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14. ABSTRACT
The Simulator (SIM) system is a powerful tool that can be used to develop, recreate, and test satellite and missile missions. SIM provides a geometrically correct focal-plane scene of the simulated sky for multiple mount and sensor types. It is operational in two modes: Pure and Hybrid. The pure-mode SIM simulates everything (time and pointing angles). Hybrid-mode SIM interfaces with actual telescope tracking and mount control software to obtain pointing angles and uses an IRIG-B signal for the time. Based upon an event-driven architecture, the SIM system provides an easy way to "script" simple to complex target sequences as viewed from a selected site, mount, and sensor combination. These scripted target sequences can be executed for viewing and edited, as necessary, using pure-mode SIM. They may also be used to support actual target acquisition and data collection missions in the hybrid-mode.

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SIM: The Satellite and Missile Mission Simulator

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Abstract

The Simulator (SIM) system is a powerful tool that can be used to develop, recreate, and test satellite and missile missions. SIM provides a geometrically correct focal-plane scene of the simulated sky for multiple mount and sensor types. It is operational in two modes: Pure and Hybrid. The pure-mode SIM simulates everything (time and pointing angles). Hybrid-mode SIM interfaces with actual telescope tracking and mount control software to obtain pointing angles and uses an IRIG-B signal for the time. Based upon an event-driven architecture, the SIM system provides an easy way to "script" simple to complex target sequences as viewed from a selected site, mount, and sensor combination. These scripted target sequences can be executed for viewing and edited, as necessary, using pure-mode SIM. They may also be used to support actual target acquisition and data collection missions in the hybrid-mode.

An overview of the SIM architecture and description of its capabilities will be presented.

1. Introduction

The SIMulator (SIM) system is a 3-dimensional geometric simulation tool that uses information from star catalogs and space object catalogs to simulate the sky, in real-time, as viewed through a selected mount-sensor combination. As such, it is a powerful tool that can be used to develop, preview, recreate, and test satellite and missile missions.

This paper describes the architecture and capabilities of the SIM system and how these capabilities are applied at the MSSS (Maui Space Surveillance Site).

2. The SIM System

SIM is based upon the *WorldView* sytem that was originally developed in 1992. Various high-level missions have been supported by WorldView requiring extensive experimental validations of accuracy. The SIM software is written in C++ using object oriented programming techniques and is based upon on a general purpose, three-dimensional object database that uses a master Earth Centered Inertial (ECI) coordinate system as a reference frame and produces a variety of special purpose local coordinate systems to render the simulated view. This allows SIM to easily simulate a complex focal plane scene relative to specific telescope-sensors and sky-viewing conditions. The SIM system simulates geometric views of the celestial sphere and near-earth space as seen from the sensor focal plane of the telescope. Positions of celestial objects such as stars, planets, the sun, the moon, and satellites as viewed from specific sites and telescope sensors are calculated. These calculations are based upon star field databases, ephemeris calculations for the planets and two-body (SGP4) propagators for satellites and missiles.

SIM is operable in 2 modes: Pure Mode and Hybrid-Mode.

In a pure-mode simulation, everything is simulated. No telescope hardware is used in the simulation. The simulation time and time increment are user specified. The simulated mount-sensor combination tracks targets of interest via the SATELLITE TRACK EVENT (refer to Section 4). Thus, a *perfect track* is simulated.

In contrast to a pure-mode simulation, a hybrid simulation does include telescope hardware in the loop. The simulation time is synchronized to an IRIG-B time signal. Thus, a hybrid-mode simulation is executed in real-time. The simulated telescope is pointed in a direction based upon mount coefficients obtained from the OCS (Observatory Control System) mount control system. Gimbal coefficients A, B, and C including time T0 for each telescope axis are required for SIM hybrid simulation mode such that the true pointing angle of the telescope can be determined at time T as follows:

$$\text{Gimbal Angle 1} = A_1 + B_1(T - T_0) + C_1(T - T_0)^2$$

$$\text{Gimbal Angle 2} = A_2 + B_2(T - T_0) + C_2(T - T_0)^2$$

$$\text{Mount Azimuth} = A_3$$

The obtained coefficients can be precisely propagated to any specified time.

Hybrid-mode simulations are made more realistic via an interface to telescope hardware in the loop such as steerable mirrors. The mount angle coefficients and steering mirror positions obtained from the mount control system are used by the hybrid-mode SIM to generate an accurate simulation of the expected telescope sensor focal plane view. Hybrid mode SIM also supports closed loop tracking of desired targets. Track errors are calculated relative to the simulated focal plane boresight. These errors may be off-loaded to the mount control system so that a target being acquired is centered in the simulated focal plane view boresight. The closed loop tracking (including interfaces to the Integrated Mount Control (IMC), and Integrated Acquisition and Track (IAT)) is illustrated in Figure 1.

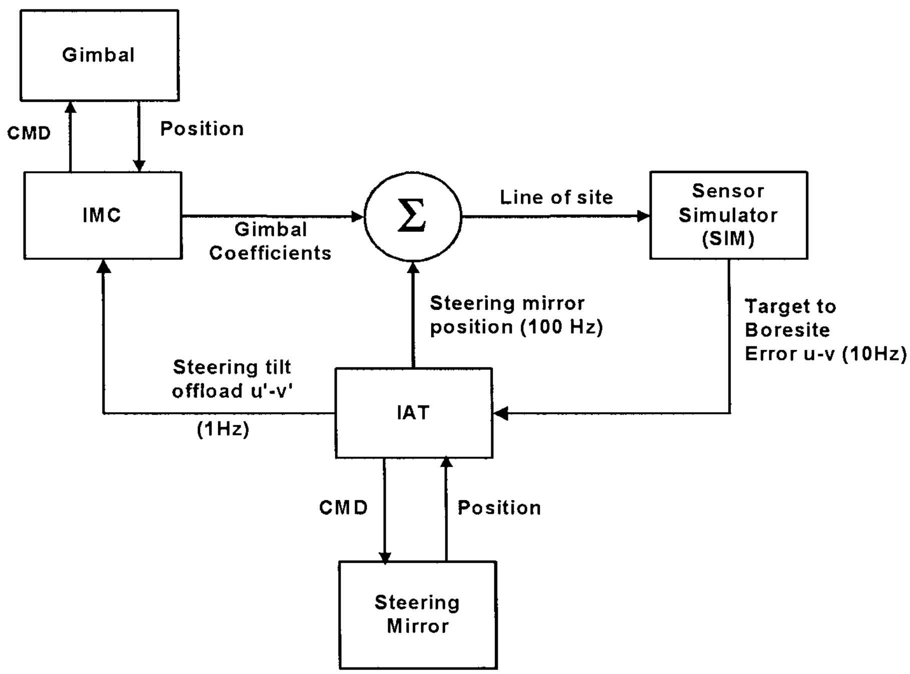

Figure 1: Hybrid-Mode Closed Loop Tracking Scheme

Figure 2 illustrates a typical SIM display window. A graphical display of the telescope being simulated, the current pointing angles (in degrees), focal plane field of view (in decimal degrees), and the current date and time are displayed in the lower right corner. The sensor name, field of view, horizontal and vertical flips indicators, and rotation are provided at the lower left corner of the window. The sky scene being displayed takes into account all 3D rotations induced by mount movements. Satellites are displayed as simple three-dimensional polygons that are velocity oriented and are scaled according to their slant range from the telescope. Stars corresponding to the currently selected star catalog that can be seen within the current field of view are displayed and scaled according to their magnitude. Several star catalogs are supported and are graphically displayed relative to brightness.

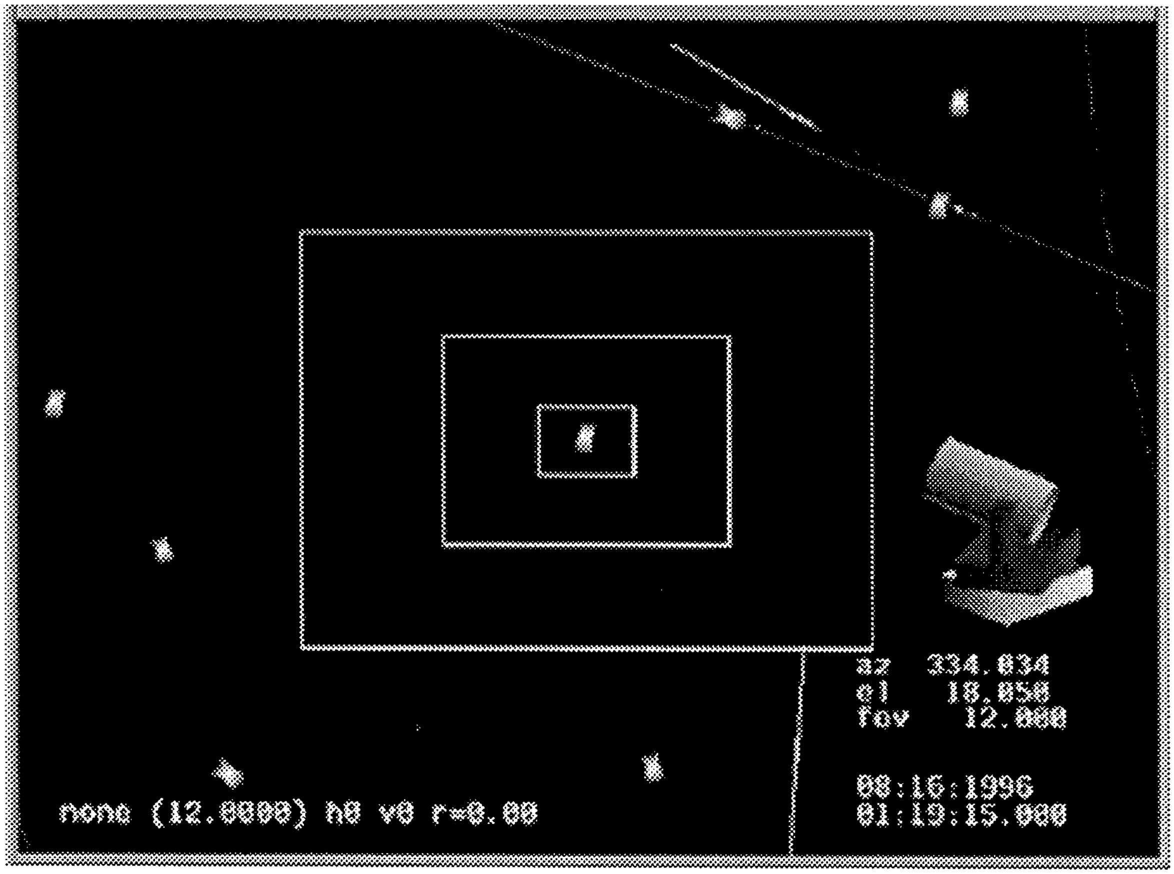

Figure 2: SIM Display Window

During execution of a simulation, settings such as the current sensor, field of view, sensor rotation, horizontal and vertical flips, and star display can be changed *on the fly* using the SIM control GUI (Graphical User Interface) shown in Figure 3. In the pure-mode, changing of the observation site and telescope is possible. The simulation time and time increments can also be changed. Execution of a pure-mode simulation is controlled using VCR like controls that can start, stop, and step the current simulation. In the hybrid-mode a powerful satellite discrimination capability is available which displays all known satellites within the simulated sensor field of view (in addition to those included in the simulation script, *SIMscript*). This capability may be selectively enabled or disabled as indicated in the GUI.

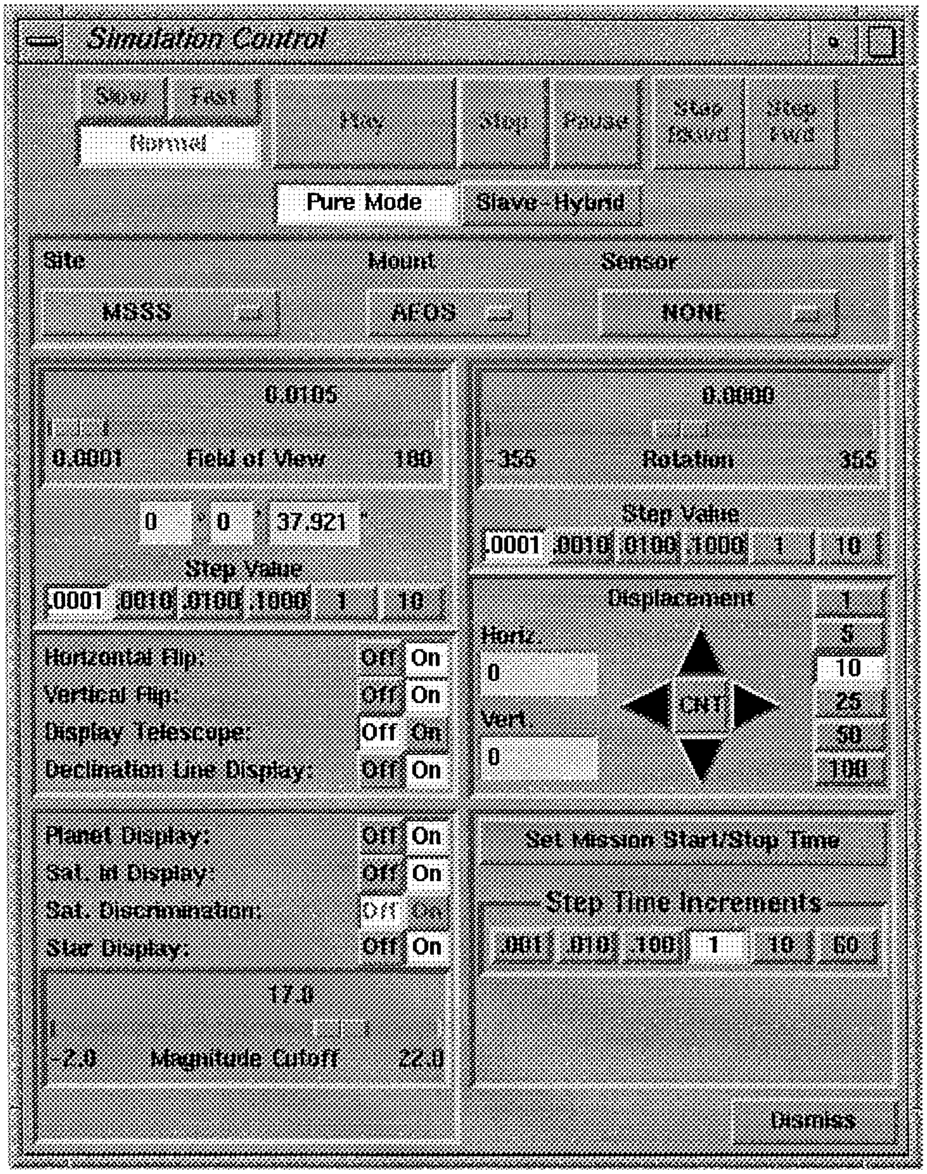

Figure 3: Simulation Control GUI

3. Simulation Paradigm

As mentioned earlier, the simulation capability of SIM is based upon *WorldView*, which is an event-driven simulation tool that uses a Gregorian calendar and a user specified time increment. Simulation events that represent particular simulation actions are parsed from a simulation-script (SIMscript) file and loaded into an event queue for execution. The loaded simulation events are time-ordered according to their execution time within the event queue. Depending on the simulation events that are used in a simulation script, the event-driven simulation paradigm is capable of executing very simple to very complex simulation scenarios.

During the simulation, the event queue is checked to see if the *event time* of the next simulation event has been reached. If so, then that simulation event as well as any other events at the top of the queue whose event times have been met, is executed. At the same time, positions of all satellites in the simulation are updated using a two-body propagator. The position of the steering mirror and the pointing angles of the telescope are also updated. Finally, the simulated view is redrawn to reflect the updated positions of all objects that can be seen within the current field of view. These steps are repeated iteratively for each increment of time (user specified or signal supplied) through the duration of the simulation. Hybrid mode iterations are executed in real-time. To support changes to certain simulation settings (such as changing sensors, turning the star display on or off, star magnitude cutoff adjustments) that are performed *on the fly,* the simulation events (called immediate events) are inserted at the very front of the event queue for immediate execution. This paradigm is depicted in Figure 4 below.

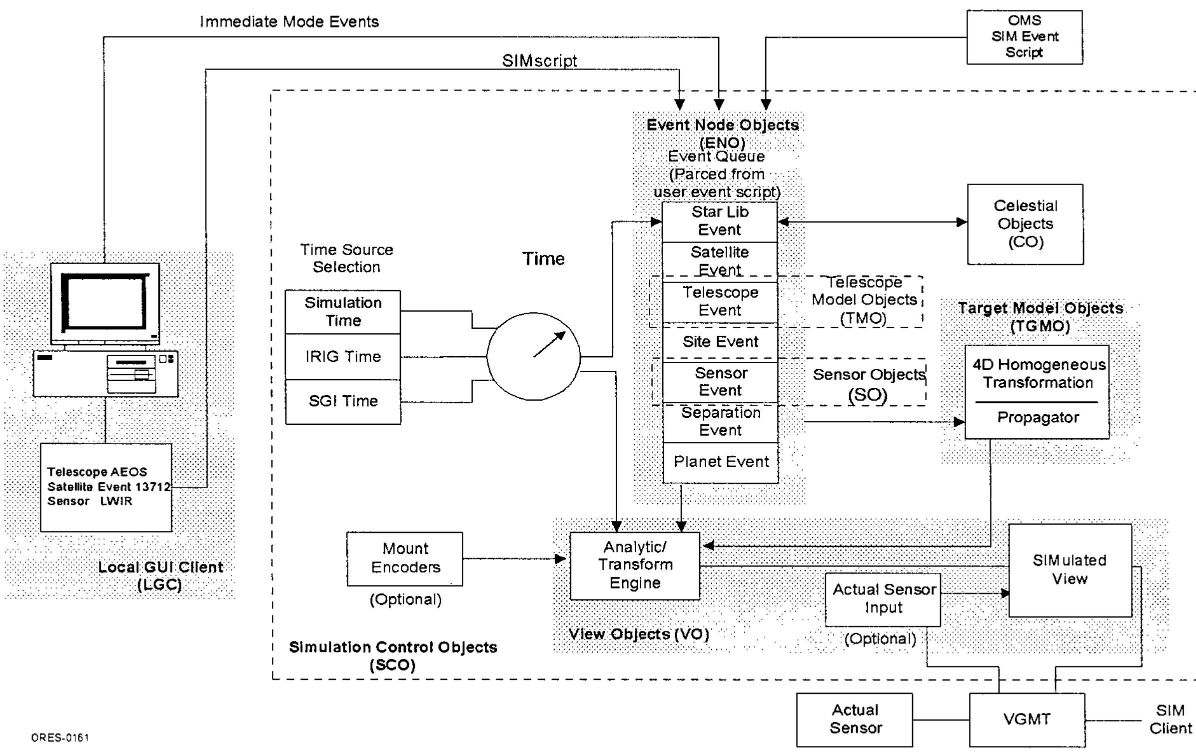

Figure 4: Simulation scheme

4. Supported Simulation Events

The following simulation events are currently supported by SIM.

SATELLITE LAUNCH EVENT
Defines a new satellite or missile from a specified ECI state vector. This vector is propagated using a two-body propagator.

SATELLITE MIRV EVENT
Causes a secondary vehicle to be launched from a parent satellite or missile at a specified time and velocity. The velocity vector is defined relative to the parent body reference frame.

SATELLITE MIRV EL EVENT
Similar to the SATELLITE MIRV EVENT except that the secondary vehicle is launched at a specified topocentric elevation.

SATELLITE TRACK EVENT
This event causes the simulated telescope to be pointed directly at a specified satellite or missile at a specified time. The simulated view will follow the specified object until the next satellite track event is encountered. Positions of all other simulated objects will be calculated from this view.

SATELLITE TRACE EVENT
This event draws a trace path of where a specified satellite has been or will be in the simulated view at a user specified time.

SATELLITE ORIENT EVENT
This event causes the re-orientation of a specified satellite or missile via a given 3X3 ECI transformation matrix.

SATELLITE MANEUVER EVENT
This event causes a specified satellite or missile to execute a roll, pitch, or yaw maneuver at a specified time.

DISPLAY TALO EVENT
Primarily used to support missile simulations, this event initiates the Time After LiftOff (in seconds) to be displayed in the simulated view.

STARPLOTTER EVENT
This event enables and disables the star field display in the simulated view. The displayed are stars are scaled in size relative to their magnitude. To support *on the fly* simulation setting changes, this event can be executed as an immediate event.

PLANETPLOTER EVENT
This event enables and disables the display of planets in the simulated view. To support *on the fly* simulation setting changes, this event can be executed as an immediate event.

DATALOG EVENT
This event initiates the logging of tabular output such as state vectors, site, telescope, and execution of simulation events during a simulation to a log file.

CHANGE TIMESTEP EVENT
Intended to be used only for the pure-mode SIM, this event changes the current time step/increment setting to a new setting that is specified. To support *on the fly* simulation setting changes, this event can be executed as an immediate event.

ANGLE SEPARATION EVENT
This event logs the simulation date and time in which the angle separation (user specified) between two specified satellites/missiles has been reached.

RANGE SEPERATION EVENT
Similar the ANGLE SEPARATION EVENT, this event logs the simulation date and time in which the range separation (user specified) between two specified satellites/missiles has been reached.

DISPLAY TELESCOPE EVENT
This event enables (or disables) the displaying of the telescope of the simulated view. To support *on the fly* simulation setting changes, this event is executed as an immediate event.

STAR CUTOFF CHANGE EVENT
If the star display is enabled, the user may adjust the star magnitude cutoff so that only stars with a magnitude less than or equal to the star magnitude cutoff are displayed in the simulated view. To support *on the fly* simulation setting changes, this event is executed as an immediate event.

SENSOR CHANGE EVENT
This event performs a change of the current sensor to a sensor that is specified. All geometric effects (horizontal and/or vertical flips, rotations, and field of view) are updated in order to accurately simulate the specified sensor. To support *on the fly* simulation setting changes, this event is executed as an immediate event.

FOV (Field Of View) CHANGE EVENT
This event adjusts the current field of view to a field of view that is specified. To support *on the fly* simulation setting changes, this event is executed as an immediate event.

HORIZONTAL DISPLACEMENT EVENT
This event adjusts the current horizontal displacement in the horizontal direction. To support *on the fly* simulation setting changes, this event is executed as an immediate event.

VERTICAL DISPLACEMENT EVENT
This event adjusts the current vertical displacement in the vertical direction. To support *on the fly* simulation setting changes, this event is executed as an immediate event.

HORIZONTAL FLIP EVENT
This event performs a horizontal flip on the simulated view. To support *on the fly* simulation setting changes, this event is executed as an immediate event.

VERTICAL FLIP EVENT
This event performs a vertical flip on the simulated view. To support *on the fly* simulation setting changes, this event is executed as an immediate event.

SIMscript files may be created or edited using the SIM Main/Script Editor GUI shown in Figure 5 below. This GUI contains menus that support file control functions (Open, Save, Close, Delete, etc.). Menus to switch star catalogs and access other SIM GUIs are also provided. Display fields that identify the current star catalog, SIMscript file being accessed, and the list of simulation events that are *scripted* in the SIMscript file are also shown.

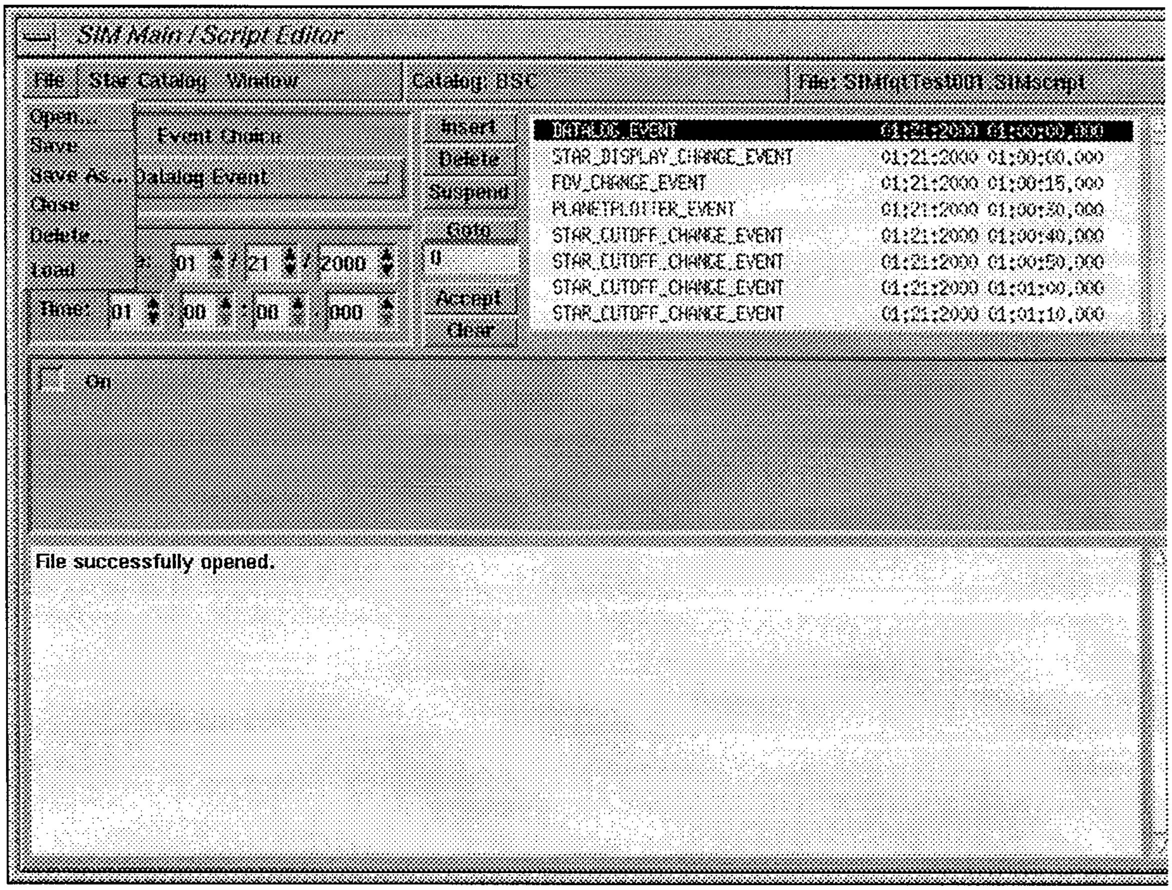

Figure 5: SIM Main/Script Editor GUI

5. Applications of SIM at the MSSS

SIM is currently being used at the Maui Space Surveillance Site (MSSS) to support operations.

The pure-mode SIM is used to preview upcoming and planned satellite and missile missions and to recreate and analyze already completed missions. The ability to preview and recreate missions has been instrumental in helping to determine requirements for new telescope sensors.

The hybrid-mode SIM is used to support OCS controlled telescopes at the MSSS. It is used to prepare and train the operations crew for upcoming satellite and missile missions. Figure 6 illustrates the SIM Suspended Events GUI. This GUI is used to select scripted simulation events to be *suspended* (i.e. omitted) from the simulation prior to execution of a SIMscript file.

The *suspended* events can be selected for immediate execution at a time that is different from the originally specified execution time. This capability is a very powerful training feature since helps to simulate any non-ideal situation(s) that may be encountered during an actual mission. Hybrid-mode SIM is used to support target acquisition during actual missions by providing telescope operators with a graphical display showing the expected position of the desired target(s). The simulated view generated by the hybrid-mode SIM can be overlaid with live sensor video to provide an actual vs. expected position of the target being acquired. The hybrid -mode SIM also has the ability to correlate/discriminate between the desired target(s) and other space objects by displaying any other satellites (in addition to the satellites that have been scripted in the current simulation) that may be in the field of view.

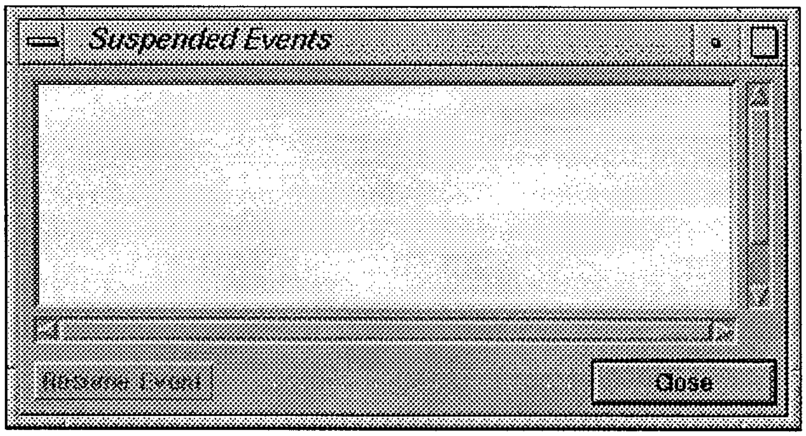

Figure 6: SIM Suspended Events GUI

6. SIM Improvements

- Library of 3-dimensional satellite models to be used in simulations
- Solar illumination of satellite models.
- Automated generation of SIMscript files to support missile missions
- Fixed wide angle simulation view to support viewing of target clusters
- Model thrusting targets

7. Summary

The architecture and capabilities of the SIM system contains many of the components that are necessary to support complex space simulations. Its event-driven scheme and object oriented design allows for additional capability to be easily added. In addition to its current applications in supporting space surveillance missions, its capabilities allow for the support of other activities in many areas of space surveillance including mission planning since many missions are preplanned and extensively rehearsed due to the one-time, high cost nature of space surveillance experiments.