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A MISSILE SYSTEM SIMULATION BENCHMARK USING THE ACSL GRAPHIC MODELLER

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ABSTRACT

The Advanced Continuous Simulation Language (ACSL) has been serving the aerospace community for over 25 years in the development of aerodynamic simulations, which include tactical missiles, commercial launch vehicles, fixed wing aircraft, rotary wing aircraft and satellites. In recent years, the ACSL Graphic Modeller (GM) has proved to be an effective means to model and simulate the dynamics of systems. GM provides the tools to graphically model and organize very large and complicated systems by both inventing graphical icons to represent specialized parts of the model and re-using graphical icons which are common in a particular application area. The paper presents a benchmark model of a six degree-of-freedom (6-DOF) surface to air missile system constructed from hierarchically structured graphical model building blocks. This model demonstrates how a graphical representation of a missile model leads to a much clearer representation of the original math model. A hierarchical (tree structured) model lends itself to easy navigation and inspection by analysts with no prior experience with the particular model. The Graphic Modeller is also the framework for simulation analysis. Parameters can be inspected and changed. Individual deterministic, parameter sweep, Monte Carlo and optimization runs can be applied to the simulation from GM.

INTRODUCTION

This paper presents a benchmark model of a six degree-of-freedom (6-DOF) surface to air intercept missile system constructed from hierarchically structured graphical model building blocks. The Graphic Modeller was used to develop and perform the initial analysis of this simulation.

The simulation contains both the Ballistic Missile Target and the 6-DOF Intercept Missile model. Utilizing the Graphic Modeller's ability to create and utilize model building blocks, the simulation was developed quickly and effectively. The Ballistic Target model is a 3-DOF, point-mass representation of a ballistic missile. At the top level, the 6-DOF Intercept Missile model contains seven major components that were developed independently, open loop tested and finally connected to create a completed missile model. The missile model contains simple forms of many components of real world missile systems. More complex or realistic forms of these component models can be exchanged by just dragging, dropping and wiring them in to the existing model's architecture. Details of the major components of each model will be discussed.

The Graphic Modeller was utilized for the initial analysis of the simulation. Individual deterministic runs utilized to debug and fine-tune the model were easily executed in GM's graphical environment. For more in-depth analysis another member of the ACSL product suite was used: ACSL Math. ACSL Math has the ability to iterate over large run sets required for Monte Carlo analysis while simplifying the data collection process. ACSL Math was utilized to perform parameter sweeps and Monte Carlo run set analysis. Both tools provided ample graphing and analysis capabilities.

As a result of this development effort, a rack of reusable tools for building similar simulations in particular and aerospace oriented simulations in general, was developed. An overview of these racks is presented.

6 DEGREE-OF-FREEDOM MISSILE INTERCEPT SIMULATION

The simulation is based on a six degree-of-freedom (6-DOF) model of a guided surface-to-air missile intercept. It also contains a ballistic missile target as a 3 degree-of-freedom (3-DOF) model. Figure 1 shows a screen shot from the Graphic Modeller and is the high level view of the Missile Intercept model.

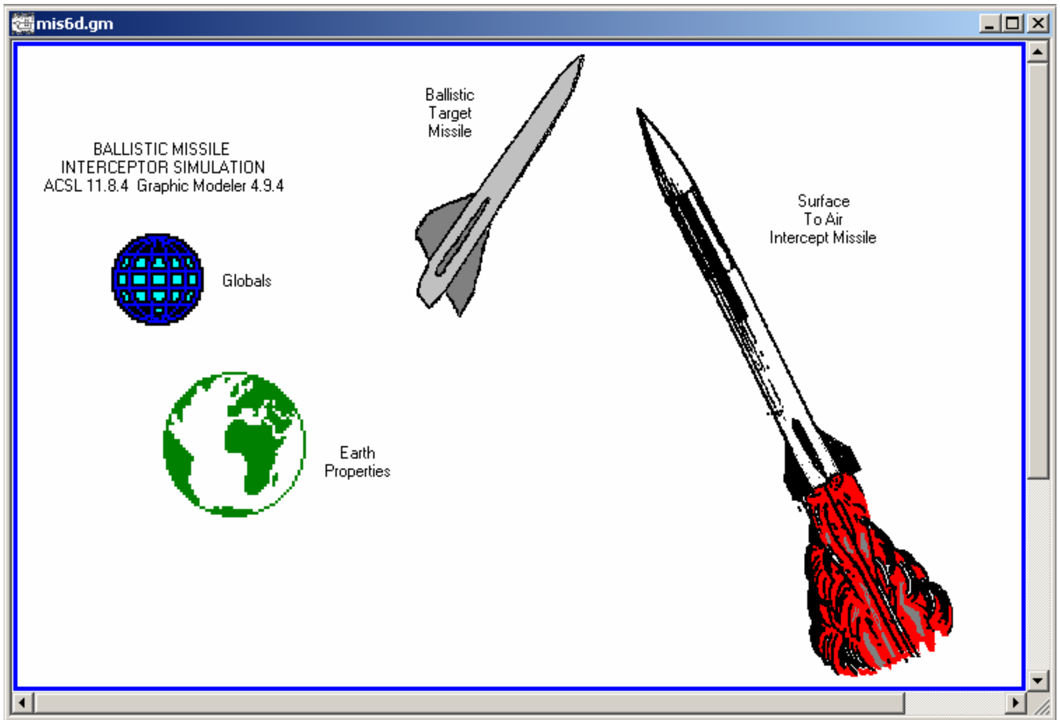

Figure 1: High Level View of Missile Intercept Model

Ballistic Missile Target

The Ballistic Target model is a 3-DOF, point-mass representation of a ballistic missile (Figure 2). It utilizes a flat earth model and is initialized in a glide mode or motor burnt condition. All terms in the ballistic target drag equation are constant. User modifiable parameters for the model consist of the initial conditions for position and velocity. The initial velocity vector has the target approaching the launch position of the intercept missile. The target model is capable of executing a lateral maneuver at a given time. The user is able to adjust the timing and extent of this maneuver

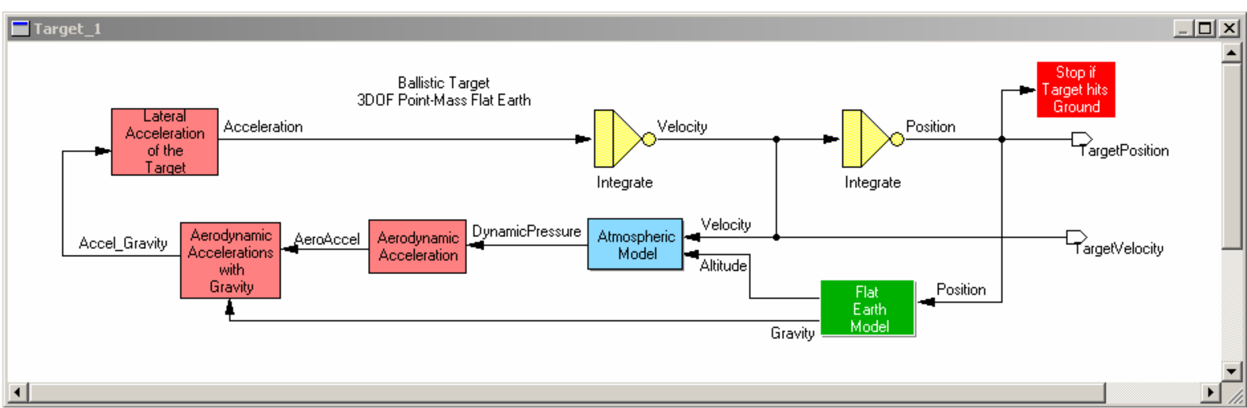

Figure 2: Ballistic Missile Target Block Diagram

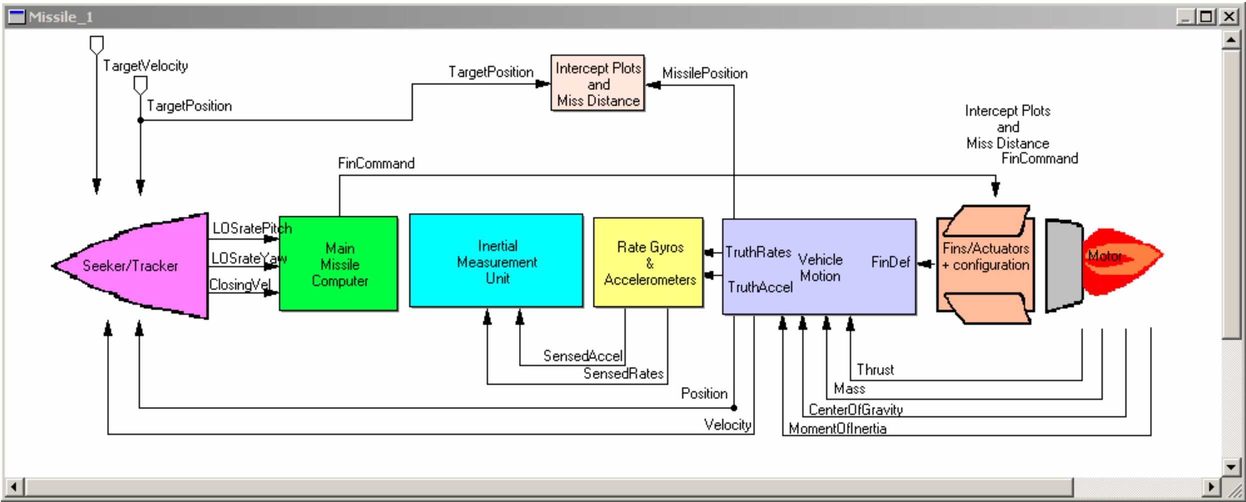

Figure 3: Intercept Missile Block Diagram

Intercept Missile

The Intercept Missile model contains seven major components at the top level (Figure 3). The following sections discuss each major component and its sub-blocks.

Seeker/Tracker

The Seeker/Tracker model is a simplified model of a seeker. The relative position of the target with respect to the missile is used to compute the actual line-of-sight (LOS) angle. Band limited white noise is added to the LOS angle to demonstrate Monte Carlo analysis capabilities. The estimated LOS rate is calculated using a first order seeker tracking loop on the measured LOS angle.

This model also calculates the time-to-go to intercept. ACSL's state event finder (the SCHEDULE statement) is used to numerically integrate up to the point that the value of time-to-go crosses zero. This state event triggers one of the termination conditions: intercept.

Main Missile Computer

The Main Missile Computer contains the models for Navigation and the AutoPilot. The inputs to the main computer are the line-of-site rates and closing velocity, which are used to calculate fin commands.

Navigation

The intercept missile is guided by proportional navigation in both the pitch and yaw plane. The desired acceleration commands are calculated and then passed to the AutoPilot model.

AutoPilot

The AutoPilot is modeled by a simple first order lag system. The output of the model is the fin commands that are sent to the Fins/Actuators Model.

Inertial Measurement Unit

The Inertial Measurement Unit (IMU) model takes the sensed rates from the Rate Gyro model and calculates the "sensed" position, velocity, and Euler angles. These "sensed" values are what the sensor model utilizes in its calculations. These values are what the missile actually thinks it is doing as opposed to the "truth" states calculated in the Vehicle Motion model.

Rate Gyros & Accelerometers

The Rate Gyros and Accelerometers are modeled using 2nd order linear systems. These provide the sensed rates and accelerations to the Inertial Measurement Unit (IMU).

Fin/Actuators

The Fin/Actuator model receives the fin commands from the AutoPilot model, translates these from roll, pitch and yaw commands to the required input for each actuator. The actuators are modeled using a 2nd order linear position limited system. The fins are in a plus configuration in order to match the aerodynamic data utilized in the Vehicle Motion model.

Motor

The Motor model is based on a solid rocket motor with a given thrust profile. This model also contains tables for mass, center of gravity and moment of inertia that are utilized to determine the vehicle dynamics. The motor model is also capable of modeling yaw and pitch misalignment in the motor nozzle. This offset will result in a force on the three body axes.

Vehicle Motion

Vehicle Motion models the missile dynamics from the aerodynamic forces and thrust model inputs.

Dynamics

This model takes all the forces and moments on the missile and determines the resulting positions, velocities, Euler angles and angular rates (Figure 4).

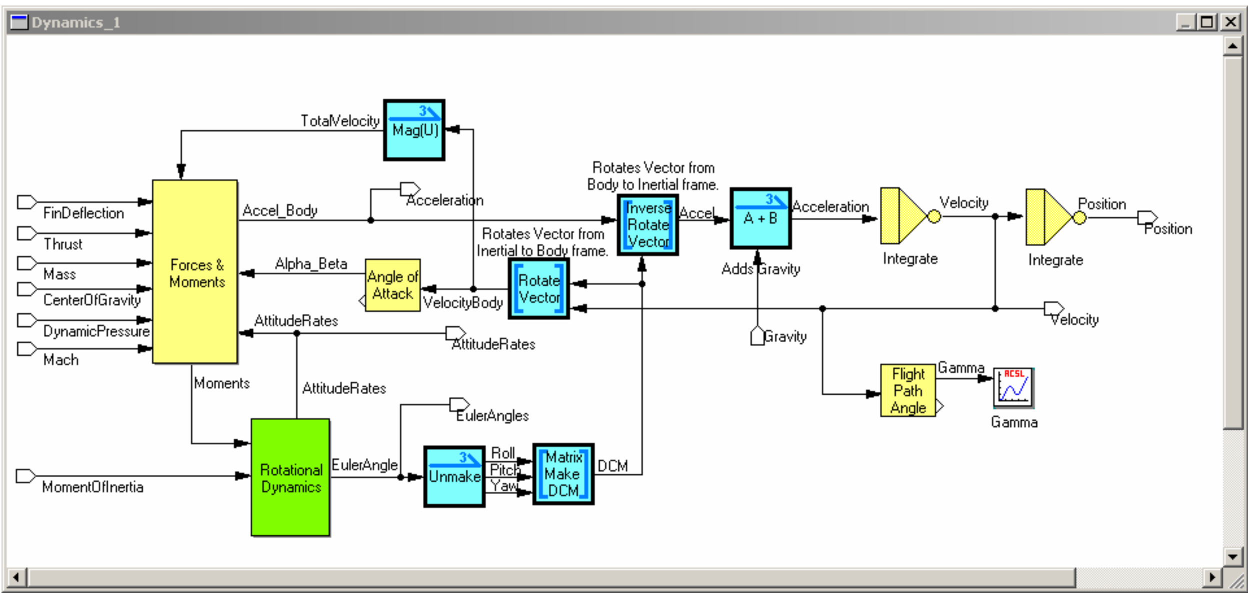

Figure 4: Dynamic Block Diagram

Atmosphere

The Atmospheric model uses the U.S. Standard Atmosphere 1976 information to form the required tables. The model calculates dynamic pressure and the mach number required to determine the aerodynamic coefficient data.

Earth

The Earth is modeled as a simple flat earth system. The third component of the inertial frame position vector is directly translated into altitude.

ANALYSIS

The ACSL Graphic Modeller is tightly integrated with an analysis and visualization package called ACSL Math. It can dynamically link to a graphic model in order to provide analysis capabilities ranging from single, deterministic runs to parameter sweeps, Monte Carlo and optimization. Visualization capabilities include 2D and 3D graphics. Both tools, Graphic Modeller and ACSL Math were used in the analysis of the 6-DOF surface to air intercept simulation.

Graphic Modeller

The Graphic Modeller itself is also the framework for some basic simulation analysis. A GM "viewer" mode provides for analysis without permitting structural changes to the basic model, thereby permitting configuration control. Once a simulation is built from a graphic model, GM provides a graphical environment for the analysis of the simulation. GM's analysis environment includes capabilities to inspect/change all parameter values and to generate 2-D plots of results by clicking on GM's intrinsic plot components.

Missile Analysis

Click on the 'start simulation' button on the GM tool bar to run a simulation with the current parameter settings. If the model has been structurally changed since its last use, it is compiled and linked into an efficient simulation. The executable simulation is run with the current parameter settings. The results are immediately available for GM to plot by double clicking on a plot icon connected to the variables of interest in the model (Figure 5).

Parameter settings (called "constants" in ACSL) can be viewed or changed by browsing through the model. A right click on a component gives you access to the constants characterizing that block (Figure 6). Changes to constants will affect subsequent simulation runs during a session, but do not affect the model's structure for purposes of configuration control. For example, change the proportional navigation gain, click "start" for another simulation run and immediately pull up plots to compare back-to-back deterministic runs (Figure 7).

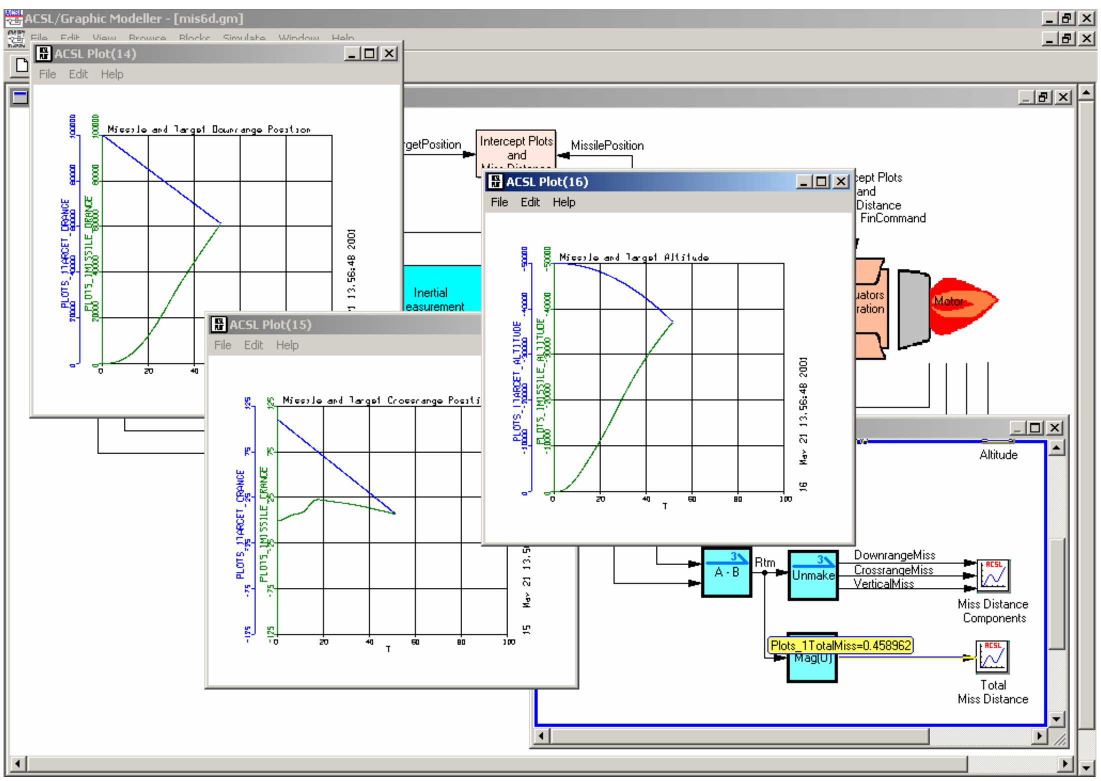

Figure 5: Initial GM Deterministic Run

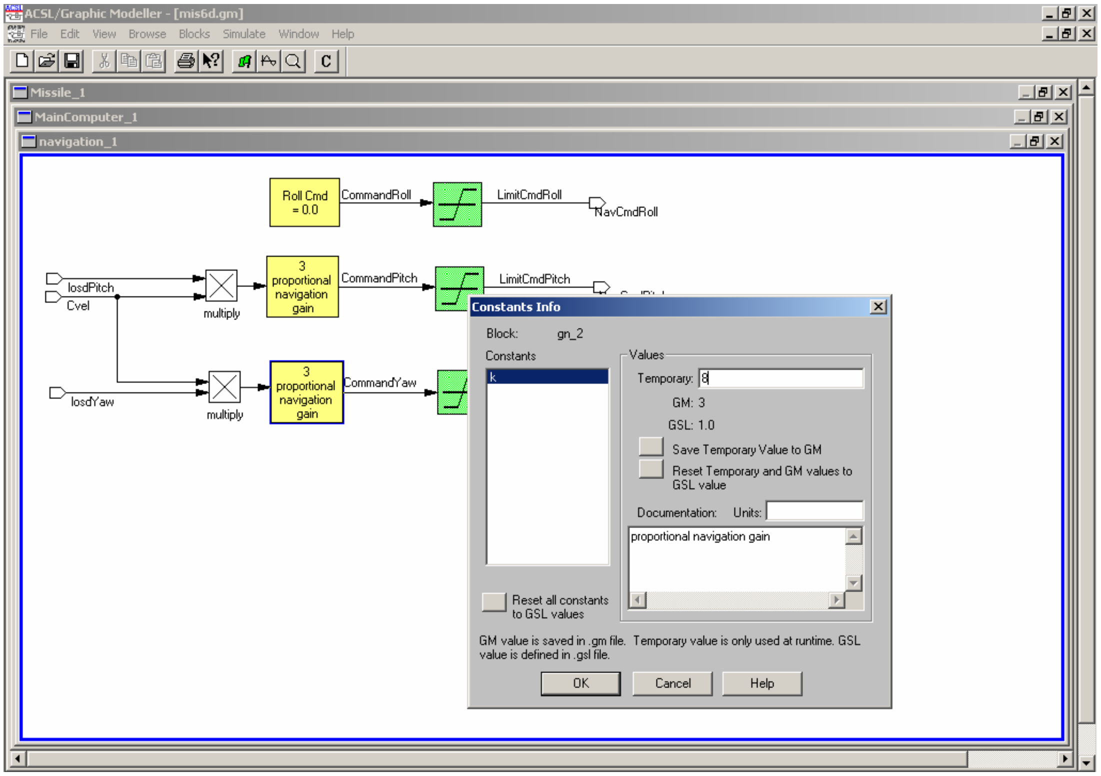

Figure 6: Change Constant for Proportional Navigation

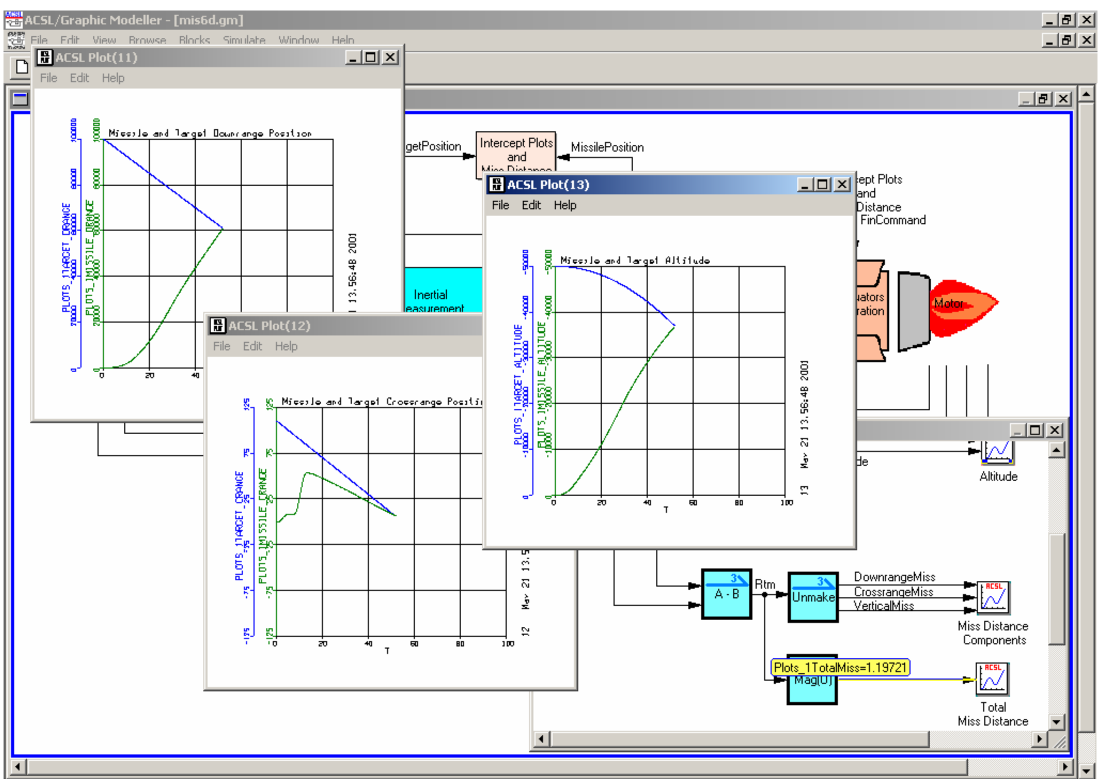

Figure 7: Results of Second GM Deterministic Run

ACSL Math

ACSL Math provides 300 advanced mathematical, statistical, scientific, and engineering functions designed for general math, linear algebra, matrix manipulation, Monte Carlo analysis, Fourier transforms, signal processing, and much more. ACSL Math uses a sophisticated graphics and data visualization system that includes features such as 3-D graphic tools, contour plots, surface rendering, volumetric visualization, and image display.

ACSL Math has the capability to accept command files, in an industry standard format, which allow the definition of repeated analysis and data collection procedures.

Missile Analysis

As an example, the 6-DOF Missile Intercept simulation utilizes ACSL Math to perform both a parametric study and a Monte Carlo analysis. The tight integration of the ACSL suite allows ACSL Math to run the GM simulation from within ACSL Math. This simplifies the data collection task. A command file is set up to allow the 6-DOF simulation to be run consecutively with the parameter ‘autopilot time constant’ evaluated between 1 and 8. The resulting 3-D plot evaluates lateral acceleration as a function of time for each value assigned to the autopilot time constant (Figure 8).

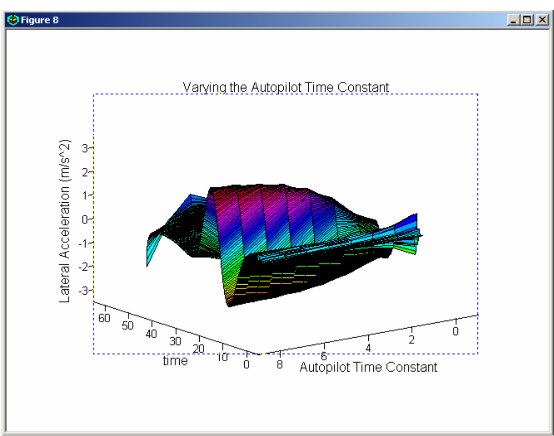

Figure 8: Effects of Autopilot Time Constant

The second example of the Missile Intercept simulation analysis involves running a Monte Carlo set. A command file is again set up to accomplish this task. A 100 run Monte Carlo set is run with the introduction of band-limited white noise into the measured LOS angle in the seeker model. The lateral acceleration is evaluated verses time (Figure 9). Statistical analysis is then done on the information to determine the mean and 3 sigma of the lateral acceleration (Figure 10). Finally the miss distance is analyzed using the histogram function and the results are plotted (Figure 11).

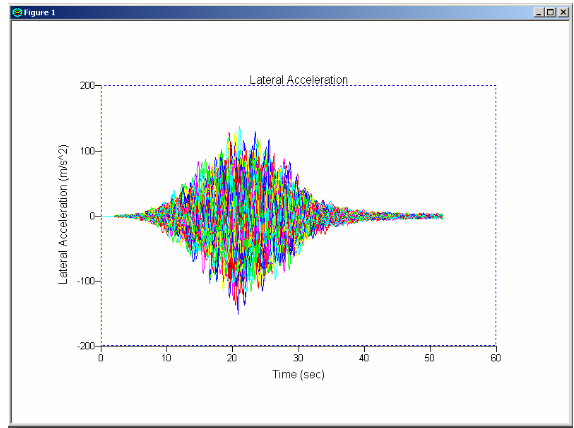

Figure 9: Lateral Acceleration

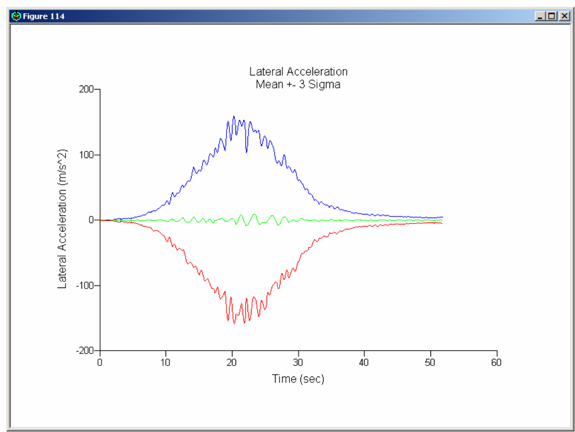

Figure 10: Lateral Acceleration $\pm$ 3 sigma

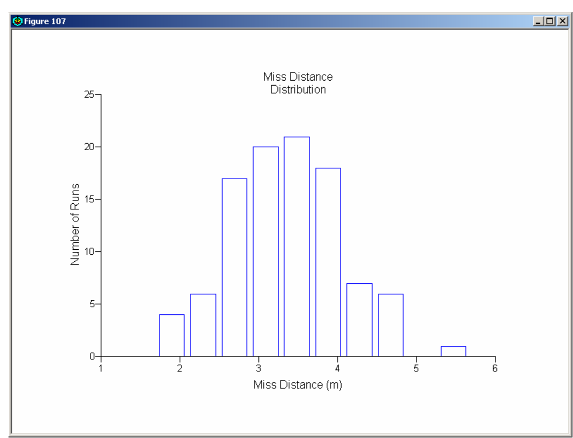

Figure 11: Miss Distance Distribution

AEROSPACE RACKS

An underlying rack of reusable tools (Figure 12) for building this benchmark in particular and aerospace oriented simulations in general was developed during this simulation effort. This will allow greater reuse of blocks and shorten development time.

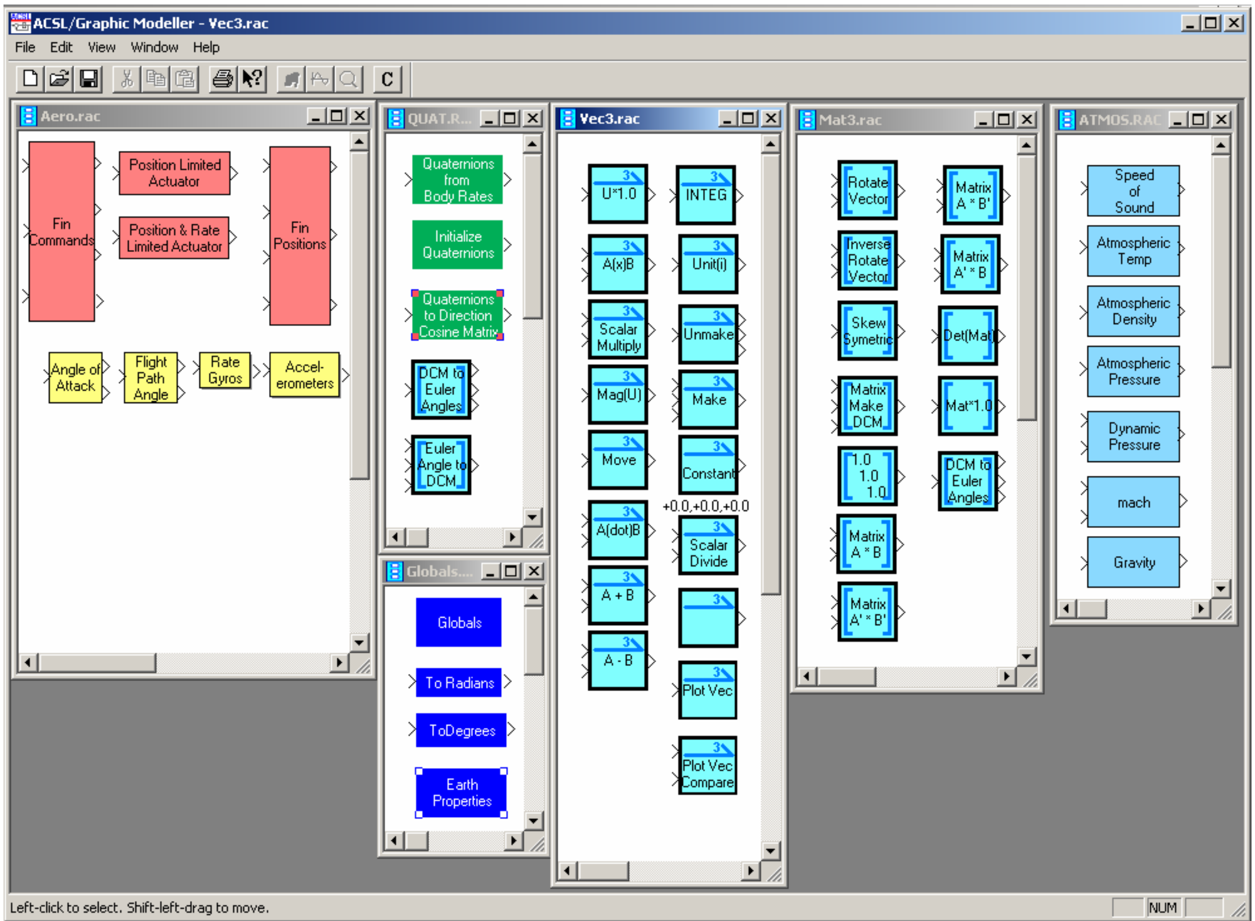

Figure 12: Overview of the Aerospace Racks

Vector Rack

The vector rack provides a set of object-oriented blocks to assist in the manipulation of a 3 element vectors. These blocks can also be easily modified to handle larger vectors and more specific vector manipulation requirements.

Quaternion Rack

The Quaternion rack blocks support operations that involve quaternions. These blocks include the ability to derive quaternions from body rates, use those quaternions to calculate the Directional Cosine Matrix and Euler Angles.

Atmospheric Rack

The Atmospheric Rack contains the basic building blocks to provide atmospheric data to the simulation. These blocks include tables containing temperature, density, pressure and speed of sound as functions of altitude and are based on the US Standard Atmosphere 1976.

Global Declarations Rack

The Global Rack provides some very useful blocks that will enable many constants that are required throughout the simulation to be defined. These global constants include PI, Radian to Degree conversion values, radius of the Earth, Earth gravitational constant, spin rate of the Earth and several other Earth properties.

3 x 3 Matrix Rack

The Matrix Rack provides a set of object-oriented blocks to assist in the manipulation of 3x3 matrices. Operations including vector rotation and computation of the Directional Cosine Matrix (DCM).

Aerodynamics Rack

The Aerodynamic Rack contains a wide range of blocks to support simulation development. These blocks include Fin Commands and Position, Position & Rate Limited Actuator, Angle of Attack, Flight Path Angle, Rate Gyros and Accelerometers.

SUMMARY

The ACSL Graphic Modeller provided an environment to develop the 6-DOF Missile Intercept model. This simulation was developed as a benchmark to demonstrate the value of graphical modeling. With its many point and click features, model development became easier and faster. Either by developing new model blocks or utilizing existing blocks from the many GM racks, large-scale development was quicker and clearer. The resulting model is graphically organized in a way that lends itself to intuitive navigation, even by those who did not participate in its development. Once the simulation is assembled, the plotting capability and the ease in which constants could be changed, made it quick and easy to debug and fine-tune the model.

Individual deterministic analysis and visualization is easily completed in ACSL GM alone. With the tight integration of ACSL product suite, ACSL Math is able to run the simulation internally, which simplifies data collection, analysis and visualization when running a large Monte Carlo simulation.