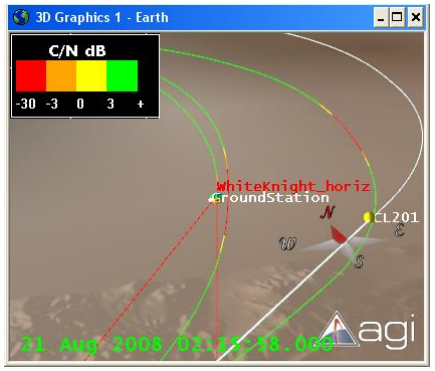
C/N Plot – Horiz & Vert

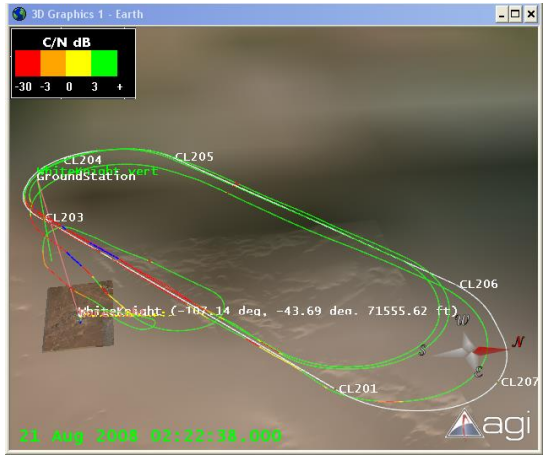


Vertical Polarization



Ground Omni





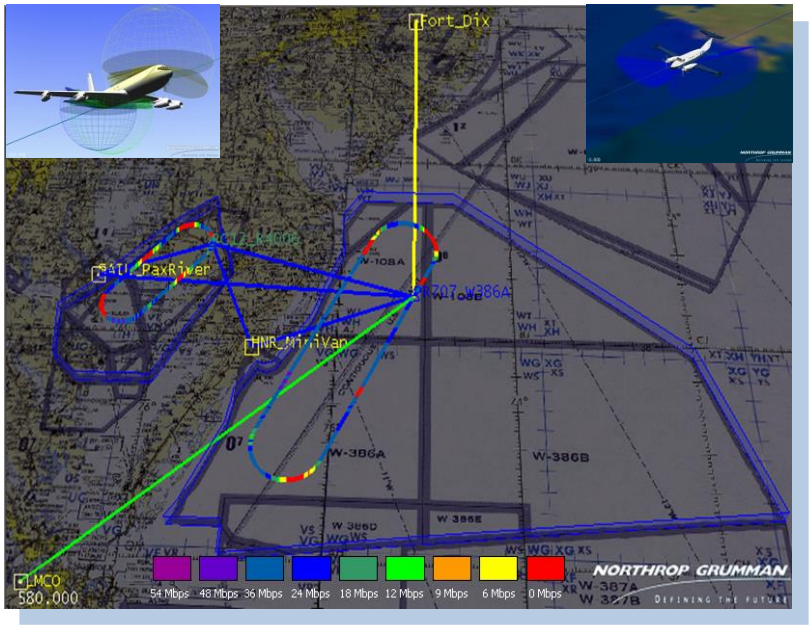
Telemetry communications prediction modeling reduced re-flights

NGAS - Airborne Networking

Problem: *Build A Realistic Model Of an Airborne Network Through Simulation to Predict Network Performance Over the Flight Regime. Validate AN Models Through Live Fly Results*

Solution: *Use STK, OPNET and Custom Integration Tools to Build a Robust Network Simulation. Compare Initial Model Results with Model Outputs Driven by Real Flight Data*

Outcome: *Allowed "Pre-flight" of the Network to Highlight Potential Issues and Supported "Post-flight" Link Performance Analysis After Live Exercise*



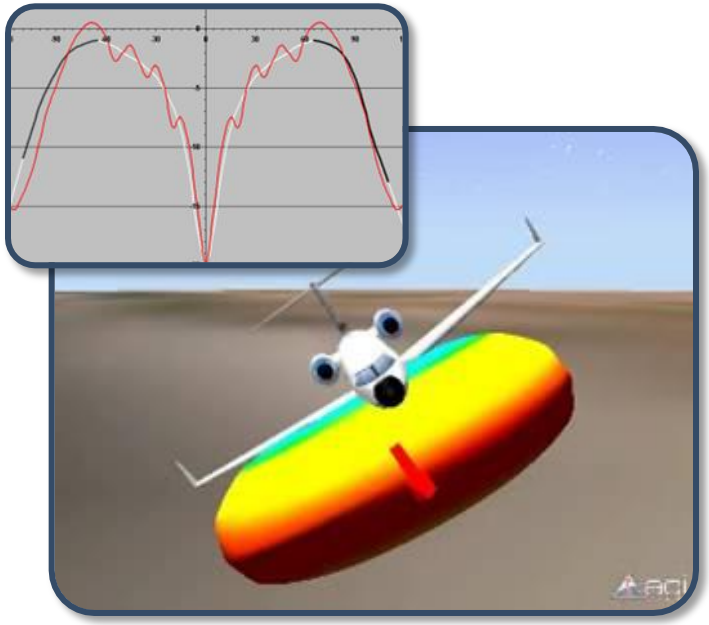
Risk Reduction Through Physics-based Modeling of the Airborne Network

This invention was made in the performance of a Cooperative Research and Development Agreement with the Department of the Air Force.

Aircraft Communications Testing

Northrop Grumman Integrated Systems

- **Problem**
  - Determine antenna coverage and blockage from aircraft keel
- **Solution**
  - "As installed" antenna patterns analyzed with multiple flight profiles for coverage



- **Outcome**
  - Millions of dollars saved in reduced required flight tests of high value aircraft and reduced schedule risk

"Valid flight testing at your desk"

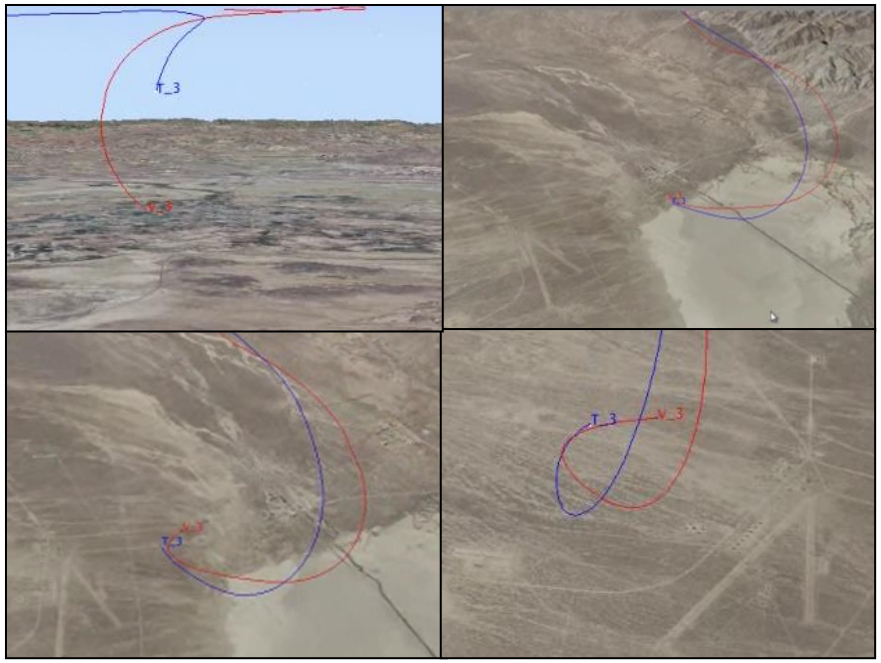
— Bruce MacDougall, NGC

Naval Strike and Air Warfare Center

Improved Training – NSAWC

Problem: Manually intensive procedures for pre-flight planning and post-flight learning

Solution: Use STK MSAF for accurate, efficient and visually intuitive learning experience



Outcome: Integrated training mission model that allows instructors to model all aspects of the flight and review outcomes with students using a dynamic 3D environment.

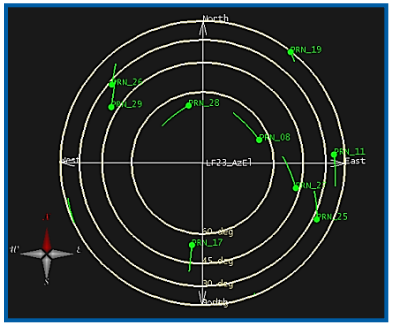
"Cost avoidance for re-flys
and
mission failure is off the charts" **(Retired Naval Aviator)**

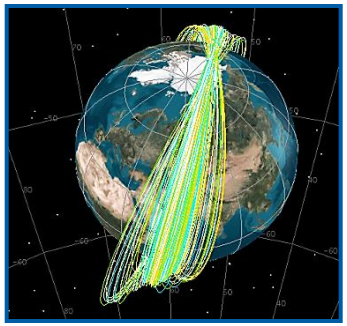
Missile Flight-test Planning and Analysis

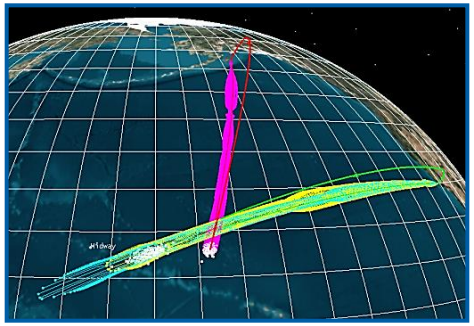
Problem: Constant, high-pressure tasks requiring complex, unique analysis approaches. Clearly communicate results to decision-makers.

Solution: STK out of the box and custom workflows via STK's open APIs. 3D animations convey complex dynamics.*

Outcome: Seven years of high customer satisfaction and increased contract support to Missile Defense Agency.







*"Much of STEPAL's work went to the President, essentially unchanged." - LTG Obering, former director MDA

'STK's off-the-shelf capability and flexibility allows STEPAL to successfully execute challenging analysis tasks.'

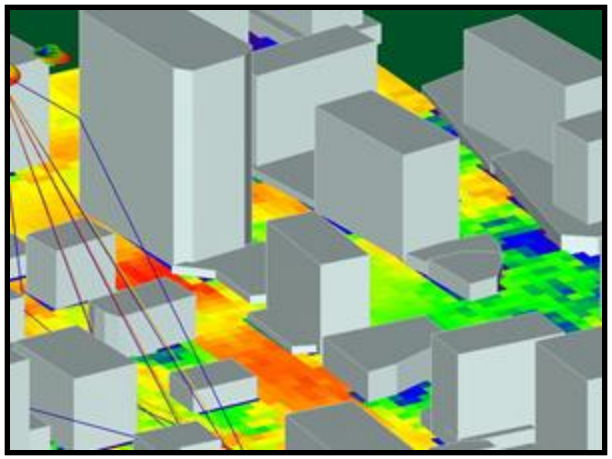
—**Frank Grose, senior space systems analyst, SAIC**

SPAWAR - Joint Tactical Radio System (JTRS)

Problem: Customer wants to run parametric analysis studies on a HWIL network simulation for JTRS. The simulation is fed from live tests that measure link budget metrics. Live testing is slow and expensive.

Solution: Use STK to stimulate the network simulation using simulated routes, terrain and 3D buildings. TIREM and Uprop used for high fidelity comms.

Outcome: STK eliminates the need to perform live radio tests and gives the JTRS program the ability to investigate the trade space.

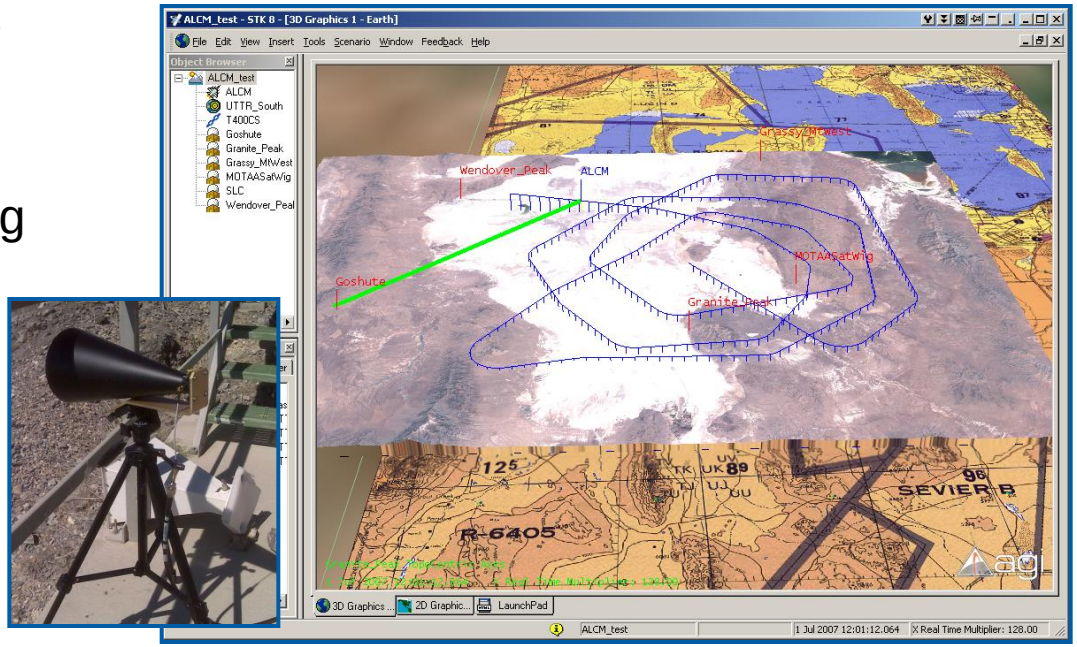


The JTRS program is saving $20K for each JTRS test and is able to run more tests in less time!

Improved Test Range Operations

Problem: Precisely replicate RF signals as they would appear in nature to support range planning and rehearsal.

Solution: Drive RF channel simulator using STK Engine.



Outcome: Integrated mission model and accurate wireless communication that allows range operators to model all aspects of range.

HWIL Simulated signals that are indistinguishable from live test events.

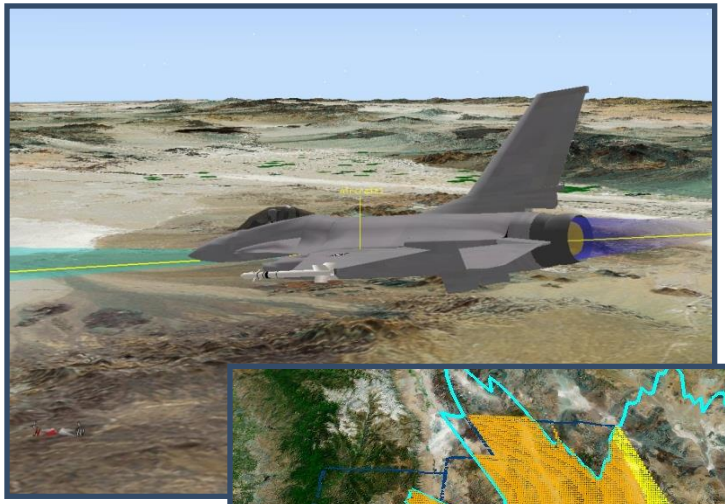
Wind Turbine Airborne Radar Model

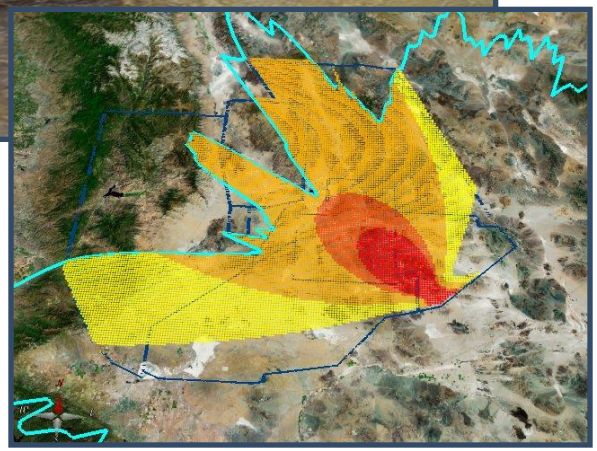
<u>Aircraft Range Safety – Edwards AFB</u>

Problem: Had no way to analyze impact of proposed wind turbines on airborne radars, needed quick-turn analysis tool

Solution: Modeled predicted noise and Doppler shift affects in STK, verified against flight test measurements

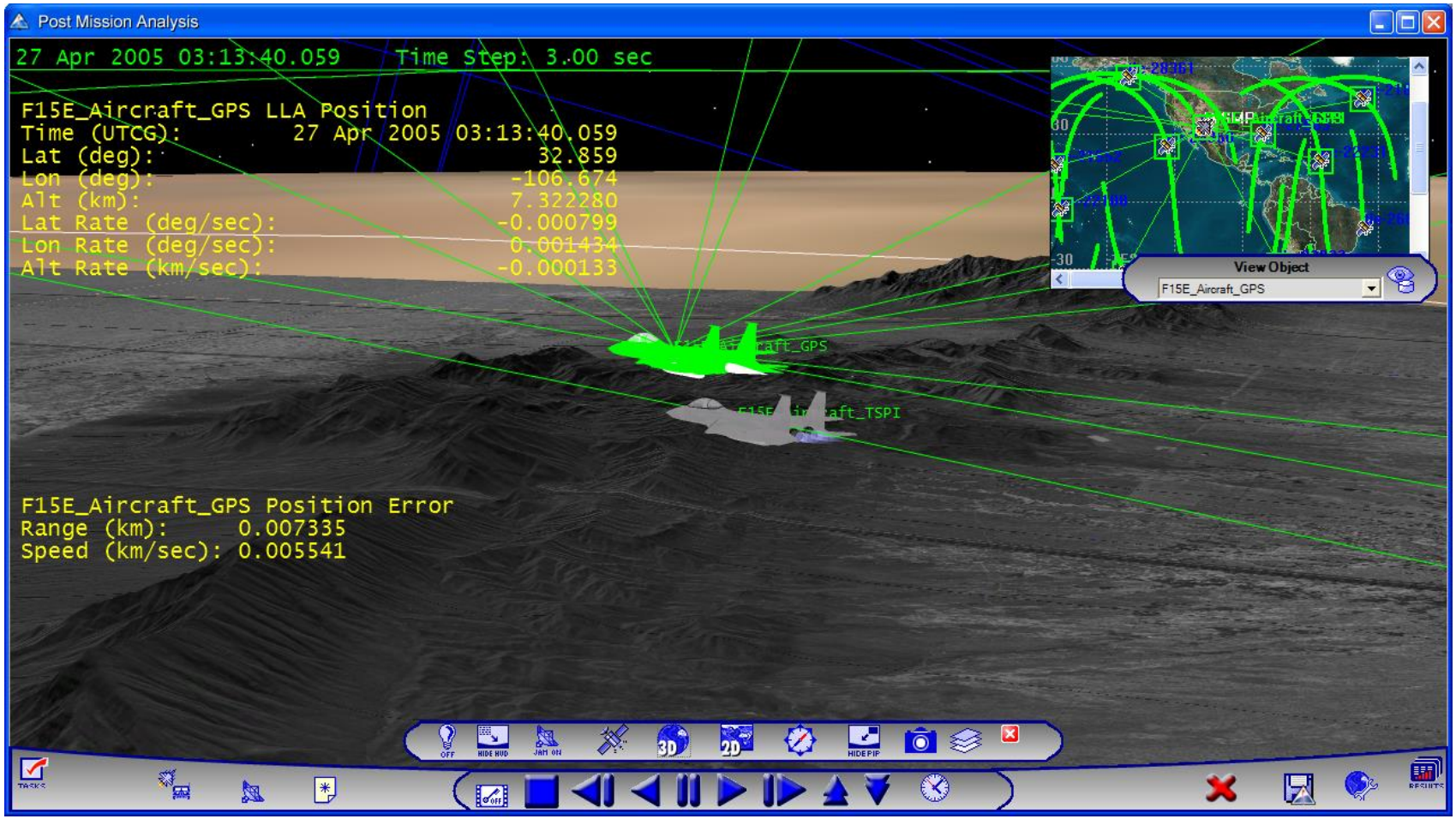
Outcome: STK provided analysis model that previously did not exist, Analysis completed in 2 weeks





$1 Million saved in reduced need for flight tests

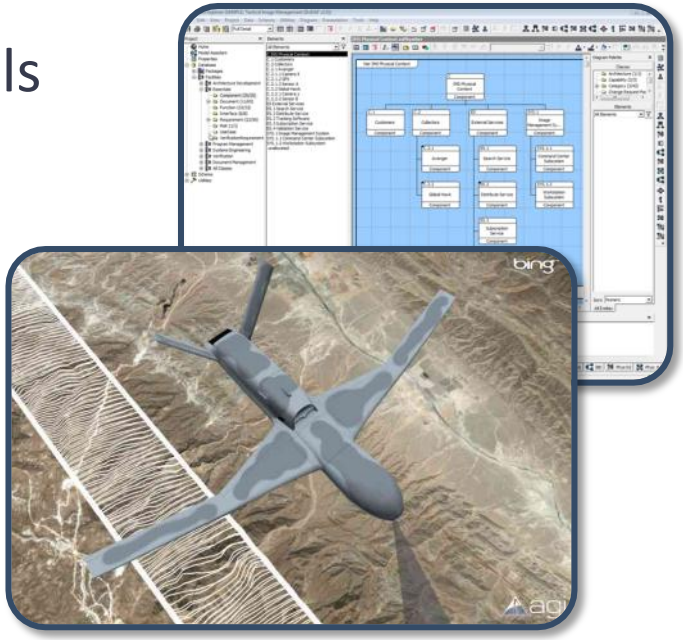
Custom STK Engine Application



JNWC Application (NCOE) EW Test Reconstruction

Early Linkage of Requirements to T&E

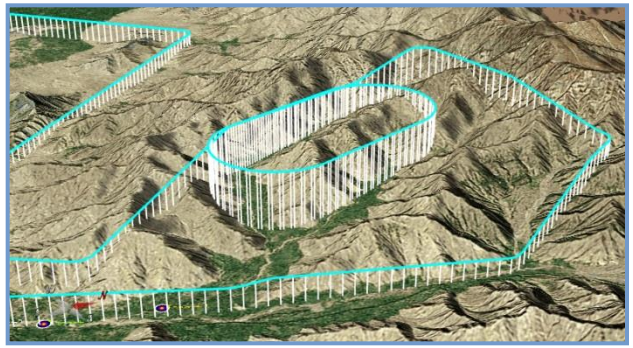
- **Systems engineering approach to T&E**
  - Incorporate predefined system models
  - Discover issues early
  - Automated documentation (TEMP)
- **Inputs**
  - T&E model developed in CORE
  - STK scenario



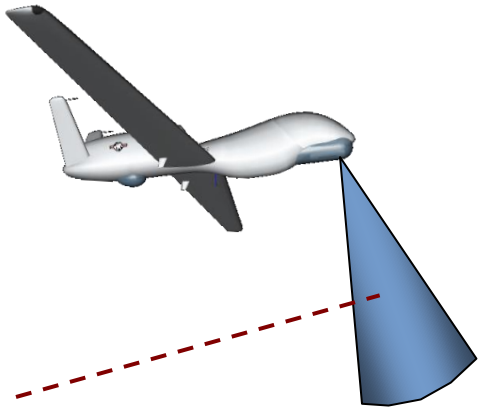
- **Results**
  - Ability to react to pre-flight changes with validated re-plans
  - More effective post flight analysis & briefing material

AGI/Legacy Tools Integration

Legacy A/C Performance Modeling & Route Generation

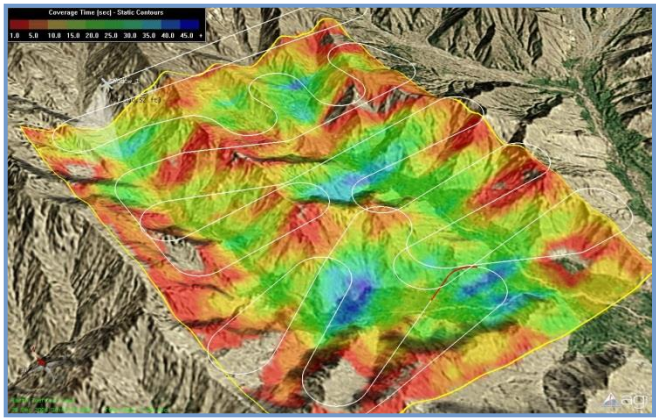


STK geometry and constraints



Legacy plug-in code for sensor performance rules & methods

Platform/payload performance prediction



Questions?