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Achieving Dramatic Increases in T&E Effectiveness and Efficiency Leveraging Dynamic and Flexible M&S Tools

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Abstract:

Much focus has been brought in recent years to the use of statistical methods to “right-size” overall test plan design using design-of-experiments, combinatorial techniques and other rigorous scientific methods. In 2012 a Scientific Test and Analysis Techniques (STAT) Center of Excellence (COE) was initiated to assist programs in developing rigorous and defendable test plans using state-of-the-art methods. These initiatives are meant to produce smarter overall test plans embodied in a given program as well as to produce smarter test plan loading and scheduling in individual test plan blocks. Less attention has been given to the use of smarter methods in the test execution phase for optimum test-card mission design to increase test-point density and to ensure execution effectiveness to reduce re-flight rates.

Modern advances in computer simulation have resulted in tools which enable flexible and interactive virtual environments that can be used to rapidly prototype route designs. Sets of candidate test-point combinations in the assembly of test-cards can be virtually modeled to iteratively arrive at a test mission plan that is more efficient and more robustly designed than by more traditional methods.

Here we will review the application of virtual methods of dynamic planning, execution, and post-flight quick-look that has proven able to increase test-point density and more often ensure test-point objectives achievement. Modeling application and iteration methods used to achieve more optimal test-flight designs will be discussed and contrasted with traditional contemporary methods.

Final consideration and discussion will describe the overall areas of positive T&E execution phase impact including practitioners’ operations efficiency, flight effectiveness & efficiency, post-flight quick-look and forensics analysis and flight safety.

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Key words: AGI, T&E, COTS, M&S, STK

Introduction

There is significant benefit to using a common modeling and simulation environment for evaluating aircraft performance and measures of mission effectiveness across all portions of the program lifecycle; from concept and engineering, through test and evaluation to training and operations.

Using a commercial modeling and simulation package maintains consistency in asset performance models, environments, and mission goals throughout the various phases of the project or program lifecycle. This ensures reliability and comparability in mission objective assessment. Additional efficiency gains are found through sharing models defined in early stages and passing them along to groups engaged in subsequent phases of product development. This reduces the amount of work to recreate models as well as lowers the risk of introducing errors due to mismatched modeling between applications.

Additionally, having an extendable interface and open API allows for customization of workflows to fit the needs of each phase while continuing to use a consistent toolset.

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This paper will emphasize the advantages of using commercially available modeling and simulation packages by highlight the use of the commercial-off-the-shelf software package Systems Tool Kit (STK) produced by Analytical Graphics Incorporated (AGI).

Support of the Aircraft Project Lifecycle

Every project or program progresses through a series of stages to go from concept to implementation. For the purpose of this paper, we will address the following phases: CONOPS and Engineering, Procurement, Training and Simulation, and Test Validation and Operations. Each phase has different requirements for modeling, analysis and visualization but having a single tool capable of participating in all phases will significantly reduce schedule risk and internal tool usage training requirements.
STK provides specific capabilities to evaluate aircraft systems and mission performance across all phases of development ranging from simplified or conceptual aircraft and sensor performance modeling, to detailed modeling in iterative trade study evaluations for engineering and testing of high fidelity mission models for test and evaluation or operational mission planning.

Commercial Modeling and Simulation Software

AGI's commercial off-the-shelf (COTS) software Systems Tool Kit (STK) is a time based 2D and 3D modeling environment for evaluating land, sea, air and space system performance. This environment incorporates terrain data and radio frequency attenuation models, complex vehicle and sensor/payload dynamic behaviors, and the ability to compute relationships between objects based on those dynamics, terrain presence, and RF environment models. Such relationships between objects include (but are not limited to) relative position and orientation, line of sight (including obscuration from terrain), and communication link and radar signal quality.

Engineers, mission analysts, operators and decision makers can model complex aircraft

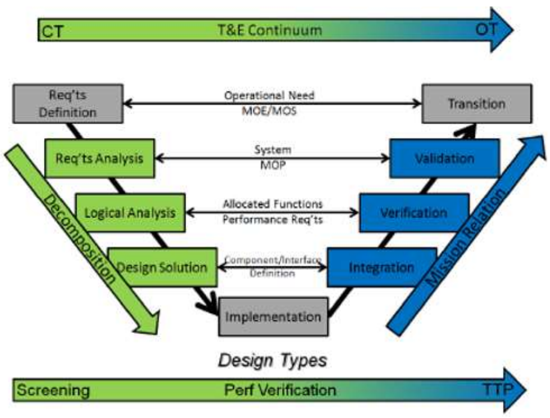

Fig. 1. Illustration of Decomposition and Mission Relation for Test Planning. [2]

and mission systems, from the aircraft performance to the payloads they carry and even the supporting assets on the ground or in space, all within the context of the mission and operating environment. System performance can be evaluated in real or simulated time, with reports, graphs and 3D visualizations to convey easily understandable results.

STK also provides an open API and software development kits for a variety of customization options. This includes analytical plugin points which are provided to allow users to augment any calculation or to compute custom measures of effectiveness in process with STK's other metrics. Alternatively, the engine behind the STK application can be used as an embeddable component in custom application development for desktop and mobile applications as well as server and web-based architectures.

This flexibility makes STK a great choice for customizing solutions for the high-fidelity needs of aircraft system test and evaluation program lifecycles.

CONOPS and Engineering

It is critical to create a realistic depiction of both the conceptual systems in question as well as provide a method for allowing invested engineering development of those systems.

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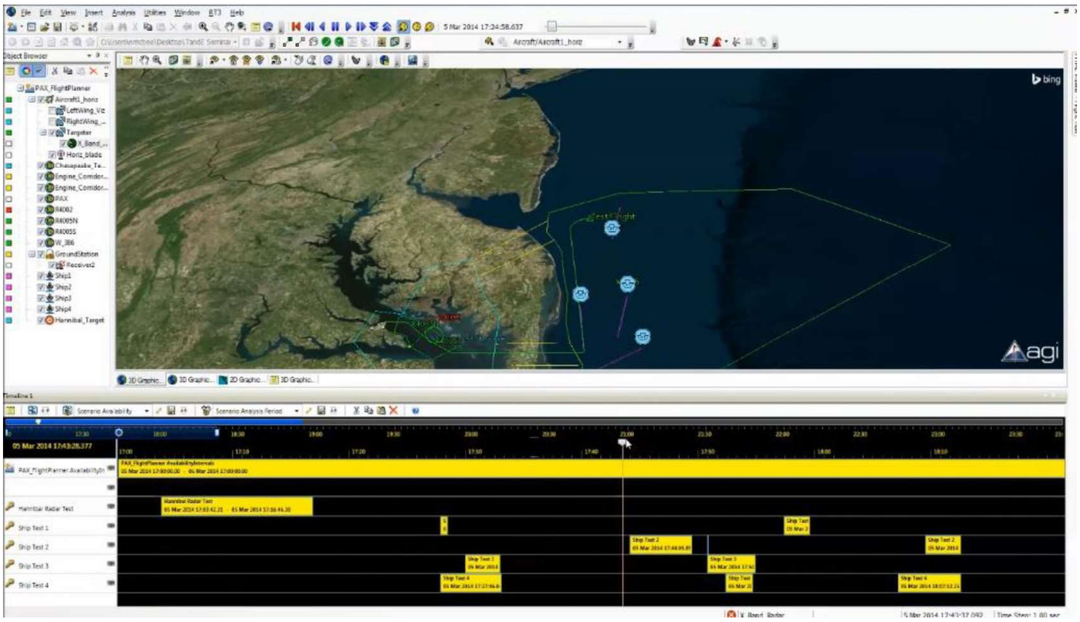

Fig. 2. Systems Tool Kit Example– Timeline of Coordinated Test Events and System Availability Windows

Modeling and simulation environments can provide the capability to simulate flights based on true or conceptual performance parameters in a wide variety of mission profiles. Modeling end to end scenarios for mission threads and vignettes allows users to quickly assess measures of performance/measures of effectiveness (MOP's/MOE's) for missions such as ISR, strike, air defense, close air support (CAS), electronic warfare, and more. This gives analysts the ability to play out a series of concepts to evaluate performance of the design and then make adjustments and reevaluate.

Another critical feature is the basis for aircraft modeling to incorporate a 6 degree of freedom simulator to ensure accurate mission planning and modeling capabilities. This takes in aircraft configuration data (aerodynamic lift and drag curves, propulsion thrust properties, climb, cruise and landing characteristics) and propagates position and attitude through a series of user defined waypoints, holding patterns (circular, racetrack, raster search) and maneuvers (push/pull accelerations, rolls, loops). Missions adhere to the aircraft performance model with realistic bank and flight path angles, turn radii, climb rates and aircraft velocity. This provides the capability to evaluate the design's ability to perform missions and combat maneuvers or to out maneuver and accelerate away from combatants or ground targets.

Utilizing a wide variety of flight profile metrics helps aide in determining design effectiveness such as fuel state over a mission, thrust required to sustain maneuvers (including environmental characteristics like wind speed and direction), load factor and thrust/power remaining throughout maneuvers. Using these data sets, analysts can determine the feasibility of mission profiles and answer questions about the mission such as: 'can the aircraft design achieve the required climb rates?', 'does the proposed aircraft have the required range or endurance?', 'does the selected propulsion system provide the required thrust?'

This provides flight planning relative to other objects in the simulated scenario including the mission environment and the local terrain profile. This allows for easily designing formation flying maneuvers, sensor pointing and weapons drops on stationary or moving targets, low altitude terrain following maneuvers and inflight refueling, just to name a few.

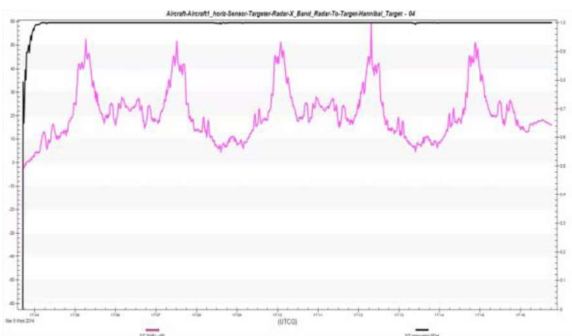

Fig. 3. Calculated Radar Detection of Simulated Target – Showing Probability of Detection (PDET) and Signal to Noise Ratio (SNR)

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Incorporating GIS data also provides the ability to establish flight corridors and no fly zones to aid in mission planning.

In addition to flight performance is the need to manage a wide variety of additional mission system models and performance metrics which provides context to the mission plan. Modeling the other subsystems, payloads and objects in the mission (communications, electronic countermeasures, weapons performance, ground based radars, communications packages and refueling capabilities) can help create a full understanding of the aircraft's capabilities such as range and endurance, the ability to avoid detection while closely approaching adversary radars, and kill chain efficiency.
An example of a mission evaluation might be determining how bank angles during fighter maneuvers may exceed sensor gimbal limits or field of regard causing loss of line of sight between sensors and targets or understanding the minimum number of aircraft required to perform ISR coverage of various size regions dependent upon fighter performance and launch/recovery locations.

Taking into account attitude changes in aircraft throughout flight plans provides relative orientation between all other objects and reference frames in the modeled scenario. When an aircraft climbs or banks, the attached payloads rotate appropriately. For example, with a series of receiver antennas mounted about the aircraft, the antenna gain patterns maintain their orientation with respect to the rolling aircraft frame which translates to a reorientation in the Earth fixed reference frame. Knowing how the range and angles between other transmitters and the rolling aircraft change over time, allows software simulations to determine which antenna and what part of its gain pattern is receiving the incoming signal and therefore how the link budget changes during the maneuver. Using information like this, engineers can design or select more appropriate antennae and determine the appropriate number and location of antennae to optimize link availability during expected operations of the aircraft.

With regards to the fighter kill chain (the time to find, fix, track, target, engage and assess), having the ability to model all the various sensors, weapons and timing of events in tandem with the fighter and target performance (stationary or moving) allows for the entire process to be simulated and evaluated early on in the project development. Sensor fields of view can be modeled, detection and tracking algorithms can be integrated, GPS receivers and position accuracy can be evaluated, and even weapon guidance modes can be simulated. Bringing all these together allows for trade studies to be conducted to find weaknesses and assess solutions to improve kill chain effectiveness.

Fig. 4. Flight Plan Editing in Simulation – Systems Tool Kit

Having these capabilities exist in a simulated software environment provides analysts with the tools to iterate through a series of trials (changing aircraft performance characteristics and sensor details or moving the targets and adversary aircraft) and having the flight path automatically update for the new mission parameters. This makes it possible to efficiently evaluate a large mission deck and determine either how well a specific aircraft design will perform in a series of missions or what the requirements need to be to achieve the goals of each mission, such as wing loading, thrust and sensor/payload requirements.

Fig. 5. Flight Plan Showing Expected Communications Link Quality – Systems Tool Kit

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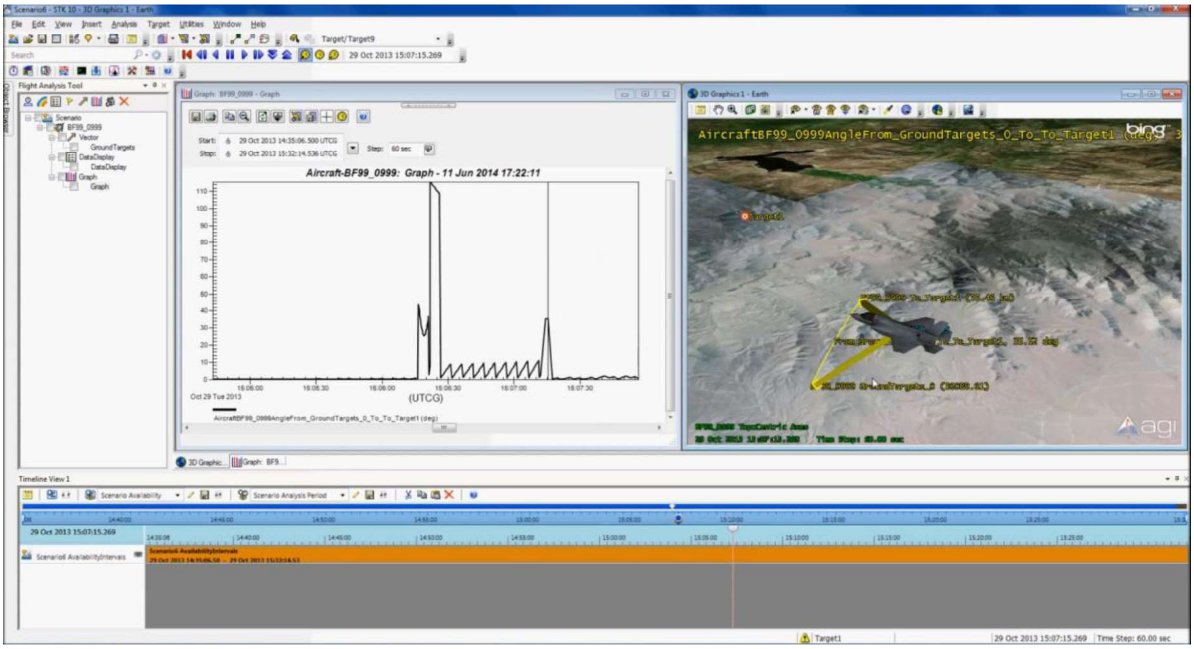

Fig. 6. Vector/Angle Calculations Between Aircraft and Target Locations During Flight

Acquisition

Proposed system designs can be explored within modeling and simulation packages and results can be compared and constrained to requirements, effectively determining whether or not the suggested system is capable of accomplishing the mission goal. For procurement of new systems, there is often the option to trade out various components (sensors/radars, weapons, etc.) and software simulation provides an analytical environment for direct comparison of component choices and their relative performance in current and future missions.

Aircraft performance models can be established for all platform choices such that each platform can be run through the same mission profiles and evaluated. Similar to definitions used during CONOPS and engineering design phases, the aircraft performance can be quantized based on metrics like maneuverability, range/endurance, detectability, and kill efficiency.

Beyond the base platform, the simulated communications and radar capabilities provide ways to evaluate the effectiveness of various payload options and their effect on the overall mission performance of the aircraft and it's systems under consideration. This provides a simple way to investigate the feasibility of different system designs in both measures of performance as well as implementation complexity or even overall system cost. For example, if a weapon has its own radar and is capable of guiding itself to an intended target, how much quicker can the aircraft be retasked rather than the aircraft's radar being required to guide the weapon to its target? Or for electronic countermeasures, which systems significantly improve an aircraft's ability to avoid being tracked by ground radars or incoming missiles?

By employing a robust modeling and simulation environment, these system design options can easily be linked to acquisition decisions and give designers and decision makers a common tool for validating and verifying design decisions.

Test and Evaluation

Modeling aircraft in a simulation environment prior to testing helps maximize the number of tests a vehicle can perform per flight such that fewer flights overall are required and ultimately contributes to saving time and money. The use of an end to end modeling and simulation package such as STK ensures a higher probability of having a successful flight, again reducing the number of required flights to accomplish a full evaluation of aircraft subsystems. The same models used in the design phase can easily be passed along to test and mission planners so that all of the high fidelity design work can be used to optimize flight planning.

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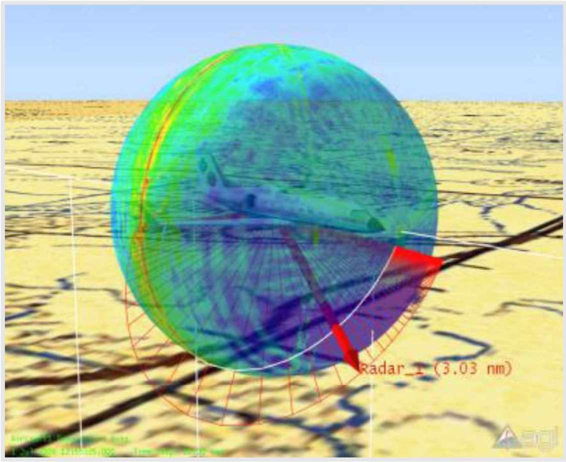

Fig. 7. Aircraft Radar Cross Section Visualized – Systems Tool Kit

These pre-mission simulation activities provide the ability to coordinate many objects and their interactions and intended behaviors. The time dynamic nature of STK provides the tools to synchronize position and orientation of all assets to maximize test efficiency. Simulating the test with supporting assets beforehand can also reveal the potential to fill white space with additional test points. For example, resetting a formation may also result in a flight path that presents an easy opportunity to test a given set of antennas at no extra cost.

Having the test plan plotted in a time-dynamic simulation environment then provides the ability to conduct pretest rehearsals or make quick changes on the day of the test. Rather than putting pilots in a real time simulator and flying the entire mission just to determine whether or not test metrics are collected as expected, operations can be simulated in faster than real time to generate test metrics and evaluate test quality. Moving this process further up the chain also yields significant time savings if test planners can evaluate each test procedure before even constructing the test mission deck, long before test pilots are involved.

On the day of the test, if flight conditions change, for example excessive winds that require the test aircraft to crab into the wind altering the geometry of the plan, a decision can be made as to whether or not adjustments to the flight plan can compensate for the crab angle or if the test is infeasible. This makes for a much more informed go-or-no-go decision, potentially saving both time and operational testing costs.

In addition to pretest planning, STK is also used for post mission playback and test validation. It provides the capability to plot the flight path, playback the mission at faster or slower than real time, visually inspect specific events and add visual indicators for test results such as color contoured flight paths, communication link indicators and dynamic data displays. Test result scenarios can even be shared as images, movies or hosted web based visualizations.

Northrup Grumman Integrated Systems used the STK desktop application to evaluate communications systems for airborne platforms. They were specifically concerned with performance based on antenna placement on the aircraft. After modeling the gain pattern, location and orientation of the antenna multiple flight profiles were evaluated to understand the coverage and blockages they would encounter during the test. By modeling the communications system and selecting optimal flight profiles before their test flights they were able to save millions of dollars in reduced number of flight tests as well as allowing them to deliver on schedule. Bruce MacDougall referred to the process as “valid flight testing at your desk”.

Operations

Moving beyond the test phase and into operations, an end to end modeling and simulation package can continue to provide performance evaluation in mission planning and real time operations. Importing intelligence information into the simulation environment allows planners to construct flight plans that optimize mission plans while minimizing other factors such as radar, acoustic and visual detectability.

Because STK offers a fully documented application programming interface (API), custom applications can be created on the same foundation as the engineering and planning tools. These custom interfaces can provide a simplified workflow which is tailored to the specific operator’s needs, only providing the features required for mission planning with the fewest number of inputs. This allows for individuals to take advantage of all the high fidelity analysis provided by the software, but without the need to learn the workflow for the detailed engineering tools available in the commercial desktop version of the application. This same API makes it possible to embed specific capabilities into existing applications. Since many operational systems cannot be fully replaced due to cost of development and time to retrain all of the operators, plugins can be integrated to augment current capabilities and provide additional functionality without building from scratch or having to change well known workflows.

In areas of real time operations, STK supports live data feeds such as DIS, HLA, and other custom data feeds as necessary to form a complete Common Operational Picture (COP). Entity tracks for all vehicles and resources involved in the operation can be imported into this same environment exposing the ability to compute relationships in real time: who can see who, where communications are available, where the areas of interest are and what assets are closest to them, and other mission critical information. Decision makers can intelligently sift through the vast amounts of data to issue well informed commands.

Summary

The commercial maturity of computer based modeling and simulation software packages provides a depth and breadth of capabilities to engineering activities, and an ease of integration within overall flight test and evaluation efforts. These modeling methods enable the evaluation of systems at reduced risk, and with significantly reduced cost.

Software capabilities are perfectly aligned for concepts development, mission analysis, and engineering design of systems under study while providing an invaluable tool in the study and development of design considerations and requirements in preparation for acquisition activities.

Leveraging commercial off the shelf modeling and simulation software provides unparalleled support across multiple aspects of the operational system program life cycle from system development to operational deployment.

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