Copernicus Trajectory Design and Optimization System

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Future space missions can involve multiple spacecraft, multiple destinations, multiple gravity fields, and multiple or hybrid propulsion systems. These complex missions will require intricate trajectory design and optimization, fast and high-precision results, large multidimensional trade spaces, and analyses of both mission design concepts and mission operations. The Copernicus Trajectory Design and Optimization System provides a solution to these future mission design demands with a general, robust, efficient, and practical high-fidelity three-degrees-of-freedom tool to determine timely and accurate solutions for both human and robotic exploration studies.

Copernicus can generate engineering solutions for a myriad of possible planetary and interplanetary destinations including, but not limited to, lunar missions, Earth neighborhood libration point missions, interplanetary missions (including missions to satellites of the outer primary planets, asteroids, and comets), powered flight landing/ascent maneuvers, formation flying, far-field rendezvous, and weak stability boundaries.

The power of Copernicus lies in a standardized methodology used to solve problems, coupled with an integrated output that provides immediate graphical feedback to the user as to the "goodness" of the solution. This approach allows Copernicus to produce high-precision solutions for a large range of (complex) missions with faster response time.

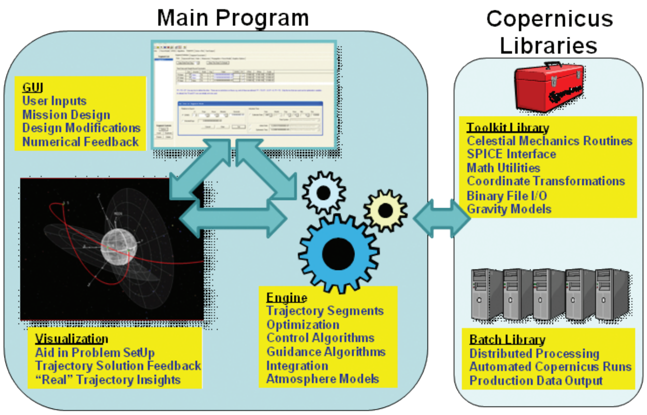

Fig. 2. *Copernicus integrated input graphical user interface, trajectory visualization, and processing engine.*

This tool can be used by mission designers, researchers, and students, and has both civil service and contractor users at several NASA centers, commercial industry, and academia locations across the country. Copernicus has been used in the trajectory design for the successful Lunar Crater Observation and Sensing Satellite mission (figure 1) as well as a plethora of architecture, mission, trajectory, and analysis studies for the Constellation Program, Orion Project, and NASA Headquarters.

A key advantage of the system is its versatility—it was specifically designed to address trajectory design and optimization issues associated with many different mission classes. Copernicus is a unique software tool because it integrates a powerful modular trajectory design and optimization engine, an easy-to-use graphical user interface, and interactive visualization. This interaction is a key component in the solution process because it helps the user to understand the construction of the solutions and to produce a convergent sequence of iterations to create a final mission trajectory.

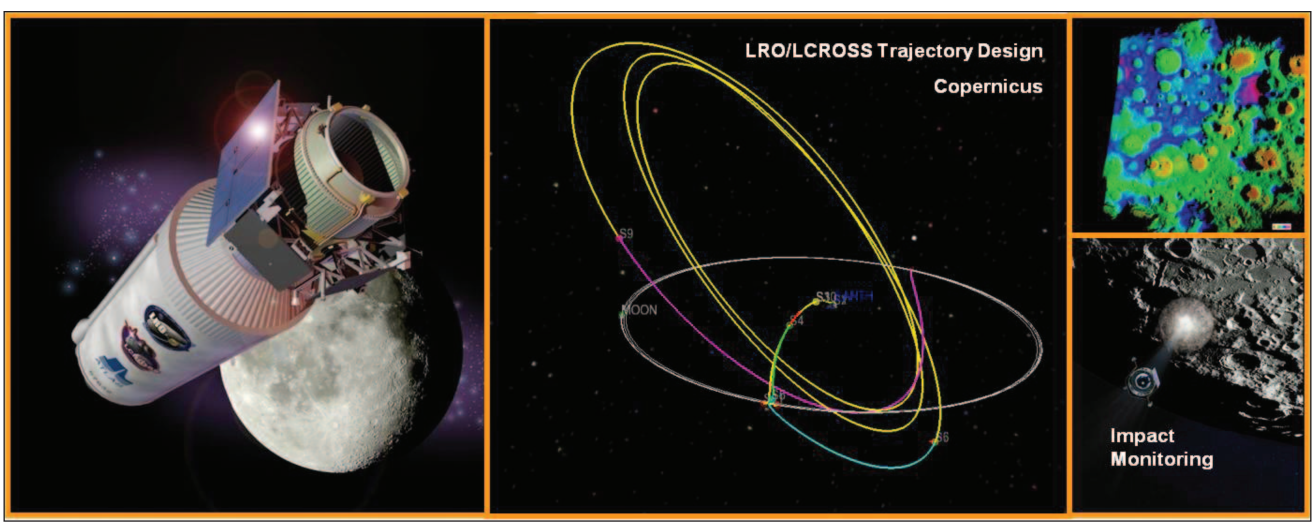

Fig. 1. *Copernicus-based trajectory design for Lunar Crater Observation and Sensing Satellite mission.*

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continued

Copernicus also interfaces with a modular tool kit library of coordinate frames, environmental models, ephemerides, and utilities (figure 2).

In addition to being a key component of the tool suite, this tool kit is also a foundation for developing other programs and processors, such as the Mission Assessment Post Processor, which was used extensively in Orion propellant requirement analyses.

Copernicus can run on a Windows-based PC platform or a Unix-based computer cluster. The Unix configuration—a batch processing mode—is well suited to computationally intensive tasks and has been used extensively. For example, analysts used this batch processing mode to run Copernicus automatically, millions of times, to generate large performance matrices in support of the Constellation Program. The team then used the large amount of data in these matrices to assess the on-orbit performance requirement for landing anywhere on the lunar surface and during a metonic cycle (approximately 18.6 years). With this batch capability, analysts could better understand the statistical nature of the performance requirement, and thus the impact of changing the Orion spacecraft propellant loading.

Copernicus is a segment-based system that uses a segment object as a basic building block to construct simple to complex trajectories (see figure 3). The segment building block contains numerous parameters that model a single spacecraft. These parameters include: mass and state properties, propulsion system, and boundary conditions. Multiple segments constitute a spacecraft mission, and because users have total control over how to connect these segments, they can model single or multiple spacecraft problems.

The methods used to propagate the equations of motion and the methods used to converge and satisfy the boundary conditions are independent and selectable. This results in a highly versatile system. It is a system that evolves seamlessly as new modeling and optimization techniques are developed and introduced to the state-of-the-art suite of algorithms.

The user-friendly design of Copernicus allows the analyst to quickly translate an idea and initial drawing or

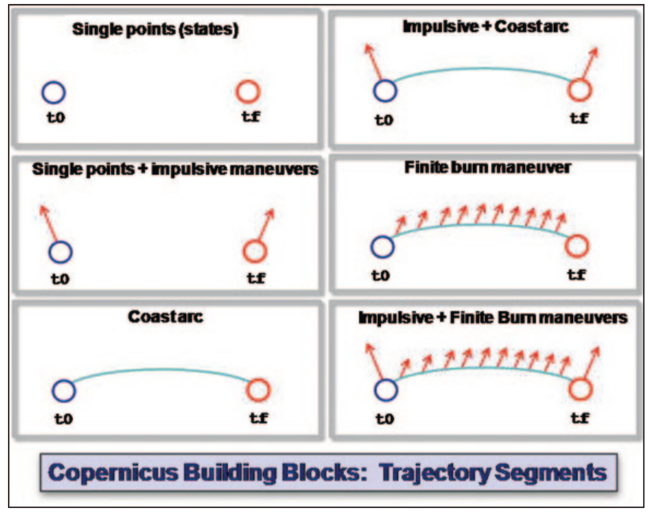

Fig. 3. Copernicus building block trajectory segments.

schematic into a high-fidelity powered flight trajectory. Figure 4 shows a conceptual view of the solution process for a low-thrust variable specific impulse round-trip Earth-Mars mission with constraints on stay time at Mars and overall mission duration. The analyst maps an initial schematic of the problem (upper left) by entering appropriate mission inputs (lower left) into the simple-to-use graphical user interface. A graphical output of the solution (right) includes the transfer orbit and indicators of thrust magnitude and direction during the trip.

Although Copernicus is a small project in terms of overall funding, this software's capability has allowed NASA centers to provide comprehensive performance analysis for the Orion Project and the Constellation Program, both of which identified Copernicus as a primary performance analysis tool. Copernicus has allowed engineers at the centers to obtain a deep understanding of the lunar mission design effects on vehicle performance in a short time (figure 5).

The Copernicus development work reflects a collaborative effort among civil servants and contractors in the Aeroscience and Flight Mechanics Division of Johnson Space Center and the University of Texas at Austin. This symbiotic relationship allowed the center to take advantage of research and development advancements in academia while more directly engaging the university in NASA projects.

Copernicus continues to adapt to serve user needs as NASA programs change and associated mission and trajectory design needs change with them. From mission architecture feasibility to spacecraft performance to prototyping of candidate guidance and targeting algorithms, Copernicus remains one of NASA's preeminent mission and trajectory design software tools, and promises to enhance user productivity with a powerful capability for years to come.

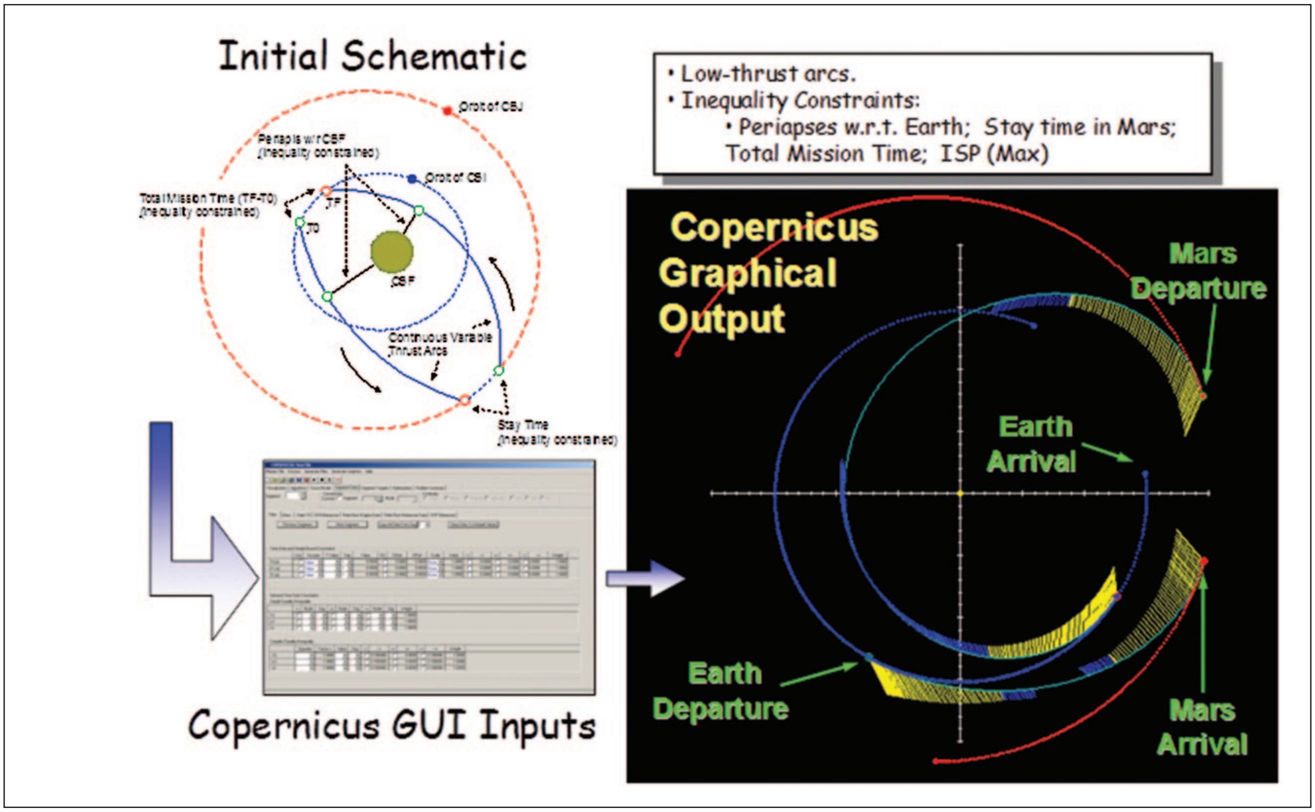

Fig. 4. *Copernicus trajectory design example.*

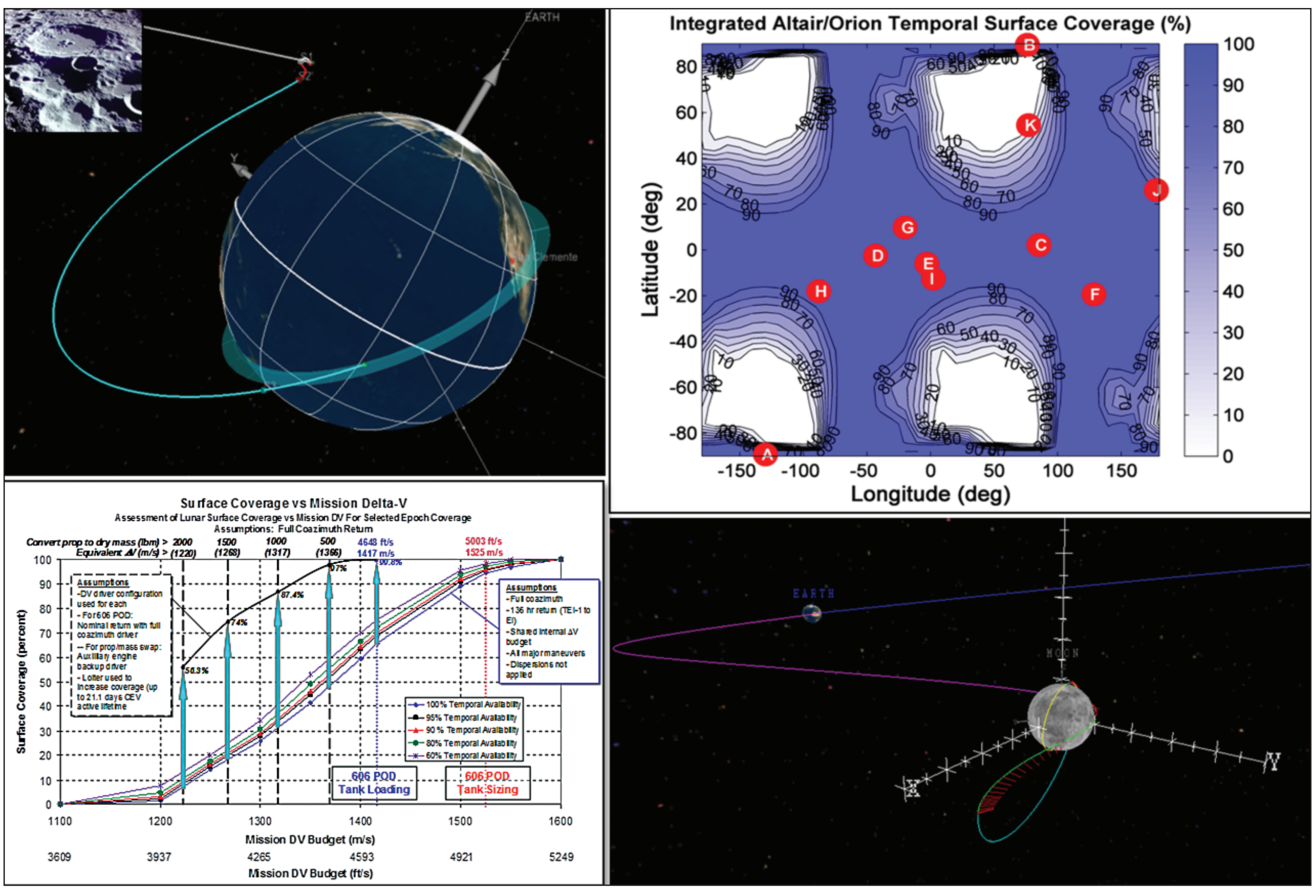

Fig. 5. *Copernicus-based trajectories, lunar accessibility, and Orion propellant requirements.*