GPS TEST RANGE MISSION PLANNING

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ABSTRACT

TASC is currently developing for the GPS Range Applications Joint Program Office (RAJPO) the mission planner which will be used by test ranges procuring RAJPO-developed GPS test range instrumentation. Test Range User Mission Planner (TRUMP) is a user-friendly, PC-resident tool which aids in deploying and utilizing GPS-based test range assets. In addition to providing satellite/jammer visibility (for a Digital Terrain Elevation Data (DTED) range map) and dilution-of-precision (DOP) information, TRUMP features:

- Time history plots of time-space-position information (TSPI)
- Performance based on a dynamic GPS/inertial system simulation
- Time history plots of TSPI data link connectivity
- DTED maps with user-defined cultural features
- Two-dimensional coverage plots of ground-based test range assets.

This paper will discuss TRUMP's role on the test ranges and its current features. In addition, the functionality to be added during the next development phase will be presented.

Key Words: GPS mission planning, TSPI performance, GPS/inertial system simulation, PC-based tool, test range assets, data link.

INTRODUCTION

The satellite-based Global Positioning System (GPS) is revolutionizing navigation and positioning by providing a worldwide, all-weather system with anticipated accuracy of under ten meters. The multi-user, all-altitude, high accuracy features of GPS will be exploited by the national test ranges as the long-sought-after solution for a common time-space-position information (TSPI) system. GPS will fulfill the requirement for test range interoperability and will provide a cost-effective solution to instrumenting large numbers of users involved in operational test and evaluation (OT & E) and training operations. Test Range User Mission Planner (TRUMP) will be the mission planner used by test ranges procuring GPS instrumentation from the Range Applications Joint Program Office (RAJPO).

There is a need for GPS-based mission planning because GPS performance is scenario dependent. Achievable GPS navigation/positioning performance is dependent on the GPS receiver/antenna architecture and integration strategy. In addition, environmental factors, including satellite availability and visibility (i.e., terrain blockage), vehicle dynamics, and the presence of jamming/interference also impact performance. The test range community will use TRUMP to aid in deploying GPS-based test range assets (including pseudo-satellites) and in assessing the adequacy of resultant positioning performance.

This discussion begins with background information about GPS instrumentation developed for the test ranges. This is followed by an overview of TRUMP and its role in helping the test range user realize the desired accuracies/benefits of GPS.

BACKGROUND

To meet the requirements of the GPS Range Applications Program (GPS-RAP), contracts were awarded to develop a family of GPS instrumentation to provide accurate TSPI for the tri-service test and training ranges. Brief descriptions of the receivers, translators, ground transmitters (pseudo-satellites), and the data link system follow.

Receivers can provide GPS-based TSPI data in the form of pseudorange and delta range (Doppler) measurements with a minimum of onboard processing, or position and velocity measurements in cartesian coordinates with a moderate amount of onboard processing. Interstate Electronics Corporation (IEC) has developed the Low Dynamics Instrumentation Set (LDIS) and High Dynamics Instrumentation Set (HDIS) for the RAJPO. The LDIS emphasizes minimum cost and size, while the HDIS emphasizes performance. The reference receiver (RR), also developed by IEC, is a rack-mounted version of the HDIS that operates from a surveyed site to calibrate the systematic errors (introduced by uncertainties in satellite location and signal transmission delays through the ionosphere) and computes differential corrections. These differential corrections are used by the HDIS and LDIS for increased accuracy. A GPS receiver normally processes signals from four different satellites to compute a position and velocity fix. Integrating the receiver with an inertial measurement unit (IMU) improves the performance of the receiver and maintains TSPI system performance through signal outages (introduced by such factors as antenna or terrain masking).

The type of receiver used, the use of an RR, and the quality of the integrated IMU impact the achievable accuracies of GPS and are important in mission planning.

A *translator* acts as a wideband RF relay which frequency-shifts (to S-band) and retransmits the unprocessed GPS signals to a translator processing system (TPS). The TPS either wideband records the unprocessed signals for post-mission processing or tracks and processes the signals for real-time tracking. The translator and TPS have been developed by IEC. Translators perform a relatively simple function, hence they are smaller and less expensive than a full-up receiver. Consequently, they are well-suited for small or expendable vehicles.

Ground transmitters (GTs), developed by Standford Telecomm, act as GPS satellites on the ground. A test range may use them to augment the GPS satellites until the constellation is complete. There are several aspects of GTs that make incorporating them into mission planning important. Because GTs are located on the ground, terrain masking is a key issue and must be taken into account. In addition, proximity to a GT may result in unmanageable Doppler rates and multiple access interference. In order to minimize the risk of excessive range acceleration, GT-induced accuracy degradation or signal capture, “exclusive regions” should be established about each GT. Mission planning can be effectively exploited to address these issues.

The GPS *data link subsystem* (DLS), currently under development by QUALCOMM, Inc. under contract to IEC, has as its primary purpose to support GPS position data collection and processing. The DLS will provide high reliability message transmission while downlinking data from highly dynamic aircraft, as well as allow cooperative interoperation among adjacent ranges. As with the GTs, tile data link ground stations are vulnerable to terrain masking. Mission planners call be used to investigate the effect of the terrain on system performance. To provide a high quality measure of overall DLS performance, a mission planner needs to assess link margin, for both direct links and relays between participants and/or data link ground stations (to allow for operation in areas without ground stations).

There are aspects of GPS mission planning that are independent of the test range instrumentation. Clearly, the availability of satellites (which changes with time, location, launching of new satellites, and problems with satellites already in orbit) must be taken into account. Certain characteristics of the vehicle involved in the mission must be specified so that dynamics, limitations, and body masking are modeled. Unintentional jamming oil the range should also be factored into performance evaluation.

USING TRUMP

TRUMP is a PC-resident tool which aids in deploying and utilizing GPS-based test range assets. It will be delivered to all test ranges procuring the RAJPO-developed instrumentation. TRUMP integrates a user-friendly, menu-driven interface and high quality graphics with a fully-modeled dynamic GPS/IMU simulation. It features GPS coherent/ non-coherent tracking, signal reacquisition, receiver aiding by an IMU, and automatic mode transition logic. The TRUMP implementation of the GPS receiver is based on the functional block diagram shown in Figure 1. DOP information, terrain blockage, and jamming are all reflected in the TRUMP-generated output. With TRUMP, the user can examine time-history plots of data link connectivity, TSPI performance, receiver channel tracking status, and TSPI asset visibility.

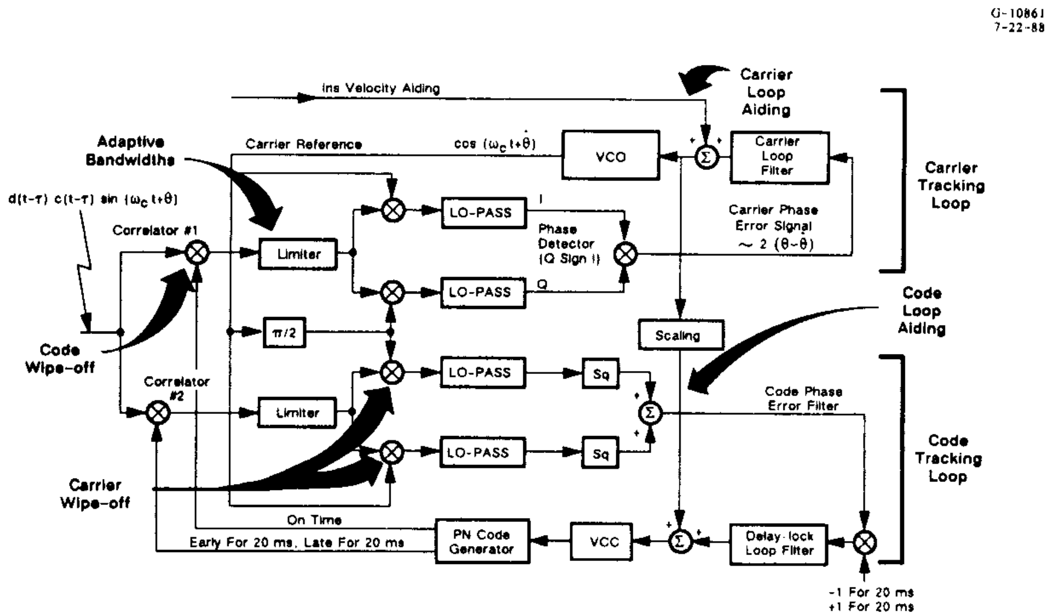

Figure 1 GPS Receiver Functional Block Diagram - Coherent Mode

TRUMP is a package of C and FORTRAN programs that requires a minimal hardware configuration of an IBM-PC/AT or its equivalent, 640 KBytes of random access memory (RAM), a hard disk with roughly 4 MBytes of available disk space, a floppy disk drive, and an EGA color monitor and adapter. The addition of a math co-processor chip, mouse, and modem enhance the system by improving the speed, facilitating scenario set-up, and allowing the update of the GPS satellite almanac, respectively. The user goes through the mission planning process with TRUMP by exploring different deployment options, setting up the desired scenario, executing the mission, and examining performance plots.

Deploying GPS Test Range Assets

Prior to setting up the mission, the user should examine the area visibility of the sites chosen to deploy the ground-based test range assets. Potential ground sites (for GTs and data link ground stations) are specified by the user on the test range terrain map (delivered with TRUMP). Figure 2 is an artist's depiction of a coverage map for ground-based assets. From such a map (normally color-coded), the user can quickly determine how many of the specified ground sites are visible from any point on the map. In this figure, ground sites are labeled G1, G2, and G3, and terrain clearance is 2000 m. The computationally efficient software allows the user to experiment with different site locations until the desired two-dimensional range coverage is achieved. These site locations are then used in specifying the mission scenario.

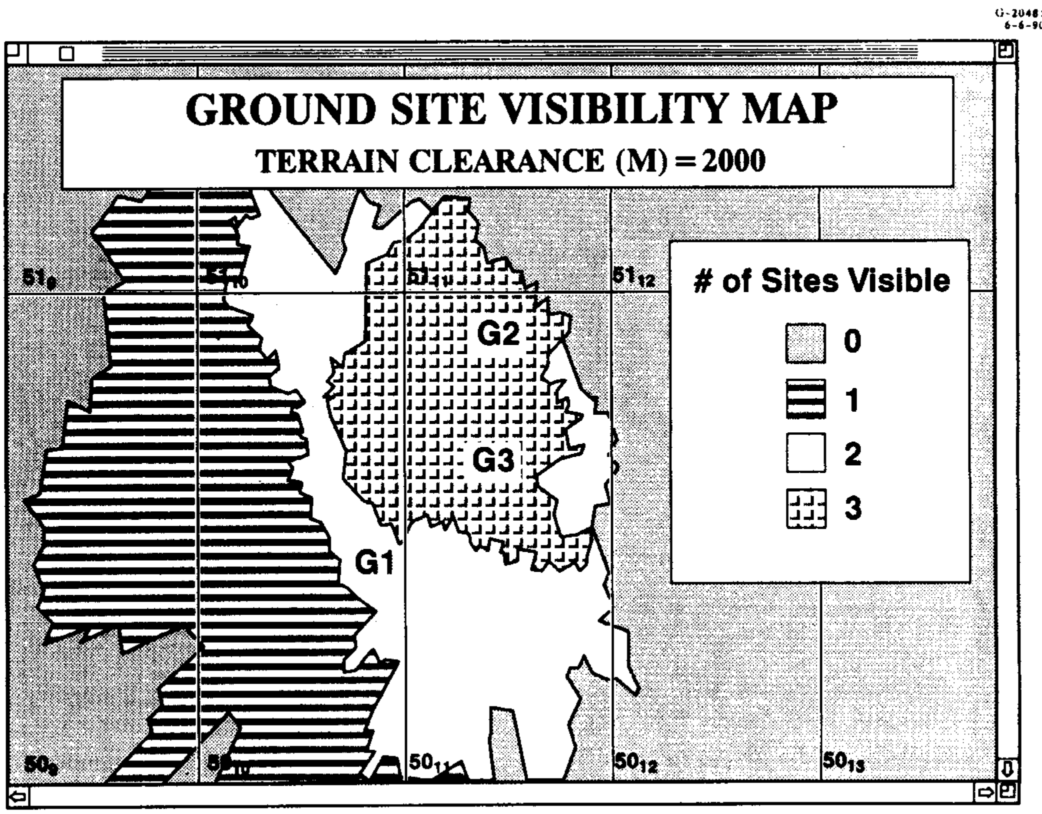

Figure 2 Two-dimensional Coverage Map

Setting Up the Scenario

With the use of built-in map and text editors, the user specifies the desired trajectory and sets parameters that define the mission. Each test range will receive the appropriate terrain elevation map along with TRUMP. The user has the option to enter the Map Editor and, with a mouse, draw the desired trajectory on the range map. Tick marks call be placed at specified time increments on the trajectory. These marks will also be displayed on the time plots so that the performance at specified points in the mission can be easily identified. In addition, jammers (representing L-band jamming sources on the range), GTs, and data link ground stations call be placed on the map; the latter two should be placed as determined by the two-dimensional coverage plots output during the test range deployment phase of mission planning. If an air vehicle is under consideration, the user may indicate those portions of the trajectory to be traversed in the cruise mode and those to be flown in the terrain following mode. Figure 3 is a monochrome rendition of a pseudo-colored terrain map on which is overlaid the mission trajectory, ground-based assets, and cultural features for a specific test range mission. Once the scenario is depicted properly on the map, the user can enter the Text Editor to supply additional mission parameters and/or refine the map entries. If desired, the user call set up the scenario entirely within the text editor and subsequently view it on the map.

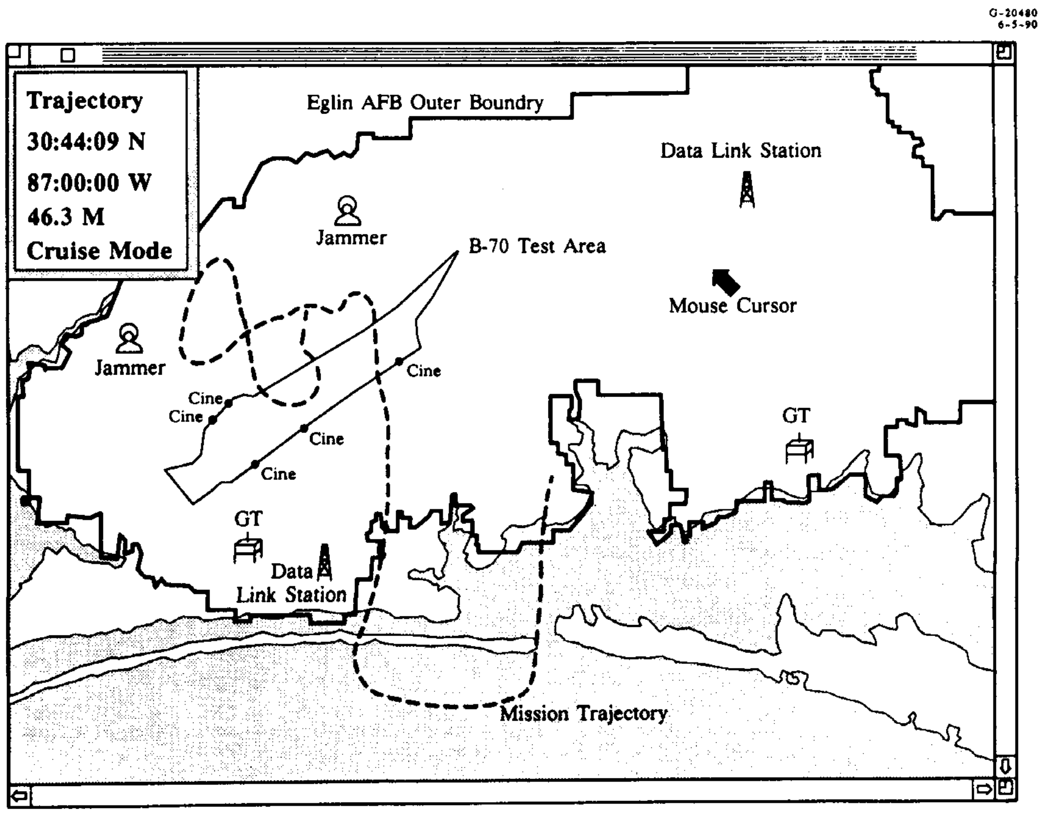

Figure 3 Map Editing with TRUMP

The Text Editor allows the user to specify several classes of parameters. *Mission Parameters* include general specifications; e.g., the date and time of the mission, as well as the vehicle type (air, land, or sea). The user may also set default cruising elevation (relative to mean sea level - MSL) and terrain following clearance; these may be overridden at any individual waypoint. In addition, vehicle limitations are defined; these include the maximum MSL elevation, speed, slope, and acceleration that the vehicle of interest can realistically maintain. If these limitations are exceeded, TRUMP will see the mission to completion but indicate the time(s) that a given limitation violation occurred. Finally, the user may indicate the desired update time interval (e.g., one second for air vehicles, ten seconds for less dynamic ground vehicles).

Trajectory Parameters define the mission course via waypoints. From the Text Editor, the user may specify waypoints or modify waypoints that were specified from the Map Editor. Each waypoint is defined by its position (lat, lon), MSL elevation (if the default cruise elevation is not desired), and the speed that the vehicle will strive to maintain from that waypoint to the next. The flight mode (cruise or terrain following) is also specified for each waypoint; the user has the option to override the default terrain clearance for terrain following mode. A turn value is associated with a waypoint, allowing the user to command a change of heading or 180-degree circular turn at that point. Finally, the user may specify the turn acceleration at each waypoint.

The quality of the GPS receiver is specified as part of *Receiver Parameters*. Carrier loop and code loop bandwidths can be adjusted to emulate the equipment implemented on a given range. TRUMP defaults to bandwidths emulating the HDIS.

GT Parameters, Data Link Parameters, and Jammer Parameters are similar to Trajectory Parameters in that they may be introduced in the Text Editor or initialized in the Map Editor and modified textually. Each item in these classes is represented by a position (lat, lon), MSL elevation, and two-character identification. Each jammer, data link ground station, and GT is also assigned a power level. While this remains constant throughout the mission for data link ground stations and jammers, the power level is specified dynamically for GTs. Test ranges have the ability to power-manage GTs so that flying at close range to a GT (whose power has been reduced) won't result in inadvertent jamming of the receiver. In addition to position, elevation, and power, jammers are assigned a type (point, sector, area, or airborne) and orientation.

Boundary Parameters, the final class represented in the Text Editor, allow the user to overlay boundary and cultural features on the terrain elevation map. While the overlaid boundaries/features don't impact the mission performance, they provide the user with important points of reference that aid in setting up the scenario.

Editing parameters, either textually or with the map and a mouse, is fast and easy with TRUMP's Custom-designed menus and on-line help. All waypoints and ground assets defined in the Text Editor call subsequently be viewed on the map.

Running the Mission/Examining Plots

The first step in running a mission is generating a trajectory. This can be accomplished by either reading a trajectory file previously created from an actual flight tape or running the *Trajectory Generator*. The former method allows the user to incorporate real vehicle dynamics in trajectories that have been previously run, while the second mode makes it possible to traverse new trajectories with characteristics specified in scenario setup. The Trajectory Generator supports use of terrain elevation data. It outputs data at a user-defined rate (e.g., once per second for air vehicles) for land, air, or sea vehicles. This module supports cruising flight or terrain following, user-specified turn modes, and vehicle limitation checks. The resulting trajectory can be viewed on the map or on an elevation time-history plot, presented relative to the local terrain.

Following trajectory generation, the user can execute *Data Link Analysis*. This set of routines provides the user with plots showing data link ground station visibility (taking into account terrain blockage) over time. In addition, a link budget is calculated for each ground station, providing the user an assessment of connectivity.

GPS Analysis generates several plots that aid the user in assessing mission performance. A polar plot illustrates the paths of the GPS satellites over the mission area at the specified time. A DOP plot provides further information about the geometry of the satellites. The receiver tracks satellites that have the best geometric dilution of precision (GDOP), so DOP impacts achievable accuracy. Visibility plots are generated for satellites, GTs, and jammers. The receiver must "see" at least four GPS signal sources (either satellites or GTS) to generate a position and velocity fix. The visibility of the satellites is determined by their orbits, while the visibility of the GTs and jammers is a function of terrain blockage. The signal-to-noise ratio (SNR) of each GPS source is plotted; SNR includes the effect of interference (by either jammers or GTs). In addition, the SNRs of those sources actually tracked by the receiver's four channels are plotted on graphs that also illustrate channel tracking status; i.e., coherent tracking (carrier and code loops), non-coherent tracking (code loop only), or loss-of-lock. GT vehicle dynamics are plotted, indicating at what time the carrier loop is unable to track due to excessive doppler. This plot tells the user when the specified trajectory is too close to a GT. Finally, the TSPI accuracy (position and velocity) is presented. Figure 4 shows the composite of three position errors in local level coordinates (north, east, down) at the user's position. These TSPI data are generated by a covariance analysis program which presumes the presence of an IMU and an eleven state navigation filter. If the TSPI accuracy (and data link coverage) meets the user's requirements, the mission can be run as planned. If not, the user can examine the data plots provided to determine what factors contributed to the unacceptable performance (e.g., poor satellite coverage, inadequate coverage by ground assets, jamming) and revise the mission scenario. After a mission has been run, the user can enter the *Report Writing* mode and generate listings of his mission specifics.

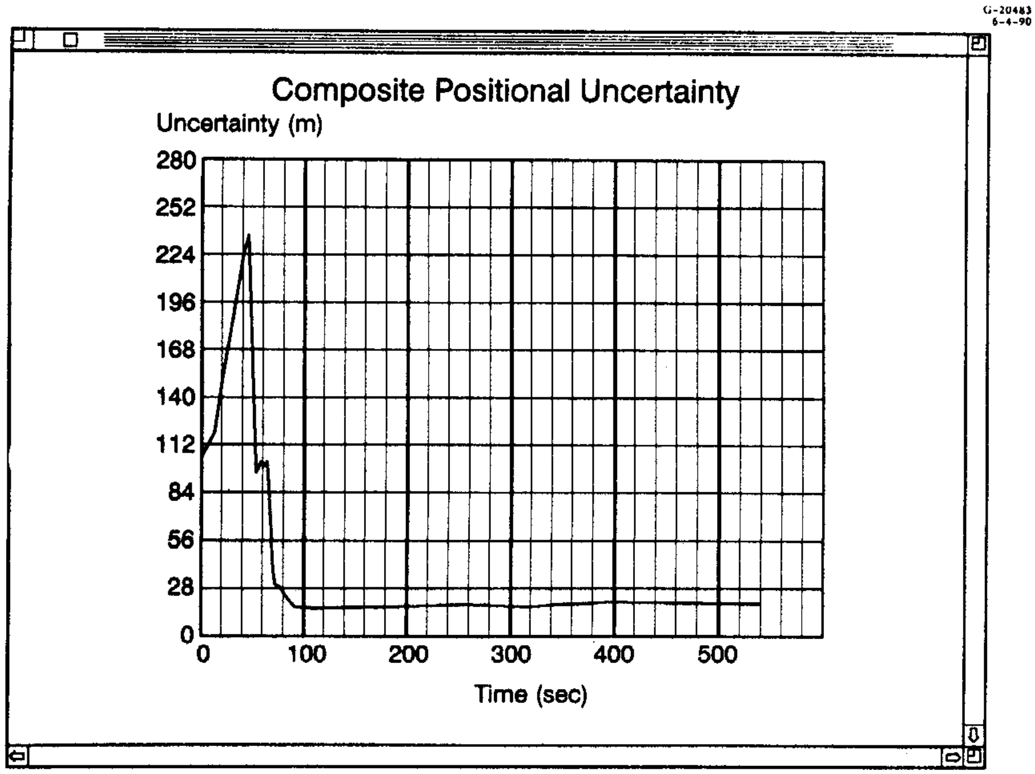

Figure 4 TRUMP Navigation Assessment Plot

SOFTWARE ENHANCEMENTS

Several features have been identified by members of the test range community as important enhancements to TRUMP. These features will be implemented in the next phase of the software's development and should be completed by mid-FY91.

The DLS supports a multi-level relay feature which allows each user to serve as a relay for other users' data. Because of the relay feature and the deployment of multiple ground stations, in many situations there are several routes from the user to the DL controller/processor. TRUMP will rank the viability of each path and derive an estimate of overall message acceptance rate.

Presently, TRUMP supports an integrated GPS/IMU configuration. Receiver parameters are user-definable to support modeling of a specific quality receiver. The IMU is presently fixed to model a low quality strap-down. TRUMP will be modified to allow the user to vary the IMU quality.

The test range community has indicated a need to be able to create range-specific jamming types. TRUMP presently supports four specific jammers. TRUMP will allow the user to specify a new jammer by using the text editor to enter jammer parameters and by using a mouse to draw azimuth and elevation antenna patterns.

The Defense Mapping Agency (DMA) is providing a set of compact discs (CDs) which contain DTED for the entire United States. As part of TRUMP's enhancements, TASC will create a software package which will utilize these CDs to create range-specific DTED maps.

Differential GPS is an operating mode whereby a surveyed-in reference receiver estimates system biases by differencing its known location with its GPS-computed location. These bias estimates are then provided to the user as corrections to his TSPI solution. TRUMP will model the differential GPS mode, including reference receiver operation, and differential correction generation and utilization.

Several additional features have been identified but are not presently scheduled for implementation. These include modeling of translator/TPS equipment and an LDIS (i.e., no IMU) and incorporating a map zoom/scroll capability.

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