Planning space missions with FreeFlyer

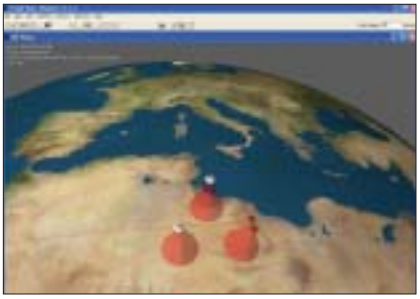
Many of these columns have focused on core engineering—structures, CFD, control design, and the like. However, this does not mean that computers in the aerospace and defense industry are used mainly for core engineering. In fact, much of their use (and that of the appropriate COTS or proprietary software) is related to the business and operations segment. Through the power of modern computers, sophisticated tasks such as space mission planning are possible on personal desktop or laptop computers. Several companies provide tools for mission planning and processes. One is a.i. solutions [http://www.ai-solutions.com] in Lanham, Md.

a.i. solutions develops and markets FreeFlyer, a COTS software suite that supports the entire mission life cycle. It comes in three different versions: Design (the core product), Engineer, and Mission.

FreeFlyer: The product

FreeFlyer *Design* provides mission concept development and preliminary design. It enables flight engineers to define trade spaces for optimum mission profiles. Tasks such as determining the best orbit design, ground station location, coverage times, and propulsion system sizing are just some of the analyses that FreeFlyer Design can provide. It also has a graphic user interface (GUI) with drag-and-drop functionality for problem setup and output generation.

Three-dimensional analysis is one of the features of FreeFlyer.



Each run is controlled by the GUI-built Control Sequence, which allows the user to set up each simulation or operations scenario in an ordered and readable form. The GUI also allows rapid access to all objects being used for the simulation, and it specifies all output types. Through the GUI, the user can build and modify spacecraft and associated hardware, ground stations, ground area targets, control boxes for stationkeeping, and close-proximity operations and formations/constellations of spacecraft to be treated as a single object.

The FreeFlyer computational engine handles complex orbit and trajectory simulation problems. The company states that all calculations have been independently verified and validated. The engine's dynamic nature, (unlike that of batch data processing) provides real-time feedback through plots, reports, and 3D graphics at each integration step. This feature allows the user to stop a run at any point rather than having to let each run finish before being able to see and interpret the results.

The product takes all spacecraft physical properties—including mass, center of mass, inertia, form factors, aerodynamic properties, sensors, tanks, thrusters, and transceivers—and makes them available for user input and manipulation. These parameters can even be accessed, monitored, and modified in real time at each integration step during any simulation.

FreeFlyer has a host of visualization, plotting, and reporting tools. It offers a 2D and 3D visualization environment for displaying simulation or operational data in real time. It provides an intuitive and user-interactive view of all simulation objects, including orbit geometry, spacecraft position and attitude, sensor projections, ground stations and their masks, and ground area targets. Each view can be preset to user-defined viewpoints or changed in real time by interactive user panels.

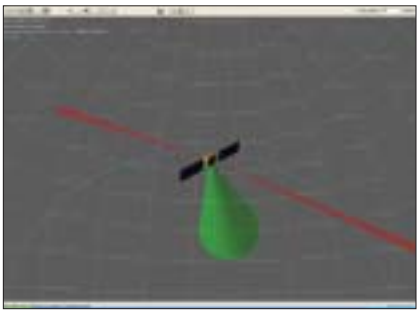
The software supports unlimited window tiling to allow multiple views of the same problem from different perspectives—all updated in real time. It also allows unlimited customizable reports and plots to be generated on any data calculated. It incorporates over 150 predefined orbit parameters in addition to the customizable parameters that can be included.

FreeFlyer *Engineer* has additional features to support detailed mission design through operations support and automated maneuver planning. The scripting language feature allows users to add other functions and implement even the most complex control laws or mission-unique requirements without the need for recompiling or purchasing add-on modules.

The maneuver and sensor analysis components are the key features of this module. FreeFlyer supports precision maneuver modeling and analysis for both impulsive and finite maneuvers. Engineers can build precise models of spacecraft propulsion systems through definitions of the tanks (spherical or interpolated) and thrusters attached to each tank.

For finite maneuvers, fuel mass depletion and mass remaining are integrated during the maneuver using the ideal gas law and mass flow rate equations. The performance, thrust scale factor, and duty cycle information for each thruster are fully modeled to give an accurate representation in either pressure-regulated or blow-down configurations. Targeting for maneuvers is handled by a differential corrector that handles standard square and nonsquare problems.

Standard detailed reports are automatically generated for each maneuver performed. In addition, the user can customize the maneuver output report to any level of detail and precision desired. For sensors, FreeFlyer allows flexible modeling of simple or complex spacecraft sensors. Engineers can select from simple conic models or define their own complex irregular polygon shapes with obscuration definitions. Sensor coverage to ground



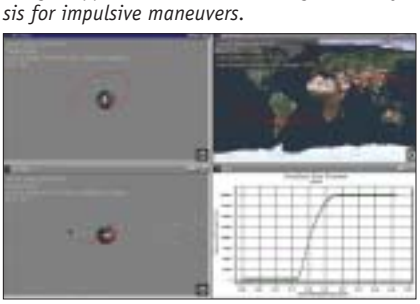
FreeFlyer Design allows attitude modeling based on Euler angles and rotation sequence as input.

targets or other spacecraft/target objects can be easily analyzed. Sensors can also be set up for active tracking of targets.

One extra set of features involves ground system integration and automation. FreeFlyer was designed to integrate with third-party ground system or mission operations software to provide the flight dynamics function as a turnkey service. It allows automation of many routine flight dynamics tasks required in the operations environment, such as maneuver planning, orbit product generation, and orbit determination. A fuzzy logic engine is included to allow for automated resolution of complex problems with conflicting constraints.

FreeFlyer *Mission* provides more features that integrate with ground system or mission operations software. It provides full-flight dynamics functionality that integrates with other ground system or third-party operations software. One key set of features for Mission is in the orbit determination function. Its features include tropospheric correction, ionospheric correction, and light-time correction measurement modeling techniques.

Design supports maneuver modeling and analysis for impulsive maneuvers.



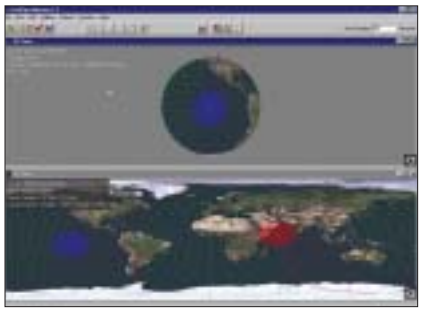
The orbit determination feature can handle a variety of data types—ground-based measurements (range, range rate, angles), TDRS-based measurements (one-way Doppler, two-way range, two-way Doppler), and GPS measurements (position only, velocity only, and position and velocity). It provides for user-selected solve-for parameters such as orbit states, drag, solar radiation pressure, ground station geodetic biases, and measurement biases. Inputs from other sources can be either ASCII/binary data files, ODBC-compliant database, or TCP/IP socket. The data formats supported include ASCII, UTDF (TDRS UTDF), DSN, GPS, CERES, and user-defined formats supported with database or socket input.

One of the benefits of using Mission is that it offers multiple external interface features that enable users to connect and exchange data with other software systems. The MATLAB interface (from MathWorks, www.mathworks.com) allows users to exchange data with MATLAB at every FreeFlyer integration step. This allows users who have algorithms already in MATLAB to attach and use these during a FreeFlyer run and gain the flexibility of the software's output functionality to display data. This feature is also extremely useful for those who have proprietary or mission-unique attitude or control laws already written in MATLAB.

Mission examples

Several aerospace examples show the versatility and range of problems FreeFlyer helps solve. For the Aqua spacecraft mission, engineers needed to find a way to automate the targeting of routine ground-track stationkeeping maneuvers. With FreeFlyer, engineers used conditional branching with specialized spacecraft events, generated via the scripting language. FreeFlyer implemented an automated solution in which the same maneuver profile was used for automating each required future maneuver.

The EO-1 on-board system needed a plan for the maintenance maneuvers carried out aboard the spacecraft. Developers at a.i. solutions created an on-board version of FreeFlyer to meet mission requirements. This solution has autonomously controlled EO-1 maneuvers on orbit.



The computational engine handles complex orbit and trajectory simulation problems rapidly.

The Global Precipitation Measurement program used FreeFlyer to determine the optimal placement of six spacecraft to complement the measurements from preexisting assets. Driving FreeFlyer with the MATLAB Optimization Toolbox through a TCP/IP socket allowed engineers to implement a system for making this determination. In addition, engineers needed to calculate coverage statistics for a complex shaped sensor within a limited latitude band of ±60°. FreeFlyer used a combination of point group and sensor objects to generate 1-hr coverage pictures for month-long propagations.

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FreeFlyer is not perfect, of course. The user interface, although quite flexible, is a bit cumbersome and clunky. Its performance is somewhat slow, specifically for larger case missions. Many missions are using just certain components of FreeFlyer and not using all the capabilities, exclusively, for a specific mission. That being stated, FreeFlyer is helping mission designers, analysts, and planners. Its continued use in current missions is a statement of its acceptance in the industry.

Its price point is also a big consideration—you can do more with it for less money than with other software on the market. Stay tuned for more about FreeFlyer—a major update is just around the corner.

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NOTED IN BRIEF

Engrasp (Arlington, Texas) [http://www.engrasp.com] announces the release of **Engineers Toolbox Version 2.5**. The graphically driven system provides rapid solutions to engineering problems using first principles, empirical correlations, experimental data, rules of thumb, and numerical solutions to conservation equations. This release is multidisciplinary and includes calculation modules for solid mechanics, fatigue and fracture mechanics, dynamics, and controls, fluid mechanics, and heat transfer. The expanded capabilities can be applied to compute flow rate, pressure drop, and heat transfer coefficient in fluid transport devices. Also included are calculation modules to compute water-hammer effects and forces resulting from flow turning. Enhanced input/output capabilities include print support, print preview, print to pdf, and the ability to save animation and image files.

GlobalSpec (Troy, N.Y.) [http://www.globalspec.com] introduces **The Engineering Search Engine**, which has garnered wide acclaim from analysts, industry experts, and engineering organizations as "the model" for vertical search. The company also unveiled **The Engineering Web**—200 million tech-centric Web pages filtered from the World Wide Web for their engineering relevance. GlobalSpec unlocked the hidden Web for the engineering community by providing proprietary technical content not found on other search engines. This includes material that is categorized and organized for greater efficiency on the part of the user—application notes, standards, patents, and material properties. SpecSearch is GlobalSpec's parametrically searchable industrial products database and is already the world's largest aggregation of digitized OEM and distributor catalogs. Last year it grew to contain more than 78 million parts from more than 1.2 million product families in 12,500 electrical, mechanical, optical, and manufacturing OEM and distributor catalogs. GlobalSpec has also formed partnerships and strategic alliances with major industry leaders, including SolidWorks, IHS, MicroPatent, MatWeb, Dice, and Onlinecomponents.com.

Agile Software (San Jose, Calif.) [http://www.agile.com] announced **Agile e6**, which supports the complex engineering business processes, technology platform, and integration requirements of aerospace and defense manufacturers. This release includes new and expanded functionality for the Agile Product Data Management module and Agile e6 PLM platform. Also new to e6 is the Agile Customer Needs Management module, which enables companies to make better, more informed decisions in the early phase of the development process by closely linking customers, marketing and product management, development, and quality assurance. This new module helps manufacturers manage the complexities that occur with products that are offered in large variances. It also enables users to manage product families and derive individual product configurations in an engineered-to-order or assembled-to-order environment.

SolidWorks (Concord, Mass.) [http://www.solidworks.com] is now offering its customers access to a new service that lets them more quickly, easily, and affordably design and test increasingly sophisticated microelectromechanical systems (MEMS), microdevices, and microscopic mechanical parts. In offering the service, called **EFAB Access**, SolidWorks has joined forces with **Microfabrica,** a leader in microdevice fabrication, and **MOSIS,** a leader in low-cost integrated circuit prototyping via multiproject runs. EFAB Access is based on Microfabrica's breakthrough technology, which involves depositing many metal layers with micron precision. The service allows organizations to use 3D mechanical design software to design and manufacture MEMS and microdevices as part of a single solution. The SolidWorks line is the recommended design software for EFAB Access and enables viewing of 3D micro geometry as it will appear when fabricated in layers. EFAB Access leverages MOSIS's unique multiproject run fabrication process, which aggregates multiple, typically unrelated projects from diverse designers on the same wafer. Normally, each customer requires a wafer dedicated to a single device, driving the cost beyond the reach of many organizations.

Esterel Technologies (Mountain View, Calif.) [http://www.esterel-technologies.com] announced the newest version of its SCADE Suite product, which includes the latest version of its KCG DO-178B-qualified and IEC 61508-certified C code generator. The **SCADE Suite 5.0** Code Generator KCG 4.2 has recently renewed its DO-178B tool qualification for use in avionics environments. Certification agency approvals eliminate the need for unit testing for SCADE block diagrams, thus enabling fast and safe implementation of design updates. It natively supports all certifiable real-time operating systems, including ARINC-653, VxWorks, MicroC/OS-II, and TTP-OS, enabling a fully certifiable design flow for safety-critical embedded systems. SCADE Suite 5.0 can now be integrated with existing design environments featuring Simulink/Stateflow; the DOORS Requirements Management environment; Microsoft SCCI-compliant configuration management tools; and the Altia graphical design environment.

Numerical Algorithms Group (Downers Grove, Ill.) [http://www.nag.com] announced that its **IRIS Explorer Release 5.2** is now available on the Mac OS X platform. A system for visualization of scientific data, it has a visual programming interface that enables users to build applications from software building blocks, or modules. This modular design maximizes flexibility in visualization development—within seconds, researchers can try several ways to convert numerical data into different types of pictures. IRIS Explorer's distribution includes hundreds of modules. Users can add new functionality by writing their own modules using the development tools provided. The 3D visualizations created by this software can be manipulated in real time and can be used for displaying scientific data from chemistry, physics, and other disciplines, together with engineering data from finite-element modeling and CFD. IRIS Explorer is especially useful in research projects that require tools for multiuser visualization, since it lets the user share a visualization pipeline with researchers on other machines in a heterogeneous network.