The General-Use Nodal Network Solver (GUNNS) Modeling Package for Space Vehicle Flow System Simulation

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The General-Use Nodal Network Solver (GUNNS) is a modeling software package that combines nodal analysis and the hydraulic-electric analogy to simulate fluid, electrical, and thermal flow systems. GUNNS is developed by L-3 Communications under the TS21 (Training Systems for the 21st Century) project for NASA Johnson Space Center (JSC), primarily for use in space vehicle training simulators at JSC. It has sufficient compactness and fidelity to model the fluid, electrical, and thermal aspects of space vehicles in real-time simulations running on commodity workstations, for vehicle crew and flight controller training. It has a reusable and flexible component and system design, and a Graphical User Interface (GUI), providing capability for rapid GUI-based simulator development, ease of maintenance, and associated cost savings. GUNNS is optimized for NASA's Trick™ simulation environment, but can be run independently of Trick.

GUNNS packages 3 main software tools:

- GUNNS, which is the real-time model, including the nodal analysis solver, hardware models, and utility classes.
- GunnShow, a design GUI for building system models graphically.
- GunnSite, a real-time analysis GUI for visibility into the model (not yet developed).

This paper will present the background theory and basic software design of the GUNNS and GunnsShow tools, graphical examples of their use, resulting performance in each of the fluid, thermal and electrical aspects, and planned future improvements to the tools.

Basic nodal analysis is implemented with an emphasis on flexibility, allowing for system topography changes at run-time. Hardware models, implemented as links between nodes in the nodal analysis, own and inform the system solver of their contribution to the system, which they can change at run-time through an object-oriented abstract interface

and polymorphism. This enables changes to system definition and initialization to be done via data files rather than in code, decreasing or eliminating the need to recompile and commensurately reducing software development costs and schedule. This flexibility also allows real-time simulation of changes to vehicle configuration, such as electrical jumpers or fluid umbilicals being moved around.

The hydraulic-electric analogy allows similar flow concepts to be modeled between the fluid, electrical and thermal aspects with a large degree of code reuse and a consistent implementation. For instance, generic potential, for which nodal analysis solves at each node, represents fluid pressure, electrical voltage, and thermal temperature. Generic capacitance represents fluid volume, electrical capacitance, and thermal capacitance. Fluid pipes and valves, electrical resistors, and thermal conductors or radiation paths all represent generic conductors. Fluid fans and electrical batteries are analogous potential sources, and so on. The generic effects such as conductivity, capacitance, potential source and others are represented in the system of equations using the Resistive Companion method of nodal analysis. They are implemented as code base classes, which various aspect models extend to implement their aspect-specific nuances. This results in significant reduction in the code base, a common approach to solving the same basic problems across the various disciplines, and associated cost savings.

GUNNS can be used for both linear and non-linear systems. Real-world systems are almost always non-linear, which GUNNS handles in two ways. First, hardware models (links) linearize their flow equations internally, obtaining a linear relationship between flow and potential local to the current point. This relationship is adjusted in each pass so that the desired non-linear effect is exhibited over multiple passes. Example applications of this kind of linearization include pipe and orifice flows in the fluid aspect, thermal radiation, and electrical diodes and constant-power loads. Second, GUNNS iterates a minor step loop inside each major step, updating the links and re-solving the resulting system in each pass until a desired convergence tolerance is achieved. The solver handshakes with each link model to either accept the system solution or to allow the link to adjust itself and keep stepping towards another convergence. GUNNS includes instrumentation for determining how fast the system is converging, for providing visibility into the system of equations on desired minor steps, and for troubleshooting problems with non-converging systems.

GunnShow is a GUI for graphically developing system models. It auto-generates simulation code and related data files from user-developed drawings. The drawings also serve as formal documentation for the delivered software. For electrical and fluid aspects, GunnShow is implemented as a plug-in to Microsoft Visio. Using a library of hardware component models, individual instances of hardware components are arranged on a Visio drawing, given their configuration and default initial state data, and connected to network nodes. For the thermal aspect, GunnShow is implemented as a plug-in to C&R Technologies Thermal Desktop, which is a traditional 3D CAD application.

Simulation of fluid properties and transport is significantly more complicated than the thermal and electrical aspects, and is implemented with an extra code layer in the fluid aspect. GUNNS includes and has a generic interface to a separate fluid package that implements properties and state equations for a library of various fluids. Liquid and gas phases and ideal and non-ideal fluids are supported. Effects such as compressibility, thermal expansion, convection and conduction, and molecular diffusion are modeled. Other effects such as gas/liquid mixing and body forces are not yet supported but are planned. The current fluid fidelity is high enough for vehicle training and some engineering design and analysis.

The simulation of a vehicle is typically broken down into multiple smaller GUNNS networks to save CPU time. For stability, boundaries are chosen between networks at locations where the systems are loosely coupled. GUNNS supports flow transport between multiple networks of the same aspect.

GUNNS is currently used at JSC in training simulators for the International Space Station (ISS), H2 Transfer Vehicle (HTV), and Orion/Multi-Purpose Crew Vehicle (MPCV), as well as various vehicle design, analysis and mission planning projects. Our goal is to eventually package and license GUNNS for use at other NASA centers and in commercial applications.