The Demand for Automated Trade Studies and Optimization

A business white paper

AGI

Analysis software for land, sea, air, & space

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1   Defining trade studies

Trade studies, often called trade-off studies, are commonly used in the design of aerospace systems to find the best configuration that meets performance criteria. For mission planners, real-time operators, and post-mission analysts in the space and national security communities, trade studies analyze the factors in all theoretically realizable solutions in order to fully understand the design space of the system.

> **Parametric studies** involve analyzing one variable at a time to study the effects of assumptions about particular data.
>
> **Carpet Plot studies** analyze two independent variables by varying the two items over ranges and evaluating the resultant behavior of another parameter.
>
> **Probabilistic analyses** show the distribution of runs. Probabilistic studies in Monte Carlo fashion set up input parameters to follow specific distribution methods so analysts can study the resultant behavior presented in histogram fashion.
>
> **Monte Carlo analysis** performs a project simulation many times to calculate a distribution of likely results, and provides the probabilities of different possible outcomes. The larger the number of simulation runs, the more accurate the result.
>
> **Design of Experiments** analyzes multiple variables, creates a table of runs, and uses various design-type algorithms to study the effects on numerous parameters.
>
> **Optimization** techniques help determine the best possible solution based on the trade study results. Use different methods to determine other options such as near-optimal solutions and which variable most affects your results.

Since software is now available to perform these repetitive, prolonged, and cumbersome calculations previously done by hand, analysts can instead focus on learning the logic behind each of the tests and discovering which test to apply.

2   Introduction to automated trade studies

Automated trade study functionality is ideal for mission planners, real-time operators, and post-mission analysts in the national security and space communities. Trade studies are especially useful for current AGI software users, who use STK software to model the dynamic relationships between moving objects, considering complex constraints such as terrain obscuration, sensor fields of view, angle restrictions, and even weather. Through a product called STK/Analyzer, software users can perform analytical trade studies through a GUI-style interface, which eliminates the need for scripting and programming, and results in easier trade analysis. Optimizer extension for STK/Analyzer enables users to fully understand the design space of their system within STK scenarios, including those that leverage coverage analysis, trajectory optimization, route planning, communications link optimization, and costing analysis.

Users may import STK scenario objects into STK/Analyzer to build a representation of their scenario. The STK scenario can then be parametrically modified from a single location, rather than navigating through multiple dialogs in STK. Besides being easy to use, STK/Analyzer also benefits its users by:

- Performing parametric studies, carpet plots, Monte Carlo analyses, optimization studies, design of experiments, and post-processing functions 80 times faster than traditional techniques.
- Supporting the creation of analysis models, visualization of dataflow, ease of deployment, and the reduction of time and errors.
- Providing engineers with the tools to systematically answer complex questions such as:
    - Ø What orbit will satisfy my mission requirements?
    - Ø How does changing the timing of my maneuver affect my overall mission plan?
    - Ø How can I optimize my antenna properties to maximize signal-to-noise ratio?

Other standout features include the ability to:
- Perform trade studies on vehicles, ground stations, transmitters, receivers, sensors, and radar systems.
- Automatically collect data from STK for use in trade studies, eliminating tedious trial and error methods.
- Use the Data Explorer to help identify trends.
- Apply advanced search techniques such as Monte Carlo analysis or optimization.

3   Usage segments

The set of tools within STK/Analyzer add value to the STK user by introducing trade study and post-processing capabilities. STK/Analyzer can be used with all STK scenarios, including those with STK/Astrogator satellites, to perform the following types of analyses:

Parametric Study	One independent variable	Vary one item over a range and study the effects on various figures of merit defining performance.
Carpet Plot	Two independent variables	Vary two items over ranges and study the resultant behavior of another parameter.
Design of Experiments (DOE)	Table of Runs	Vary multiple parameters, creating a table of runs, using various design-type algorithms, to study the effects on various parameters.
Probabilistic Analysis	Distribution of runs	Run studies in Monte Carlo fashion, wherein input parameters are set up to follow certain distribution methods and study the resultant behavior. Output data can be analyzed and presented in histogram fashion.
Optimization	Minimize, maximize, or target a specific value	Systematically modify variables in a scenario until some objective is achieved.
Sensitivity analysis	Plot trends of selected parameters	Generate variable importance plots that illustrate the relative impact of selected parameters on a scenario, and generate main and interaction effects plots to view and understand overall trends.
Prediction capabilities	Interactively explore the design space	Predict output variable values for any combination of input variables, visualize slices of the resulting /n/-dimensional design space (including the effects of constraints), and manually explore and search the design space for good designs.

3.1 Visualize data trends through Data Explorer

View and understand trends and relationships within STK scenarios. Trade studies in STK/Analyzer are set up to automatically collect data from STK. The resulting data trends can be visualized in the Data Explorer to better understand the behavior of the scenario.

3.2 Easily incorporate into STK scenarios

STK scenario compatibility. STK/Analyzer is easily incorporated into STK scenarios focusing on mission planning, real-time operations, and post-mission assessment—including analyses that utilize other STK modules.
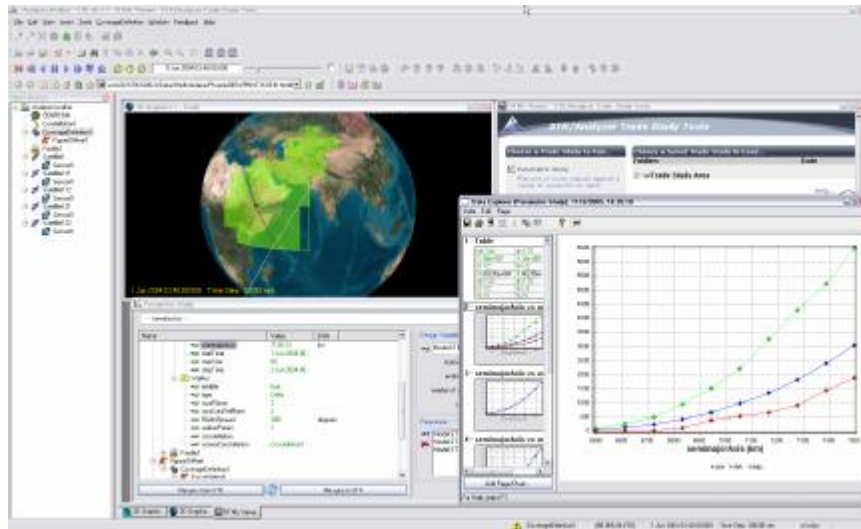
Easily import STK object parameters in STK/Analyzer for rapid trade space analysis.

Easily import STK parameters into the STK/Analyzer GUI by dragging and dropping for quick analysis of a scenario trade space. Analyze variables and segment types, such as maneuvers, stopping conditions, backwards propagation sequences, and other parameters from STK/Astrogator. STK/PRO features the Aircraft Mission Modeler propagator that allows aircraft route optimization through the use of STK/Analyzer.

3.3   High-fidelity outputs

High-fidelity outputs. A tabular report produced by STK/Analyzer contains all of the possible output data, including customizable reports and graphs, coverage and deck access reports, and gap duration for access times. Any subsets of these outputs can be exported to Microsoft Excel for further manipulation. Some of the graphs styles available include:

- 2D Area
- 2D Bar
- 2D Horizontal Bar
- 2D Line

- 2D Pie
- 2D Point
- 2D Polar
- 3D Surface Plot

- Carpet Plot
- Color Grid
- Contour Plot
- Main Effect

3.4   Optimization techniques

The Optimizer extension for STK/Analyzer is an integrated add-on module that adds three different optimization algorithms to the four existing parametric analyses offered with STK/Analyzer, and is accessed from the same GUI interface. Using any combination of input variables and objectives, Optimizer extends STK/Analyzer's capabilities by employing three optimization algorithms along with two design space tools.
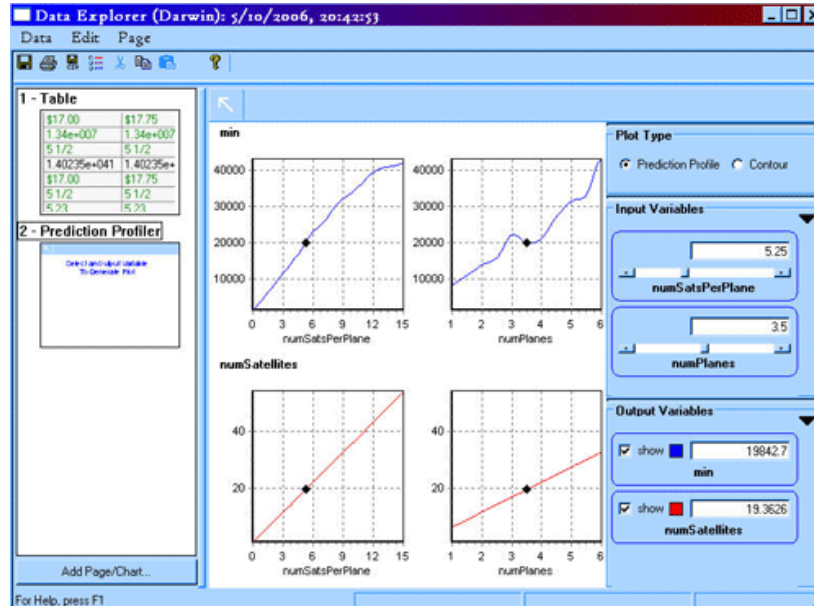
Explore data trends through the use of the Prediction Profiler tool found in the Optimizer extension of STK/Analyzer.

Three optimization algorithms

Gradient-Based Optimizer: Local search for optima in problems with smooth, continuously varying objective and constraint functions.

Adaptive Surrogate Optimizer: Part of Boeing's Design Explorer software, the Adaptive Surrogate optimizer solves complex problems characterized by long running analyses. It intelligently uses non-physics-based mathematical models (Kriging models) to reduce the number of required scenario executions. A global search algorithm, it is not likely to get stuck in local optima. The software also performs well in noisy design spaces and is robust in the face of scenario failures.

Darwin Genetic Optimizer: Darwin Genetic algorithms are ideally suited for design problems with discretely valued design variables (e.g. integer variables). Because they do not require objective or constraint gradient information, genetic algorithms effectively search discontinuous and "noisy" design spaces. Compared to gradient-based optimization algorithms, genetic optimizers are much more likely to find the best design. They can find many near-optimal designs too, thus providing more design alternatives.

Darwin Genetic algorithms accommodate up to three objectives for your design problem. For multi-objective problems, Darwin generates a Pareto trade-off curve. The design points on the Pareto curve are all optimal in that they represent a point that would be impossible to improve without degrading one objective over the other(s).
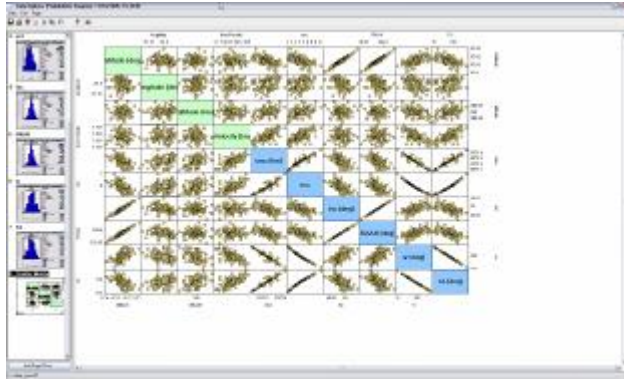
Design space tools

Variable Influence Profiler: The complexity of the design task can be significantly reduced by focusing on those variables that are most influential, and by placing less emphasis on those variables with little influence. Gaining a better understanding of variable relationships and overall design trends encourages more effective design problem formation and location, and ultimately, more accurate optimization results.

Prediction Profiler: This tool can be used as a "manual optimizer" to locate good designs, or it can be used to find good starting points for a more formal optimization algorithm. It may also be used as a post-processor to visualize the design space around an optimum point generated by an optimization algorithm.

4 Use cases

4.1 Overview

STK/Analyzer is an engineering tool to understand & manipulate relationships of objects in STK, perform trade studies/"what if" analyses, and discover optimal solutions within a system design space. This is truly an analysis tool for all STK users across the board—not for a specific market or type. Many STK users need to perform comprehensive engineering studies with their STK scenarios that involve satellites, missiles, sensors, transmitters, receivers, and radar systems in order to understand and/or optimize system performance. Users also need to optimize their STK scenario as part of optimizing their overall system.

The following "use case" examples describe the usage of STK/Analyzer for mission planning, real-time operations, and post-mission assessment in the areas of space systems, battlespace management, national defense programs, and geospatial intelligence.
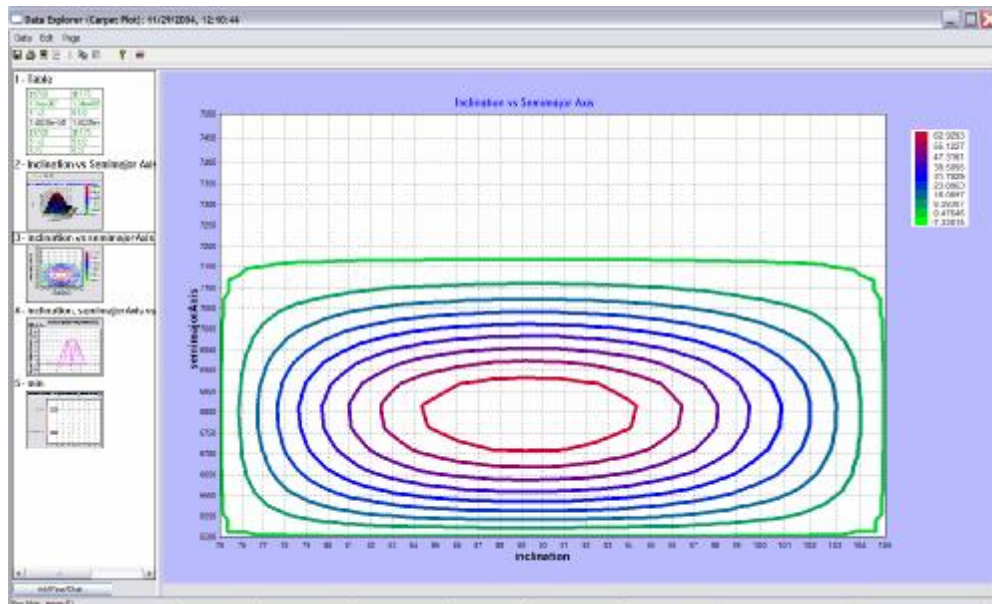

STK/Analyzer provides numerous graph and report styles for custom data analysis.

4.2   Space systems

AGI products support space-based systems for concept, design, deployment, and actual operations. System designers need to study proposed systems to evaluate and understand the effect of varying different aspects of the system. Users may include satellite system designers, payload/sensor designers, communications engineers, and more. Their usage may involve analyzing the effects of different satellite orbit parameters (one or multiple), different sensor designs, or different receiver/transmitter designs versus requirements. Mission designers—pre-mission or during satellite operations—can analyze orbit sensitivities to different initial conditions, whether from launch vehicle drop-off dispersions at the beginning of the mission or satellite maneuver performance throughout the mission. Satellite operators need to design maneuvers to understand the effects of burning at different attitudes or different times. STK/Analyzer aids in analyzing all areas of space systems including applications in reconnaissance, communications, navigation, science, and exploration by discovering solutions to questions such as:

- What particular orbit will best satisfy my requirement?
- How do I optimize maneuvers to minimize fuel usages?
- How does changing maneuver timing affect the overall mission plan?
- My launch vehicle will give me a certain set of drop-off conditions with known distributions – what will that mean to my final orbit?
- How do parameters affect inter-visibility with communications and navigation systems?
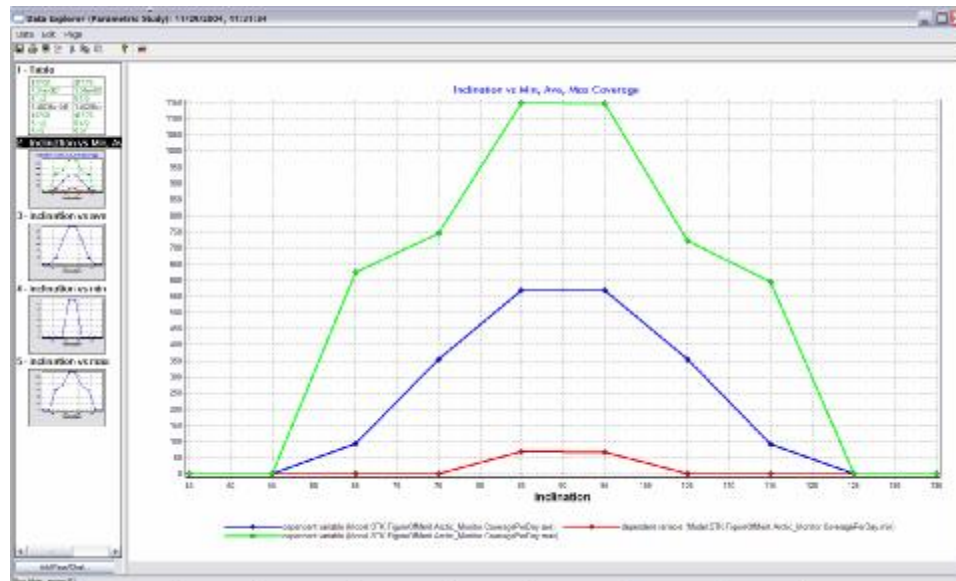
Perform parametric analyses to study the effects of orbital parameters on Space System missions.

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4.3 Battlespace management

Driven by the speed of battle today, decision makers need visibility into all assets and feedback on all activities and movement on the battlefield. The Aircraft Mission Modeler tool allows users to specify mission parameters and phases, along with empirical, airframe-specific deterministic models, to model any necessary flight in STK. Further analysis can then be performed with the STK suite of tools, knowing that the mission representation is accurate. By combining the Aircraft Mission Modeler with the expanded capabilities of STK/Analyzer, users can now perform system trade studies of various mission routes, analyzing the effectiveness of different plans. STK/Analyzer allows battlespace management professionals to analyze tactical information of theater operations by discovering solutions to questions such as how to:

- Perform engineering trade studies of radar systems?
- Configure my satellite constellation to maximize coverage time?
- Design optimal sensor characteristics?
- Evaluate multiple asset/target performance as a function of time?
- Maximize my aircraft/ground vehicle routes for communications and observation?

4.4 National defense programs

AGI software provides accurate detailed solutions for specific defense program needs such as missile system design, radar system design, threat analysis, and intercept analysis. STK/Analyzer assists system engineers throughout all phases of missile defense programs by discovering solutions to questions such as:

- How can I optimize defense system parameters to maximize coverage?
- How do changes in power affect the link budget?
- How can I perform engineering trade studies of missile systems?
- How can I optimize my antenna properties to maximize SNR?
- How do communication system parameters and constraints affect navigation?

4.5   Geospatial intelligence

AGI technology can calculate the precise locations of dynamic platforms and assets and model sensor motion and field of view by using algorithms ranging in fidelity from simple analytical models to high-precision physics-based simulations, or by ingesting real telemetry and tracking data. STK/Analyzer provides tremendous benefit to geospatial analysts by discovering solutions to questions such as:

- How can I modify orbit characteristics to maximize coverage time?
- How should I vary transmitter frequency, data rate, and power in order to get the best minimum Eb/No?
- How does modifying UAV routes affect the over-flight period of an area of interest?
- How can I optimize my sensor characteristics?
- How does my coverage change if inclination and RAAN are allowed to change?
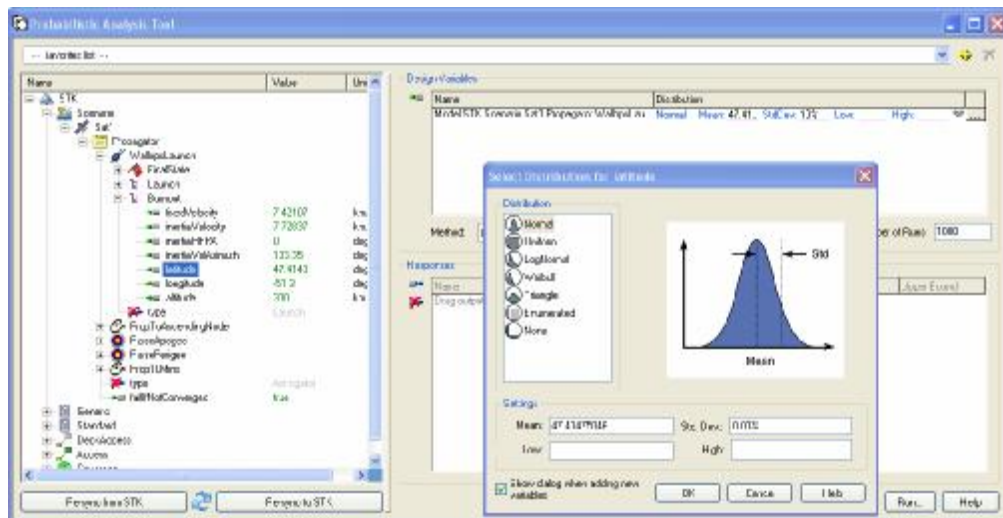
Use the Probabilistic Analysis Tool to run studies in which input values are not exact, but which follow a distribution function.

5   Implementing STK/Analyzer with other STK modules

Those who use AGI products STK/PRO, STK/Comm, STK/Astrogator, STK/Coverage, or STK/Radar will recognize the complementary nature between these products and STK/Analyzer.

5.1 STK/PRO

STK/PRO and its Aircraft Mission Modeler enable users to perform complex, highly accurate, time-based mission analysis for aircraft operations. Use Aircraft Mission Modeler with STK/Analyzer to discover solutions to questions such as:

- How can I maximize my collection time over an area of interest?
- How will changing my maneuver timing affect the overall mission plan?
- How can I optimize my aircraft route to avoid threats?
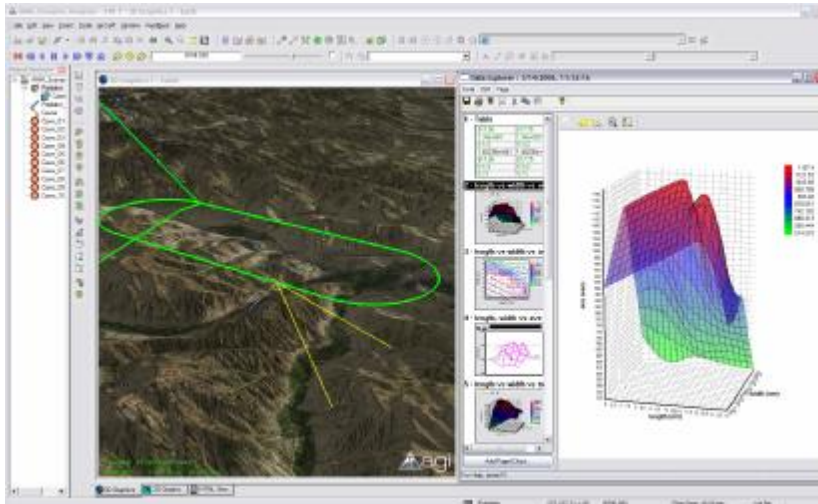
Use Optimizer extension for STK/Analyzer to optimize aircraft routes for analysis of maneuver timing on overall mission planning.

5.2   STK/Coverage

STK/Coverage aids a user's ability to quantitatively measure trade study results. Use STK/Coverage with STK/Analyzer to discover solutions to questions such as:

- How can I configure my constellation to maximize coverage time?
- How does my coverage change versus inclination?
- How does my coverage change if I change my sensor focal length?
- How does my coverage change if inclination and RAAN are allowed to change?

5.3   STK/Comm

Use STK/Comm with STK/Analyzer to discover solutions to questions such as:

- How do changes in power affect the link budget?
- How do I design optimal sensor characteristics?
- How should I vary transmitter frequency, data rate, and power in order to get the best minimum Eb/No?
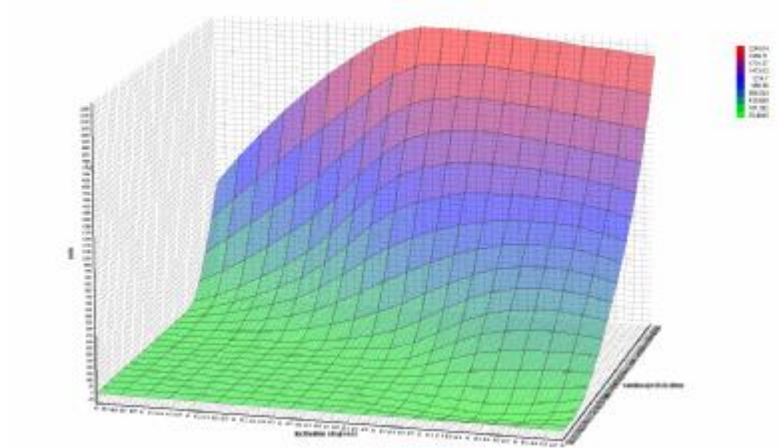
Use Carpet Plots to quickly analyze communication system parameters.

5.4   STK/Astrogator

Use STK/Astrogator with STK/Analyzer to discover solutions to questions such as:

- How to figure out what particular orbit will best satisfy a requirement?
- How to optimize maneuvers to minimize fuel usage?
- How changing the timing of my maneuver will affect the overall mission plan?
- How does my semi-major axis change if I vary my finite burn attitude?
- My launch vehicle will give me a certain set of drop-off conditions with known distributions – what will that mean to my final orbit?
- How do I determine the optimal position to minimize fuel for a maneuver?

5.5   STK/Radar

STK/Radar is a fully-integrated add-on application for STK that provides thorough analysis and graphic displays of radar systems. Use STK/Radar with STK/Analyzer to discover solutions to questions such as:

- How do I perform engineering trade studies of radar systems?
- How do I evaluate multiple asset/target performance as a function of time?
- How can I optimize my antenna properties to maximize SNR?
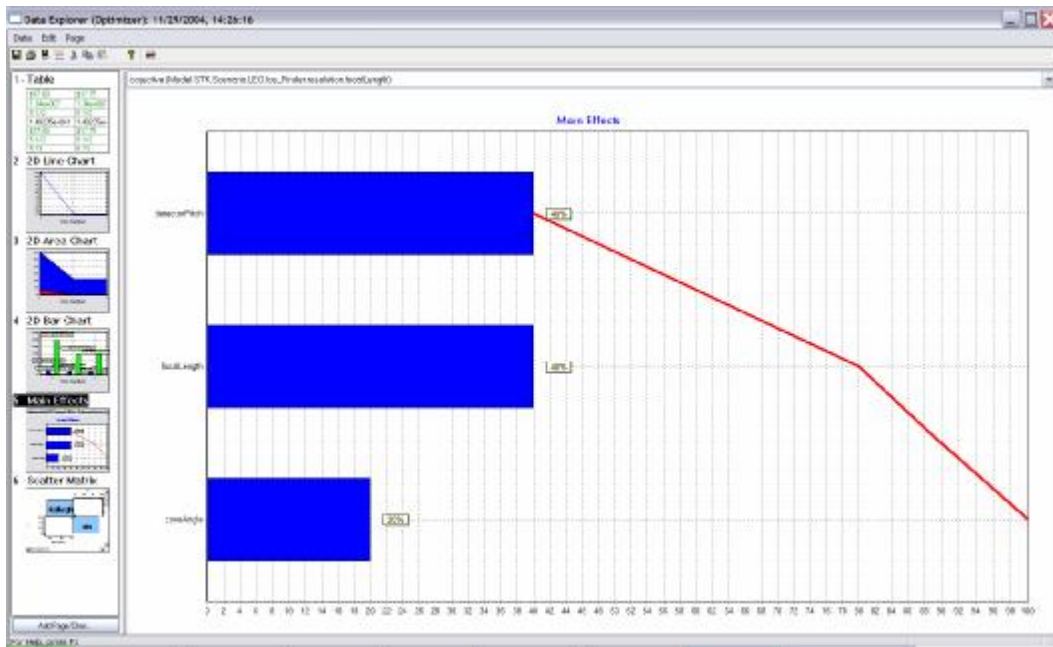
The Carpet Plot tool produces a variety of charts, including Main Effects that reports the average impact across data sample of changing one variable from its minimum value to its maximum value.

6   Accelerate analyses and adoption of new techniques

6.1   Customers

A sample of current STK/Analyzer customers include: The Aerospace Corporation, Boeing, Booz Allen Hamilton, Department of National Defense, Johns Hopkins University Applied Physics Laboratory, Honeywell Aerospace, L-3 Communications, Lockheed Martin, Mantech International, NASA, Northrop Grumman, Raytheon, U.S. Navy, and U.S. Air Force.

A case study on NASA Goddard's use of STK/Analyzer is available by request at *info@agi.com*.

6.2   Business partners

STK/Analyzer was created to blend the engineering analysis capabilities of Phoenix Integration, Inc.'s ModelCenter™ with AGI's STK software.

Background of Phoenix Integration
- Experience providing flexible and scaleable enterprise solutions for process integration and design optimization for nearly a decade.
- Commitment to saving time, streamlining processes, optimizing successes, and enhancing product performance for multi-disciplinary engineering design problems.

6.3   Training

Ø   HANDS ON: Year-round AGI training opportunities are available at worldwide locations. Review course descriptions, schedules, and registrations online at: *www.agi.com/training*.

Ø   ONLINE: Instructional monthly webinars give users "how-to" demonstrations; join your colleagues at *www.agi.com/webinars*.

Ø   EVENTS: Check out the AGI Events page at *www.agi.com/events* to meet AGI experts in person. Stay tuned to *www.agiuc.com* for information about the next AGI Users' Conference.

6.4   Annual software support & upgrade agreement (UGA)

AGI's software maintenance program (UGA) provides customers with:

- Ø   Frequent upgrades
- Ø   Software transfers
- Ø   Live product support

Frequent upgrades:

STK upgrades are comprehensive enhancements of the software suite, with an emphasis on the core modules—STK, STK/PRO, STK/Advanced VO, and STK/Connect. These core modules enhance the capabilities of all customers' configurations regardless of their additional module selections. Most upgrades are also applicable across multiple modules. For example, an enhancement to STK/Communications (STK/Comm) that supports customizable plug-in models for atmospheric modeling is also applicable to the STK/Radar module. All major product upgrades are proactively shipped on CD-ROM directly to the customer's maintenance point of contact upon official AGI software release. Maintenance releases are available via the AGI Web site at *www.agi.com/mr* or on a CD-ROM upon request. AGI software under active UGA may be transferred from one computer or operating system to another up to three times within the annual contract dates. Additional transfers of these products may be performed by incurring a nominal software transfer fee.

Software transfers:

To guarantee superior performance with future releases, all AGI software products should be upgraded.

Live product support:

AGI employs aerospace engineers dedicated to providing high level customer support. The primary role of this tech-savvy team is to provide product support to customers with active UGA. Direct access to them is available weekdays from 8:00 a.m. to 8:00 p.m. ET.

Accommodations for customers requiring additional, after hours, or weekend support can also be arranged.

Product support activities include:

- • Scenario development

- • Integration with third-party applications

- Installation trouble-shooting

- Support for software best practices

Product Support contact information:

Phone: 800.924.7244 (toll-free in U.S. & Canada)

      610.981.8888

E-mail: *support@agi.com*

6.5 Operating systems, compatibility, and licensing

Operating systems:
Windows 2000, XP, NT

Compatibility:
STK/Analyzer is compatible with STK 6.1 and all subsequent versions.
Software footprint: 110 MB

Licensing:
STK/Analyzer is a separate STK module, requiring a separate CD and license. Although a separate executable, it requires STK Standard (free version) to run, and is launched from within STK, appearing to the user as an embedded STK module. Contact your AGI sales representative for further information on obtaining a demo license.

Phone: 610.981.8000 or 800.220.4785 (toll-free in U.S. & Canada)
E-mail: *info@agi.com*