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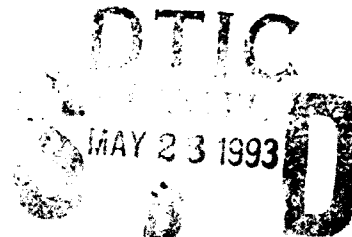


Orbit Analysis Tools Software (Version 1.0) Users Manual

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| 13. ABSTRACT (Maximum 200 words) A program to perform satellite mission and coverage analysis has been written. The Orbit Analysis Tools Software (OATS) program uses numerical and graphical techniques to analyze and display earth coverage data and ground to satellite geometrical parameters. Satellite ephemerides can be computed by any one of three orbit propagators provided with the program or imported from an external source. The program is written in FORTRAN and is designed to run on a Macintosh personal computer. | | | |
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ORBIT ANALYSIS TOOLS SOFTWARE (VERSION 1.0) USERS MANUAL

1.0 Introduction

In the course of our work in mission planning and analysis we have developed a set of computer programs that address many of the questions commonly asked by designers when planning a new satellite system and by managers wishing to assess the performance of an existing system. The Orbit Analysis Tools Software (OATS) is an organization of this collection of computer programs unified by a single graphical user interface. The graphical and tabular output from OATS may be printed directly from the program or cut and pasted via the clipboard into any other Macintosh application program. The FaceIt¹ utility is used to establish the interface between the FORTRAN code and the Macintosh Toolbox.

The OATS program combines orbit propagation models with numerical and graphical coverage analysis algorithms. The design philosophy of OATS has been to separate the orbit models from the analysis functions. The reason for selecting this architecture is so that an arbitrary number of different orbit propagation codes can be added to the program without affecting any of the analysis codes. Thus, when doing mission analysis with OATS the user always must generate the satellite ephemerides before proceeding with any of the coverage analysis functions. The following orbit propagation models are provided with version 1.0 of the program:

- PPT2 - Full Brouwer-Lyddane analytic model. Input elements: One Line Element Sets (OLES). Charlie, PME, and Z OLES formats are supported.
- RUK12 - Fourth order Runge-Kutta numerical integration with WGS84 geopotential of order and degree 12. Input elements: Osculating cartesian state vector.
- FOJ2 - First order analytic theory with earth oblateness effects. Input elements: Mean Keplerian orbital elements.

Satellite ephemerides may be computed using any of these models or they may be imported from external sources using a common ephemeris file format. The user may associate antenna models and ground

¹Manuscript approved December 28, 1992.

station visibility constraints with each satellite ephemeris file and then perform any of the following analysis functions:

- Plot world maps. Four map projections are supported in OATS version 1.0: Mercator, orthographic, oblique stereographic and rectangular. High and low resolution map databases may be selected.
- Display satellite geographical information including ground tracks, satellite fields of view, and satellite positions. Graphically display the ground station database including the ground station locations and fields of view for specific satellite altitudes and minimum elevation angles.
- Compute pass parameters for a satellite and a ground station. The pass parameters include times of acquisition and loss of signal, as well as topocentric azimuth, elevation, range and range rate.
- Compute coverage statistics on a set of targets for a system of satellites and ground stations. The coverage statistics include pass up and down times, coverage, outage and revisit durations, overall minimums, maximums, averages, standard deviations, and totals of coverage, outage and revisit times, and percentages and averages of daily coverage and revisit times.
- Compute global coverage and outage data for a system of satellites and ground stations. This data is computed on a global grid. The density of the grid is selectable by the user. The data is intended to be overlaid as contour plots on world maps using the OATS Plot Contour function.

OATS runs on a Macintosh computer with a math coprocessor under System 6 or System 7. OATS requires a minimum of two megabytes of memory. Installation of the Apple Computer Inc. program ResEdit is required to run OATS.

2.0 About This Manual

This manual is intended to provide an overview of the Orbit Analysis Tools Software. Potential users should be able to determine if the OATS program meets their analysis needs from reading this document. Section 1 is an introduction to the software in which the main functions of OATS are listed. The files necessary to run the OATS application are listed in Section 3. These files may be obtained from the authors on a distribution diskette. Section 4 contains an overall description of program operation including selecting windows, setting window parameters, and control of the print quality. The purpose and use of each of the orbit propagation, graphics, and analysis functions is listed in Section 5. Finally,

Section 6 discusses the format of the internal and external files and databases used by OATS. The satellite antenna pattern definitions are contained in Appendix A. Appendix B contains an example analysis session in which satellite ephemerides are created, Earth coverage is computed and some results are plotted.

3.0 The OATS Distribution Diskette

The OATS program and related files are contained on a single high density 3.5" diskette. The distribution diskette may be obtained from the authors. The following file are needed to run OATS:

| | |
|--------------|--|
| OATS | Applications program |
| OATS.RSRC | Resource file |
| MAP.DAT | High resolution map database file |
| NEWMAP.DAT | Low resolution map database file |
| TARGET.INPUT | Sample target input file |
| DBASE.CC_PCT | Cumulative coverage (percent) contour database file |
| DBASE.CC_TC | Cumulative coverage (total coverage) contour database file |
| DBASE.CC_AC | Cumulative coverage (average coverage) contour database file |
| DBASE.AO | Average outage contour database file |
| DBASE.MO | Maximum outage contour database file |

4.0 The OATS User Interface

The OATS graphical user interface consists of the **OATS Graphics Window**, the **Reduced View Window**, and the **Tabular Output Window**. The images created by all of the Plot functions are displayed in the **OATS Graphics** and **Reduced View Windows**. The output from the **Tabular Coverage** function and the **Look Angles** function is sent to the **Tabular Output Window**.

The OATS graphical user interface allows the user to control the operation of the program by selecting among the various items on the menu bar.

4.1 File

The main menu item **FILE** contains the standard program file operations. These include:

- Open
- Save

- Save As
- Save Settings
- Page Setup
- Print
- Return
- Transfer
- Quit

4.1.1 Open

The **Open** command is used to open picture files that have been saved from within the OATS program. Text files may also be opened into the text window for editing. User created input files and imported ephemeris data are read in through dialog boxes or opened from the **Open Eph** menu item, respectively. The **Open** command may be used to read in frequently used map projections which have been previously saved within the OATS application. This greatly reduces the time required to draw the map. **CAUTION:** Be sure to enter the **Map Options** dialog and set the proper projection and bounds for the map that you have opened. This sets the parameters and scale for additional graphics on the map. Failure to do this will result in incorrect positioning and scaling of graphics.

4.1.2 Save

The **Save** command is used to save graphics or text. These saved graphics/text documents can later be opened with the **Open** command. Before saving a multi-layered picture, be sure to use the **Select All** command to select all the layers and then **Combine** them. Failure to do so will result in only the top layer of the graphics (last drawn) to be saved in the file.

4.1.3 Save As

The **Save As** command is used in the same way as the **Save** command. **Save As** allows the user to rename a file that has been opened under a different filename.

4.1.4 Save Settings

The **Save Settings** command saves the users preferences for program graphics and text settings at launch time. This includes the size of the graphics window at launch time, as well as the font size of the text window. The user may wish to set a window size that fits on the terminal screen for their

computer. More information for the graphics window settings can be found in section 4.3 under **Graph Setup**. More information on the text window settings may also be found in section 4.3 under **Editor Setup**.

4.1.5 Page Setup

The **Page Setup** command is used to set the orientation of the printing on the paper and also the size reduction for printing. **Note:** 25% reduction produces a 300 dots/inch resolution for Laser Writers.

4.1.6 Print

The **Print** command sends the contents of the active window to the printer. The contents of the window may be either graphics or text. Use the **Chooser** command under the Apple menu to select a printer.

4.1.7 Return

Return is used to return to the OATS program if the user is operating with Finder (not Multifinder). The **Return** command will only be activated if the user has already issued the **Transfer** command.

4.1.8 Transfer

The **Transfer** command is used to launch another application from within OATS when the user is operating in Finder.

4.1.9 Quit

The **Quit** command is used to exit the program.

4.2 Edit

The main menu item **Edit** contains the standard program edit operations for both graphics and text. These include:

- Undo Resize/Undo
- Cut

- Copy
- Copy Frame Area/Copy As Table
- Paste
- Clear
- Select All/Tabs-To-Spaces
- Original Size and Combine
- Bring To Front/Search For
- Send To Back/Next Case

Note: If two functions are listed, the first is applicable when the **OATS Graphics Window** is active and the second is applicable when the **Tabular Output Window** is active.

4.2.1 Undo Resize/Undo

The **Undo Resize** command is used to restore a graphic to its original dimension after manually resizing the picture. To resize a picture, move the cursor to the edge of the picture and the cursor will turn into an arrow. Click-drag the edge of the drawing to the desired size. This may be accomplished by extending one edge at a time, or by click-dragging on a corner of the drawing area.

The **Undo** command is used to undo the previous edit action while using the text window.

4.2.2 Cut

The **Cut** command deletes the selected item (top layer in graphics) and stores it on the clipboard so that it may be **Pasted** into another application or into another area.

4.2.3 Copy

The **Copy** command creates a copy of the selected item (top layer in graphics) onto the clipboard so that it may be **Pasted** into another application or into another section of the drawing area in OATS. It can also be used to copy text from the Tabular Output (text) window.

4.2.4 Copy Frame Area/Copy As Table

The **Copy Frame Area** command allows the user to select a smaller (sub)frame area than the entire drawing area and copy it to the clipboard. To select the area depress the apple key and then click-drag

out the area that you wish to copy. Select the **Copy Frame Area** command to copy the area. This area may then be **Pasted** into another application or repositioned on the graphics window for printing. **Note:** If an area smaller than the original full drawing is selected and then pasted into a new position on the graphics window nothing new should be plotted on the picture as the scale factor is determined by the size of the full drawing.

The **Copy As Table** command allows the user to select a portion of the text window and copy it to the clipboard. Each entry that is separated by one or more spaces is now separated by a Tab. This may then be **Pasted** into another application or onto another part of the text window.

4.2.5 Paste

The **Paste** command is used to paste a picture or text that has been copied or cut to the clipboard. Use the cursor to select the place for the object to be pasted and then execute the **Paste** command from the menu.

4.2.6 Clear

The **Clear** command is used to delete the top layer of a picture. The deleted picture cannot be recovered as with the **Cut** command. It can also clear successive layers of pictures by clearing the top layer and then clicking the arrow on the next layer (to activate that layer) and clearing it. This process may be repeated until all the layers have been cleared. The **Clear** command can also be used in the text window to clear selected text.

4.2.7 Select All/Tabs To Spaces

The **Select All** command can be used in the graphics window to select all the layers of pictures. This command must be used if the user wishes to **Copy** and **Paste** all of the layers of a picture into another application or to **Save** a picture. It can also be used in the text window to select all of the text.

The **Tabs To Spaces** command replaces all of the Tabs in the selected text with spaces. The original spacing is kept the same, however there are no longer Tabs in the text.

4.2.8 Original Size and Combine

These functions are both used for the graphics window.

The **Original Size** command will restore a picture to its original size if it has been manually resized by the user.

The **Combine** function is used to group several layers of pictures into a single picture. This menu item will appear AFTER the user has drawn at least 2 layers in the graphics window and has executed the **Select All** command. This is useful for saving pictures.

4.2.9 Bring To Front/Search For

The **Bring to Front** command is used to bring the selected layer of graphics to the top layer. This command only becomes activated (non-grayed) in the menu if a layer other than the top layer has been selected.

The **Search For** command brings up a dialog which allows the user to input a string to be searched for in the text window.

4.2.10 Send To Back/Next Case

The **Send To Back** command allows the user to send the top layer of the graphics window to the bottom layer. Click on the new top layer to activate that layer.

The **Next Case** command is used after the **Search For** command has been used. It highlights the next occurrence of the string input in the **Search For** dialog box.

4.3 Window

The main menu item **Window** contains standard program Window operations for both graphics and text windows. These include:

- Graph Setup/Editor Setup
- Left/6 point
- Centered/9 point
- Right/12 point
- OATS Settings
 - Frame Size
 - Record Method

- Frame Info
- Save Frame
- Reduced View
- OATS Graphics Window
- Tabular Output

Note: If two functions are listed, the first is applicable when the graphics window is active and the second is applicable when the text window is active.

4.3.1 Graph Setup/Editor Setup

The **Graph Setup** command allows the user to set the characteristics of the graphics window. This option appears in the menu when the graphics screen is active. When the **Graph Setup** command is executed the dialog box in Figure 1 appears on the screen.

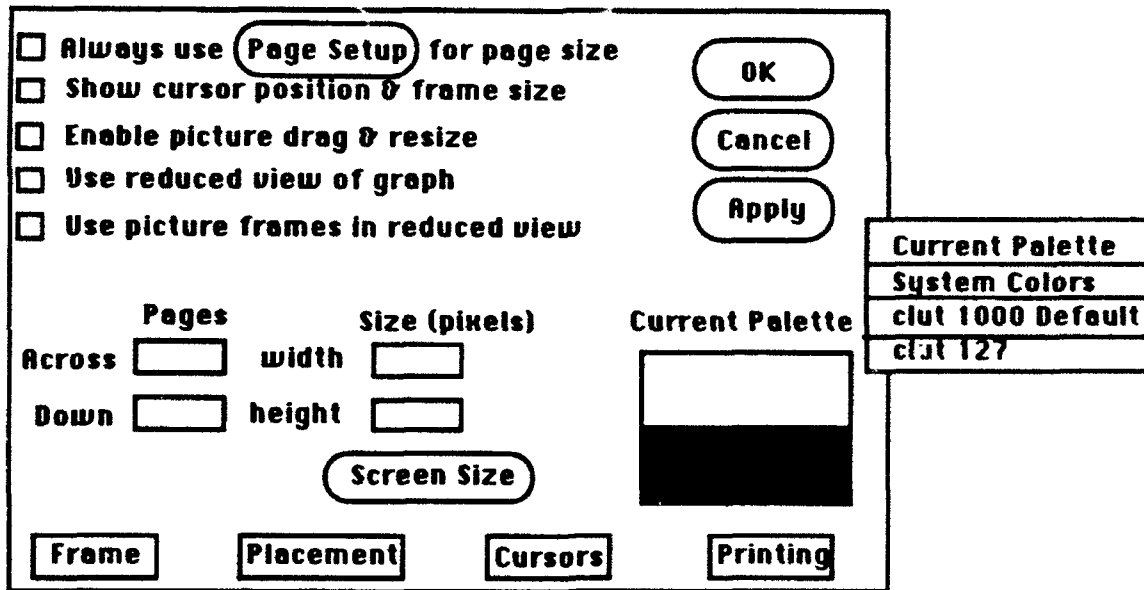


Figure 1 Graph Setup dialog

At the top of the dialog box are five different checkbox options for the graphics. These can be activated or deactivated at the users discretion. The Pages option allows the user to specify the number of pages in the drawing area. These pages are laid out according to the reduction and page orientation specified in the page setup if the Always use Page Setup for page size option is activated. The Size(pixels) option will display the size of the drawing area. This can also be used to set the size of the drawing area. The Screen Size button can be clicked to insert the size in pixels of the screen that is attached to your computer. The drawing area can be opened to the full size by clicking and dragging in the box located at the bottom right

of the graphics area. The four bottom boxes in the dialog bring up help information to the screen on the subject the user clicks. The Current Palette provides for color options which have not yet been added to the program. This should be set to Current Palette.

The **Editor Setup** command allows the user to set the characteristics of the **Tabular Output Window**. This option appears in the menu when the editor screen is active. When the **Editor Setup** command is executed the dialog box in Figure 2 appears on the screen.

Tab Size Auto Indent

Use ENTER Key as:

- TAB
- Space-based TAB
- %-Return
- Scroll to Insertion Point

File Handling:

- Selection-based
- One file per window

Show cursor position & selection size

OK

Cancel

Help

Figure 2 Editor Setup dialog

The Tab Size allows the user to specify the size (spacing) of the tab key. The Auto Indent check box will activate/deactivate auto indenting. The user has a selection of four options for the use of the Enter key specified by selecting the appropriate radio button. The user has a choice for file handling in the Editor window specified by selecting the appropriate radio button. The Show cursor position & selection size check box, when activated, shows the position and size of a selection when the mouse button is depressed. The Help button may be clicked to display on-screen help for the Editor setup screen.

4.3.2 Left, Centered, Right

These commands are the choices for text justification in the **OATS Graphics Window**. To insert text into the graphics window, select a text area by depressing the Apple key on the keyboard and

then click-dragging out the desired area. Then press the Enter key and a text cursor will appear. When you are finished typing in text, press the Enter key again and OATS will return to the normal graphics mode. More help on this subject can be found in the Graph Setup window by clicking the Frame box.

4.3.3 6 point, 9 point, 12 point

The **6, 9, 12** point option specifies the Font size for the **Tabular Output Window**.

4.3.4 OATS Settings

The **OATS Settings** menu has a sub menu of four items: **Frame Size**, **Record Method**, **Frame Info**, and **Save Frame**. Selecting one of these menu items will bring a dialog box to the screen. These are discussed below.

4.3.4.1 Frame Size

Selecting the **Frame Size** command brings up the dialog box in Figure 3.

Frame Size in inches

Horizontal

Vertical

Screen Resolution - Pixels/inch

Horizontal

Vertical

Figure 3 Frame Size dialog

When this dialog box appears, it contains the values for the size of the current active frame in inches and a screen resolution of 72 pixels/inch. You may either set the frame size (in inches) or the screen resolution (in pixels/inch), then select OK and the active drawing area will be set to the size you have specified. **Caution:** The size you select may not exceed the size of the present drawing board. To increase the size of the drawing board, use the **Graph Setup** option in the **Window** menu. Also, for a selected drawing area, a resolution for the printer may be specified and the drawing area will be increased accordingly. Most screens have a resolution of 72 pixels/inch. To print at 300 pixels/inch (Laser Writer), use 25% reduction in the **Page Setup** dialog and draw the picture at the appropriate size. This is calculated and set in this window by specifying the resolution. **Caution:** Check that the drawing board area is large enough for the complete enlargement of the active drawing area (broken line box) for the specified resolution. This can be enlarged using the **Graph Setup** option under the **Window** menu.

4.3.4.2 Record Method

Select **Record Method** to set the type of drawing on the drawingboard. The dialog in Figure 4 will appear on the screen.

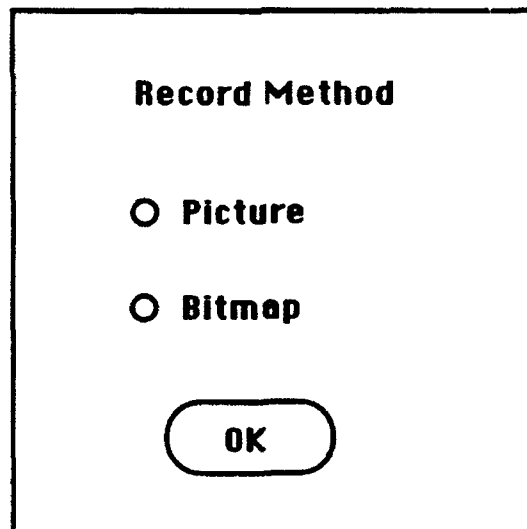


Figure 4 Record Method dialog

The user can select how the image is drawn to the drawing area. It can be drawn as a picture or as a bitmap.

4.3.4.3 Frame Info

More information about the current drawing frame can be found in the **Frame Info** dialog box. The **Frame Info** dialog box is shown in Figure 5.

The diagram shows a dialog box titled "Frame Info". It contains six input fields for "Top", "Left", "Bottom", "Right", "Length", and "Width". To the right of these fields are two buttons: "OK" and "Cancel".

Figure 5 Frame Information dialog

This dialog displays the position, in pixels, of the four sides of the drawing area. Also displayed is the length and width of the drawing area. The user may check on the size of the current drawing area, or set it from this dialog.

4.3.4.4 Save Frame

The **Save Frame** command brings the standard Save dialog box to the screen which allows the user to save the current active frame. **Caution:** If more than one layer has been drawn, be sure to **Select All** and **Combine** before saving or only the top layer will be saved.

4.3.5 Reduced View and Font, Size, Style

To bring the **Reduced View Window** to the front (active window) select the **Reduced View** command. The **Reduced View Window** shows the entire contents of the **OATS Graphics**

Window. The contents of the **Reduced View Window** can be manipulated the same as the **OATS Graphics Window**. This window is useful if the drawing area is larger than the screen and you wish to view the entire contents of the **OATS Graphics Window**. The **Reduced View Window** cannot be resized and the reduction ratio is shown at the top of the window.

When entering text into the drawing window, the **Font, Size, Style** option will appear in the menu in place of the **Reduced View** command. This is used to set the characteristics of the text. For information on placing text in the graphics window, click the Frame box in the Graph Setup dialog box (4.3.1).

4.3.6 OATS Graphics Window

The **OATS Graphics Window** command brings the main graphics window to the front (active). The user can then see the contents of the drawing area. Note: The graphics window need not be active to draw to it. It only needs to be active if the user wishes to see what has been drawn.

4.3.7 Tabular Output

The **Tabular Output** command brings the text window to the front. This is the window where the Tabular coverage and the Look Angles information is written. The window also serves as a general text editor.

5.0 Orbital Propagation, Coverage Analysis and Plotting

This section is devoted to the description and use of the primary function of OATS: Numerical and graphical earth satellite coverage analysis. Section 5.1 explains the use of the internal orbit propagation routines. Section 5.2 explains how ephemeris files are loaded into memory for the coverage analysis functions. Section 5.3 describes the Tabular, Graphical, and Look Angles analysis programs. Finally, the plotting functions of OATS are described in section 5.4.

The Tabular coverage function computes coverage statistics for a system of satellites against a set of ground targets on an oblate earth. Ground stations may be included as viewing constraints for any or all of the satellites. The satellite antenna pattern for target viewing is specified for each satellite individually. A target is said to be covered when one or more of the satellites in the system is visible to the target. The Graphical coverage function computes world-wide coverage of a system of satellites using a fast technique in which a spherical earth is used as a simplifying assumption. The output data from this technique is best

understood via the **Plot Contour** function provided with the OATS plotting functions. The **Look Angles** function computes the azimuth, elevation, range, and range rate from a ground station to a satellite as functions of time. The OATS plotting functions allow satellite coverage data, ground tracks, fields of view and target and ground station positions to be displayed on world maps.

Two coordinate systems are referred to throughout the remainder of this document. They are: Earth Centered Inertial (ECI), and Earth Centered Fixed (ECF). The fundamental plane of the ECI system is the mean celestial equator. The *x* axis lies in the direction of the Vernal equinox and the *z* axis points toward the North celestial pole. The ECF system is a non-inertial, rotating system which is fixed to the earth. The fundamental plane is the true celestial equator. The *x* axis is fixed to, and rotates with, the Greenwich meridian. The *z* axis is parallel to the rotational axis of the earth.

All of the analysis and plotting functions in OATS to which satellite ephemerides are input require the coordinate frame to be ECF.

5.1 Propagate

The **Propagate** menu contains all of the items necessary to select an orbit propagation model, input an element set, select a propagation time and propagate an orbit. This produces an ephemeris file that can be used for plotting or coverage analysis.

5.1.1 Select Model

The **Select Model** command contains a sub menu in which the user selects the type of orbit propagator that will be used by OATS. The choices are:

- PPT2
- RK12
- J2

PPT2

The **PPT2** propagator uses a full Brouwer-Lyddane analytic model for propagation and requires the input of a One Line Element Set (OLES). There are three different formats for the OLES. After selecting **PPT2**, a dialog to specify the type of OLES will appear on the screen. The three different formats are:

- PME
- Charlie
- Z

The formats for each of these types are defined in section 6.1.1.

Select the appropriate radio button and then click OK. The dialog specific to the format type chosen will appear on the screen.

The dialog box for PME format is shown in Figure 6.

PME-format One-line Element Set

| | | | |
|-------------------------|----------------------|--------------------------|----------------------|
| Sat ID: | <input type="text"/> | Arg. of Asc. node (deg): | <input type="text"/> |
| Uers. #: | <input type="text"/> | Inclination (deg): | <input type="text"/> |
| Rev #: | <input type="text"/> | Last digit of Year: | <input type="text"/> |
| Mean Anomaly (deg): | <input type="text"/> | Month: | <input type="text"/> |
| Mean Motion (rad/berg): | <input type="text"/> | Day: | <input type="text"/> |
| Decay (rad/berg/berg): | <input type="text"/> | Hours: | <input type="text"/> |
| Arg. of Perigee (deg): | <input type="text"/> | Tens of Minutes: | <input type="text"/> |
| Eccentricity: | <input type="text"/> | | |

Figure 6 PPT-PME Format OLES input dialog

To read in a PME OLES, click on the File... button. Enter the name of the file to be placed in the dialog box. An element set may also be input by the user directly into the dialog box. Modifications to a PME OLES which has been read in can also be performed at any time the dialog is open. Make sure that all user inputs have the correct units! When the desired inputs are displayed in the boxes, they may be saved as an OLES file by clicking Save or Save As.... To exit the dialog box click the OK button or the CANCEL button. Note that the epoch for the PME OLES contains only the last digit of the year and the minutes are in Tens of Minutes. The format for the PME OLES file is specified in Section 6.1.1.2.

The dialog box for Charlie format is shown in Figure 7.

Charlie-format One-line Element Set

| | | | |
|--------------------------------|----------------------|--|----------------------|
| Sat STC #: | <input type="text"/> | Arg. of Asc. node (deg): | <input type="text"/> |
| Mean Anomaly (deg): | <input type="text"/> | Inclination (deg): | <input type="text"/> |
| Mean Motion (rad/herg): | <input type="text"/> | Year (YY): | <input type="text"/> |
| Decay (rad/herg/herg): | <input type="text"/> | Month (MM): | <input type="text"/> |
| Eccentricity: | <input type="text"/> | Day (DD): | <input type="text"/> |
| Arg. of Perigee (deg): | <input type="text"/> | hrs, mins, and secs=0 Epoch at 0 hours Zulu | |

Figure 7 PPT-Charlie Format OLES input dialog

To read in a Charlie OLES, click on the File... button. Enter the name of the file to be placed in the dialog box. An element set may also be input by the user directly into the dialog box. Modifications to a Charlie OLES which has been read in can also be performed at any time the dialog is open. Make sure that any user inputs have the correct units! When the desired inputs are displayed in the boxes, they may be saved as a Charlie OLES file by clicking Save or Save As.... To exit the dialog box click the OK button or the CANCEL button. Note that the epoch for the Charlie OLES contains only the year, month and day. The Epoch is at zero hours Zulu. The format for the Charlie OLES file is specified in Section 6.1.1.1.

The dialog box for Z format is shown in Figure 8.

Z-format One-line Element Set

| | | | |
|-------------------------|----------------------|--------------------------|----------------------|
| Set STC #: | <input type="text"/> | Arg. of Perigee (deg): | <input type="text"/> |
| Rev #: | <input type="text"/> | Arg. of Asc. node (deg): | <input type="text"/> |
| Mean Anomaly (deg): | <input type="text"/> | Inclination (deg): | <input type="text"/> |
| Mean Motion (rad/berg): | <input type="text"/> | Year (YY): | <input type="text"/> |
| Decay (rad/berg/berg): | <input type="text"/> | Month (MM): | <input type="text"/> |
| Eccentricity: | <input type="text"/> | Day (DD): | <input type="text"/> |

OK CANCEL File...
SAVE SAVE AS...

Figure 8 PPT-Z Format OLES input dialog

To read in a Z OLES, click on the File... button. Enter the name of the file to be placed in the dialog box. An element set may also be input by the user directly into the dialog box. Modifications to a Z OLES which has been read in can also be performed at any time the dialog is open. Make sure that any user inputs have the correct units! When the desired inputs are displayed in the boxes, they may be saved as a Z OLES file by clicking Save or Save As.... To exit the dialog box click the OK button if the information is correct, or the CANCEL button if you wish to exit the dialog. Note that the epoch for the Z OLES contains only the year, month and day. The Epoch is at zero hours Zulu. The format for the Z OLES file is specified in Section 6.1.1.3.

RK12

The RK12 model is a Fourth order Runge-Kutta numerical integration with WGS84 geopotential of order and degree 12. The input for this model is an osculating cartesian state vector and an epoch for the state vector. This model requires a small integration step size to obtain accurate results (1-10 seconds). This stepsize is rather small for plotting and coverage analysis and tends to yield very large ephemeris files to store the data. Because of this, the user specifies the integration step size for the propagation and also a print interval for the ephemeris data.

The dialog for the RK12 propagator is shown in Figure 9.

Input for Ruk12 Propagator

Reference Frame

ECF
 ECI

| State: | | Epoch | |
|--------------|----------------------|-------|----------------------|
| X (km): | <input type="text"/> | YY | <input type="text"/> |
| Y (km): | <input type="text"/> | MM | <input type="text"/> |
| Z (km): | <input type="text"/> | DD | <input type="text"/> |
| Xdot (km/s): | <input type="text"/> | HH | <input type="text"/> |
| Ydot (km/s): | <input type="text"/> | mm | <input type="text"/> |
| Zdot (km/s): | <input type="text"/> | ss.ss | <input type="text"/> |

Time Steps

Integration (sec): Output (sec):

Figure 9 Runga-Kutta elements input dialog

The state vector and epoch are input manually or the entire dialog can be read in from a file using the File... button. The format of this file is specified in section 6.1.2. The user can input a state vector in either Earth Centered Fixed (ECF) or Earth Centered Inertial (ECI) coordinates and should specify which is being used by selecting the appropriate radio button at the top of the dialog box. The Epoch is entered in the format of YY, MM, DD, HH, mm, SS.SS. Two time steps are input by the user. The time step on the left is the integration time step used by the RK12 propagator. The time step on the right is the interval that ephemeris states will be written to the output file. After a file has been manually input, it can be saved by clicking the Save As button. After the inputs are set to the desired values, click the OK button. To exit the dialog, click the CANCEL button.

The J2 propagator uses a first order analytic theory with earth oblateness effects. The input elements are mean Keplerian orbital elements and an epoch for these elements.

The input dialog for the J2 model is shown in Figure 10.

INPUT FOR J2 PROPAGATOR

| | | | |
|---------------------------|--|----------------------------|--|
| Reference Frame | | Anomaly | |
| <input type="radio"/> ECI | | <input type="radio"/> Mean | |
| <input type="radio"/> ECF | | <input type="radio"/> True | |

| | |
|-------------------------|--------------|
| Orbital Elements | Epoch |
| Semi-Major Axis (km): | YY |
| Eccentricity: | MM |
| Inclination (deg): | DD |
| Arg. Asc. Node (deg): | HH |
| Perigee (deg): | mm |
| Anomaly (deg): | ss.ss |

Figure 10 J2 elements input dialog

The Keplerian elements and epoch are input manually or can be read in from a file, using the File... button. The format of this file is specified in section 6.1.3. The user can input the Keplerian elements in either Earth Centered Fixed (ECF) or Earth Centered Inertial (ECI) coordinates and should specify which is being used by selecting the appropriate radio button at the top of the dialog box. Also, the user needs to specify if the anomaly for the element set is true or mean by selecting the appropriate radio button at the top of the dialog. The Epoch is entered in the format of YY, MM, DD, HH, mm, SS.SS. After the dialog has been manually filled, it can be saved by clicking the Save or Save As button. After the inputs are set to the desired values, click the OK button. To exit the dialog, click the CANCEL button.

5.1.2 Edit Interval

The **Edit Interval** command brings up the Edit Interval dialog box shown in Figure 11. This dialog box is used to set the start and stop times for the ephemeris propagation. The format for the start time and stop time is YY, MM, DD, HH, mm, ss.ss where each letter represents a place for a number. Leading zeros may be left out of the entry. The next entry is the time step size. The user needs to specify the granularity (in seconds) of the ephemeris data written to the ephemeris file. The user also inputs a filename to designate an output file for the ephemeris data.

| Start Time | | Stop Time | |
|-----------------------------------|----------------------|---------------------------------------|----------------------|
| Year (YY): | <input type="text"/> | Year (YY): | <input type="text"/> |
| Month: | <input type="text"/> | Month: | <input type="text"/> |
| Day: | <input type="text"/> | Day: | <input type="text"/> |
| Hour: | <input type="text"/> | Hour: | <input type="text"/> |
| Minutes: | <input type="text"/> | Minutes: | <input type="text"/> |
| Seconds: | <input type="text"/> | Seconds: | <input type="text"/> |
| Step size (seconds): | <input type="text"/> | | |
| OUTPUT FILE NAME: | <input type="text"/> | | |
| <input type="button" value="OK"/> | | <input type="button" value="Cancel"/> | |

Figure 11 Edit Interval dialog

5.1.3 Edit Elements

The **Edit Elements** command will bring up the element and epoch dialog for the currently selected model type. The current model is denoted by a check mark placed next to the model in the **Select Model** sub menu. These dialogs and their inputs are described in detail in section 5.1.1.

5.1.4 Execute

The **Execute** command is used to run a specified propagator. After selecting a model, inputting the elements and epoch for the selected model, and specifying the start and stop times in the Set Interval dialog, select the **Execute** command to perform the orbit propagation. This will create an output file, the name of which was specified in the Edit Interval dialog, with the ephemeris data for the specified times and elements.

5.2 Open Eph.

The **Open Eph.** command is used to open ephemeris files for use in plotting and coverage routines. Execution of the **Open Eph.** menu command brings the dialog shown in Figure 12 to the screen. Up to 10 files may be open at any given time. As ephemeris files are created with the **Execute** command in the **Propagate** menu, the filename is automatically added to the list of ephemeris files on the left. To open an imported file, an ephemeris created by another application, type the name of the file in the File Name box and then click the **ADD** button. This will add the file name to both the list on the left, which is saved upon exiting the program, and the list on the right, which is the list of files to be opened. To add a file from the list on the left to the list of Files to be Opened, highlight the desired file by clicking the arrow on the file name, click the **ADD** button and the file will be added to the list on the right. When all of the files to be opened appear in the list on the right, click the **OPEN** button. This will open all of the files in the list (up to 10) for use in the coverage and plotting routines. **Note:** The files to be opened must be located in the same directory as the OATS executable program.

The files in the lists can be deleted by highlighting the file and the clicking the **DELETE** button under the appropriate list. The Files to be Opened list may also be cleared by clicking the **CLEAR** button under that list.

If the Files to be opened list has been modified from a previous use of the **Open Eph** dialog and you decide you do not want to change it, click the **CANCEL** button and you will return to the main program and the list of open files will revert back to its original state.

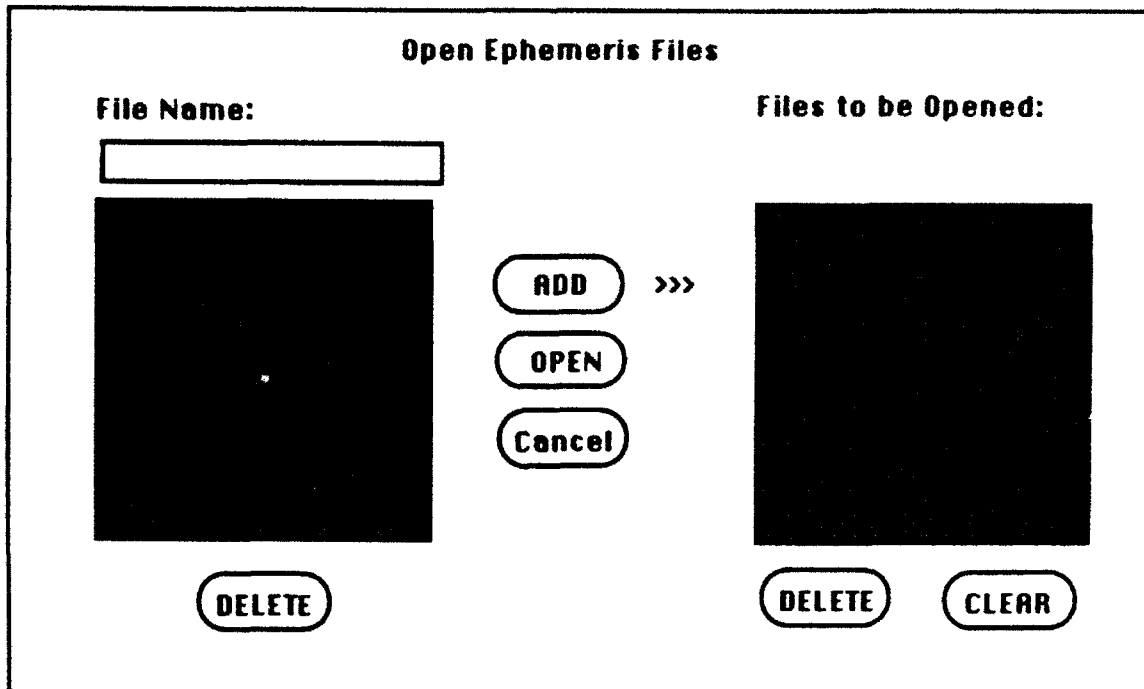


Figure 12 Open Ephemeris dialog

5.3 Coverage

The OATS program has the ability to perform three types of coverage analysis. The first type is **Tabular** coverage. This produces a list of rise and set times and other statistics for a set of ground stations, satellites, and targets. Up to 20 ground stations, 10 satellites, and 100 targets may be used in this analysis. The second type of coverage is **Graphical** coverage. This is global coverage with a mesh size specified by the user. Inputs are ground stations and satellites. This produces files used to plot contour lines for coverage analysis and graphical evaluation. The third type is **Look Angle** coverage. A list (tabular) is produced with azimuth, elevation, range and range rate information for a single ground station and a single satellite. The ephemeris data for the satellites used in the coverage analysis may be created using one of the propagators in OATS or may be imported from another source.

The fundamental quantities computed by the coverage functions in OATS are defined as follows:

Coverage Time: The interval between Acquisition of Signal (AOS) to Loss of Signal (LOS).

Revisit Time: The interval between one AOS to the next AOS.

Outage Time: The interval between LOS and AOS.

5.3.1 Tabular

The **Tabular** coverage function uses an oblate Earth and atmospheric refraction effects for calculating coverage, outage, and revisit statistics. Four things must be set; the ephemeris files, the ground stations, the antenna type for each ephemeris file, and the target positions.

The ephemeris files are opened by using the **Open Eph** command. More information on this menu item can be found in section 5.2

5.3.1.1 Edit Ground Stations

The **Edit Grnd Stns** command allows the user to select ground station positions for tabular coverage analysis. Up to twenty ground stations may be selected at one time. Executing the **Edit Grnd Stns** command will bring the dialog box shown in Figure 13 to the screen. The list on the left is all of the ground stations that are in the OATS ground station database that is saved in the program and can be modified by the user. To activate one of the ground stations in the list, highlight the ground station name in the list on the left and click the **ADD** button located between the two lists. The name of the ground station will appear in the active list and the information for the ground station will be displayed in the ground station information boxes at the top of the dialog box. Double click on a ground station in the left list and the information (name, lat, lon, alt., mask) will appear in the GS information boxes. Where, lat is the station geodetic latitude in degrees, lon is the station longitude in degrees, and alt is the station altitude above the geoid in kilometers. If the desired ground station is not in the list, it can be manually typed into the GS parameter boxes. It must be added to the permanent list by clicking the **ADD** button above the ground station list. Ground stations in the list may be removed from the permanent list by highlighting the ground station to be removed and clicking the **DELETE** button above the list. Ground stations may be removed from the active list by highlighting the ground station to be removed in the active list and then clicking the **DELETE** button between the two lists. The entire active list may be cleared by clicking the **CLEAR** button between the two lists.

The Ground Station dialog described above and shown in Figure 13 is the same dialog that is used for the plotting routines. To select ground stations for the plotting routines, follow the same procedure as selecting ground stations for coverage analysis.

Ground Station Dialog

Size of GS (pixels):

Input GS Information:

GS Name:

GS Lat. (deg): GS Alt. (km):

GS Lon. (deg): GS El. Mask (deg):

Figure 13 Ground Station dialog

5.3.1.2 Edit Antennas

After the desired ephemeris files have been opened, the antenna type for each ephemeris file can be chosen by selecting the **Edit Antennas** command in the **Tabular** sub menu. Execution of this command will bring up the Antenna Parameter dialog shown in Figure 14. To select a particular ephemeris file, double click on the name of the desired file in the Ephemeris File List. The information for that file will be displayed in the parameter boxes. The name of the selected file will appear in the Ephemeris File box. The type of antenna will be displayed along with the antenna angle parameter for that antenna type. The antenna pattern may be defined as earth central angle, cone angle, or elevation angle. These geometries are defined in Appendix A. Also a ground station flag may be set for the selected ephemeris file. If the GS flag is activated, the satellite must be in view of the target AND the ground station at the same time for the

coverage event to be added to the statistics. The parameters for the antenna may be changed for the currently active ephemeris file. This process can then be repeated to select the antenna type and parameters for each the ephemeris files in the Ephemeris Files List.

Antenna Parameter Dialog

Ephemeris File:

Antenna Type:

- Elevation
- Cone
- Earth Central

GS Flag

Antenna Angle Parameter (deg):

Ephemeris File List:

Figure 14 Antenna Parameter dialog

5.3.1.3 Edit Targets

The target list for the Tabular Coverage function is set by selecting **Edit Targets** command from the **Tabular** sub menu. This brings up the Target List dialog shown in Figure 15. Targets may be input manually using the Target geodetic Latitude, Target Longitude and Target Altitude boxes. Fill in the parameters for the target and then click the **ADD** button above the list on the left. This adds the target position to a list that is stored within the program and saved upon exiting the program.

To add targets to the active list so they will be used in the tabular analysis, either highlight the target number in the list on the left and then click on the **ADD** button between the two lists or read in a list

of targets from a file. The format of the file is described in section 6.3. To read in a file, type the name of the file in the Target File Name box and click the Open Target File... button. The entire list in the file is automatically read into the active list. Other targets may be added to the active list by the method described above, or removed by highlighting the target to be removed and then clicking the DELETE button between the two lists. The entire active list may be cleared by clicking the CLEAR button between the two lists.

Because target positions change often, each position is given only a number, not a name. The list of targets that is saved internally is numbered from 1 to N (the number of targets in that list). To display the position of a target in this list, double click on the number and the position of the target will appear in the Target position boxes. Similarly, the active list of targets numbers range from 1 to n (the number of active targets). To check the position of target in this list, double click on the number and the position of the target will appear in the Target position boxes. The number of active targets also appears in the box at the top of the dialog.

The image shows a window titled "Target List Dialog". At the top, it says "Input Target Information:". Below this, there are several input fields: "Number of Active Targets:" followed by a text box; "Target Lat." followed by a text box; "Target Lon." followed by a text box; and "Target Alt. (km):" followed by a text box. Below these fields are two buttons: "ADD" and "DELETE". To the right of these buttons is the heading "Active List of Targets:" followed by a large, empty rectangular area representing a list. Below this list area are three buttons: "ADD", "DELETE", and "CLEAR". At the bottom of the dialog, there is a "Target File Name:" label followed by a text box, and a large button labeled "Open Target File". At the very bottom are two buttons: "OK" and "CANCEL".

Figure 15 Target List dialog

5.3.2 Run Tabular

When all of the parameters for Tabular coverage have been set, select the **Run Tabular** command in the **Coverage** menu. The dialog shown in Figure 16 will appear with the start and stop times that are the common minimum and maximum time for ALL of the ephemeris files being used. The user also specifies an output file name for the data to be written to in this dialog. This is in addition to automatically being written to the text window in OATS. The step size for the coverage analysis is also input here. **Note:** The step size may be smaller or larger than the step size in the ephemeris files because the routine uses an interpolator to determine the state at each time.

The user also has the option to have the up and down times for each coverage period printed. To select this option, check the Print Up/down Times box.

If All the information is correct, click the OK button. If you do not wish to calculate the coverage at this time, click the CANCEL button.

| Tabular Coverage | |
|---|--|
| Start Time | Stop Time |
| Year (YY): <input type="text"/> | Year (YY): <input type="text"/> |
| Month: <input type="text"/> | Month: <input type="text"/> |
| Day: <input type="text"/> | Day: <input type="text"/> |
| Hour: <input type="text"/> | Hour: <input type="text"/> |
| Minutes: <input type="text"/> | Minutes: <input type="text"/> |
| Seconds: <input type="text"/> | Seconds: <input type="text"/> |
| Step size (seconds): <input type="text"/> | |
| OUTPUT FILE NAME: <input type="text"/> | |
| <input type="checkbox"/> Print Up/Down Times | |
| <input type="button" value="OK"/> <input type="button" value="Cancel"/> | |

Figure 16 Run Tabular Coverage dialog

5.3.3 Graphical

It is often useful to visualize the world-wide coverage characteristics of a system of satellites and ground stations. The **Graphical** coverage function of OATS uses the meridian mesh technique of Casten and Gross² to compute the cumulative coverage, average outage, and maximum outage times over a global grid uniformly spaced in latitude and longitude. The user specifies the grid density in latitude and longitude. Coverage statistics are computed at each point in the grid.

Three output files are created upon completion of the graphical coverage program; the cumulative coverage file, the average outage file, and the maximum outage file. The units of the average and maximum outage files are in minutes. The user may select the units of the coverage file to be the percentage of time covered relative to the simulation duration, the total time covered in minutes, or the average daily coverage time in minutes. The output files are sequential ASCII. The graphical coverage program uses a file naming convention when creating the output files. The user specifies a file name in the Run Graphical Coverage dialog box and the program appends characters to this name for each of the three output files based on the data type; ".cc" for the coverage file, ".ao" for the average outage file, and ".mo" for the maximum outage file. For a description of how the data in the output files is mapped onto the global grid, see section 6.5.

The **Graphical** coverage analysis uses a spherical Earth for the target positions and an oblate Earth for the Ground Station positions. The coverage is calculated using geometry only. No atmospheric or aberration effects are included in the model. Four things must be set to run the **Graphical** coverage; the ephemeris files, the ground stations, the antenna type for each ephemeris file, and the mesh size.

5.3.3.1 Ephemeris Files

The ephemeris files are opened by using the **Open Eph** menu. More information on this menu item can be found in section 5.3.1.1.

5.3.3.2 Edit Ground Stations

The ground stations are set by placing the desired ground stations into the active ground station list. More information on the ground station dialog can be found in section 5.4.5.1.

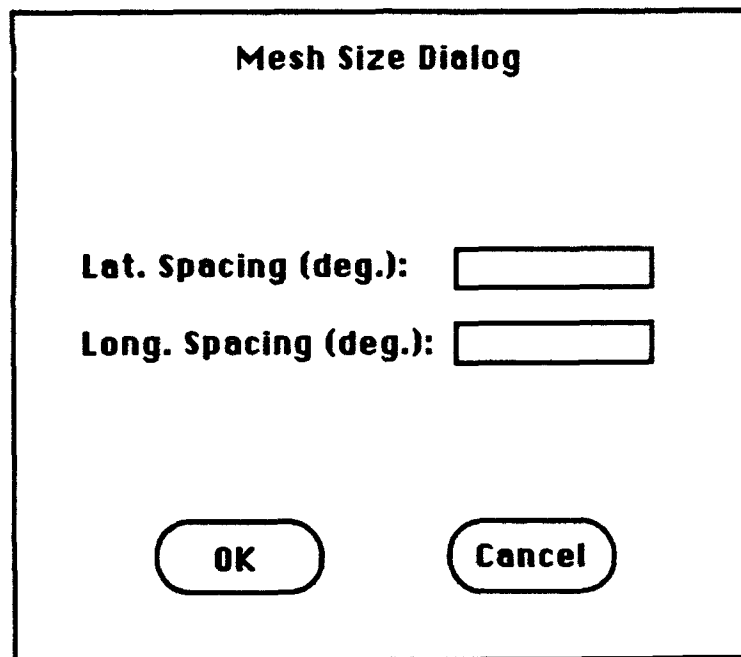
5.3.3.3 Edit Antennas

After the desired ephemeris files have been opened, the antenna type for each ephemeris file can be chosen by selecting the **Edit Antennas** command in the **Graphical** sub menu. The Antenna

Parameter dialog box shown in Figure 14 will appear. A description of this dialog box can be found in section 5.3.1.2.

5.3.3.4 Edit Mesh

To set the mesh size for the **Graphical** coverage, select the **Edit Mesh** command from the **Graphical** sub menu. The Mesh Size dialog shown in Figure 17 will appear. The default setting for the mesh is 5 degrees X 5 degrees. You may set the mesh size to any dimension (i.e. the mesh does not need to be square). This determines the number of data points that need to be evaluated by the graphical coverage routine. **Note:** The smaller the grid size, the larger the computation time. The minimum allowable grid size is 1 degree X 1 degree.



The image shows a rectangular dialog box titled "Mesh Size Dialog". Inside the box, there are two input fields. The first is labeled "Lat. Spacing (deg.):" followed by a rectangular text box. The second is labeled "Long. Spacing (deg.):" followed by another rectangular text box. At the bottom of the dialog, there are two buttons: "OK" and "Cancel", both enclosed in rounded rectangular frames.

Figure 17 Mesh Size dialog

5.3.4 Run Graphical

When all of the parameters for graphical coverage have been set, select the **Run Graphical** menu item in the **Coverage** menu. The dialog shown in Figure 18 will appear with the start and stop times that are the common minimum and maximum time for ALL of the ephemeris files being used. The user also specifies, in this dialog, an output file name to which the coverage data is written. The file name will be used to create three files, each with different suffixes. One file is cumulative coverage (.cc), the second is average outage (.ao), and the third is maximum outage (.mo). The step size for the coverage

analysis is also input here. **Note:** The step size may be smaller or larger than the step size in the ephemeris files because the routine uses an interpolator to determine the state at each time.

The user also must select the type of cumulative coverage that the graphical coverage routine calculates for the .cc file. Use the radio button to select either % coverage, Total Coverage, or Average Daily Coverage. It is necessary to remember the type of cumulative coverage that has been calculated if you wish to use the OATS contour function to plot the data.

If all the information is correct, click to OK button. If you do not wish to calculate the coverage at this time, click the CANCEL button.

Graphical Coverage Dialog

| Start Time | Stop Time |
|---|---------------------------------|
| Year (YY): <input type="text"/> | Year (YY): <input type="text"/> |
| Month: <input type="text"/> | Month: <input type="text"/> |
| Day: <input type="text"/> | Day: <input type="text"/> |
| Hour: <input type="text"/> | Hour: <input type="text"/> |
| Minutes: <input type="text"/> | Minutes: <input type="text"/> |
| Seconds: <input type="text"/> | Seconds: <input type="text"/> |
| Step size (seconds): <input type="text"/> | |
| OUTPUT FILE NAME: <input type="text"/> | |

Select Units for Coverage:

- % Coverage
- Tot. Cov. (minutes)
- Avg. Daily Cov. (minutes)

Note: This program also automatically creates average outage and max outage files.

Figure 18 Run Graphical Coverage dialog

5.3.5 GS Look Angles

The **Look Angles** function of OATS is used to calculate the azimuth, elevation, range, and range rate for the pass of a satellite over a ground station. The calculations for the look angles solutions use an oblate earth, atmospheric refraction, aberration, and a Hopfield propagation delay model. The inputs to the **Look Angles** function are a single satellite ephemeris, a single ground station, a step size for the evaluation, and an output file name.

5.3.5.1 Select Eph. File

To choose an ephemeris file, select the **Select Eph. File** command from the **Look Angles** sub menu in the **Coverage** menu. The dialog shown in Figure 19 will appear. If no files appear in the list, no files have been opened. To open files, use the **Open Eph** command in the **Open Eph.** menu. More information on opening files can be found in section 5.2. If there are files in the list, select the file you want to use for this **Look Angles** run by highlighting the file name. Then click the OK button to select the file, or click the CANCEL button to exit the dialog box.

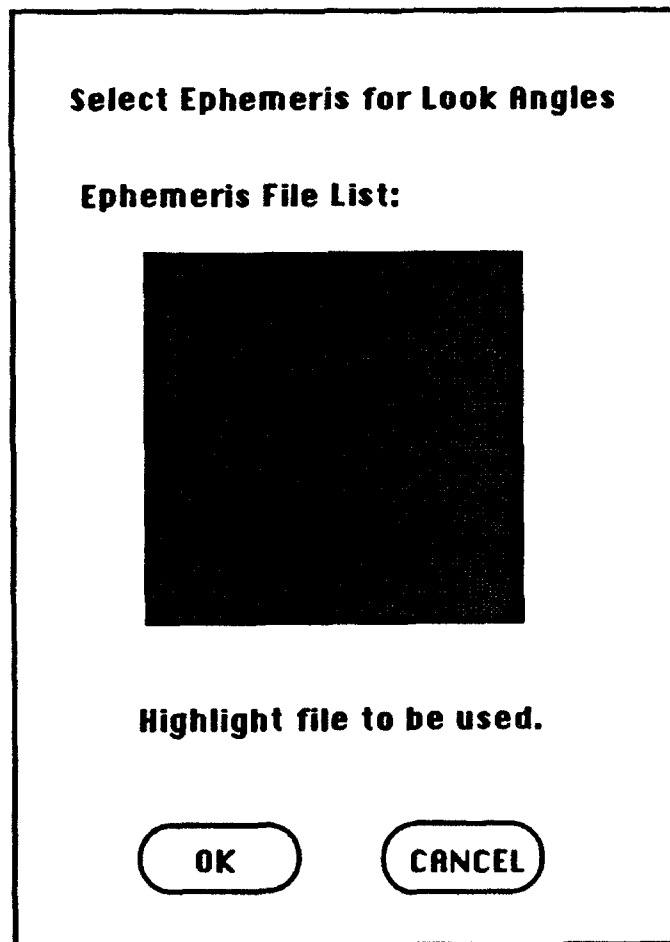


Figure 19 Look Angles Select Ephemeris dialog

5.3.5.2 Select GS

To select a ground station for the **Look Angles** run, select the **Select GS** command from the **Look Angles** sub menu in the **Coverage** menu. The **Look Angles Ground Station** dialog shown in Figure 20 will appear. The list on the right is all of the ground stations that are in the OATS ground station database that is saved in the program and can be modified by the user. To select one of the ground stations in the list, double click on the ground station and the information (lat. lon, alt., mask) will appear in the GS information boxes. If the desired ground station is not in the list, it can be manually typed into the GS information boxes. It may also be added to the permanent list by clicking the **ADD** button above the ground station list. Ground stations in the list may be removed by highlighting the ground station to be removed and clicking the **DELETE** button above the list.

When the ground station information to be used in the **Look Angles** coverage is displayed in the dialog box, click the **OK** button, or to return to the main OATS menu click the **CANCEL** button.

Look angles Ground Station Dialog

Input GS Information:

GS Name:

GS Lat. (deg): **ADD** **DELETE**

GS Lon. (deg):

GS Alt. (km):

GS El. Mask (deg):

OK **CANCEL**

Double click on GS to activate.

Figure 20 Look Angles Ground Station dialog

5.3.6 Run GS Look Angles

To execute the **Look Angles** function, select the **Run Look Angles** command from the **Coverage** menu. The **Look Angles Run Parameters** dialog shown in Figure 21 will appear on the screen. Displayed in the dialog are the start and stop times from the ephemeris file that was selected in the **Select Eph. File** dialog. This time may be left as it is or may be shortened. If you change the start or stop time, be sure that the times still fall within the times in the selected ephemeris file. In this dialog the user sets the step size for the look angles analysis and also the name of the output file for the look angles coverage data. When the information in the dialog is correct, click the **OK** button to execute the **Look Angles** run, or click **CANCEL** to return to the main menu. The data from the look angles run is also written to the text window **Tabular Output**.

Look Angles Run Parameters

| Start Time | Stop Time |
|---|---|
| Year (YY): <input style="width: 80%;" type="text"/> | Year (YY): <input style="width: 80%;" type="text"/> |
| Month: <input style="width: 80%;" type="text"/> | Month: <input style="width: 80%;" type="text"/> |
| Day: <input style="width: 80%;" type="text"/> | Day: <input style="width: 80%;" type="text"/> |
| Hour: <input style="width: 80%;" type="text"/> | Hour: <input style="width: 80%;" type="text"/> |
| Minutes: <input style="width: 80%;" type="text"/> | Minutes: <input style="width: 80%;" type="text"/> |
| Seconds: <input style="width: 80%;" type="text"/> | Seconds: <input style="width: 80%;" type="text"/> |
| Step size (seconds): <input style="width: 80%;" type="text"/> | |
| OUTPUT FILE NAME: <input style="width: 90%;" type="text"/> | |
| <input style="border: 1px solid black; border-radius: 15px; padding: 5px 15px;" type="button" value="OK"/> <input style="border: 1px solid black; border-radius: 15px; padding: 5px 15px;" type="button" value="CANCEL"/> | |

Figure 21 Run Look Angles dialog

5.4 Plot

The **Plot** menu contains all of the drawing routines for OATS. These drawing options all draw to the **OATS Graphics Window**. Each new drawing is on a new layer on the drawing area so it is easy to remove layers without having to redraw an entire multilayer drawing. The **Plot** menu contains the following commands:

- Contours
- Sat. FOV
- Sat. Posn
- Sat. Trks
- G.S. Posn
- G.S. FOV
- Map
- Clear Screen

Each of these menu items, with the exception of **Clear Screen**, has a sub menu which contains two commands:

- Options...
- Plot

The **Options...** command for each item brings up a dialog box with all the options for that particular drawing type. The **Plot** command will draw the picture to the graphics window with the options selected in the Options dialog.

5.4.1 Contours

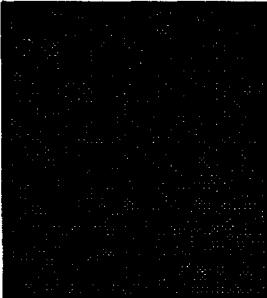
The **Contours** command is used for drawing the contour lines for Graphical Coverage data files generated by the **Graphical Coverage** function of OATS.

5.4.1.1 Contour Options

To plot contour lines, select the **Options...** command in the **Contour** sub menu in the **Plot** menu. The dialog box shown in Figure 22 will appear. The Draw Contours dialog box allows the user to select the file to be plotted and also the contour levels to be plotted. OATS supplies several typical databases for contour levels that may be loaded into the Contours level box. To load a database, select the type of information that is contained in the file you want to plot from the list at the top right of the dialog

Draw Contours Dialog Box

Contour Levels:



Add

Select Contour Levels Database:

Clear

Delete

Load

% Coverage

Total Coverage

Avg. Coverage

Avg. Outage

Max Outage

Other

Input Database Name:

Append Contour Level:

Bold_switch

Input Contour File Name:

Select Data Type:

Comulative Cov.

Avg. Outage

Max Outage

OK

Cancel

Figure 22 Draw Contours dialog

box. The Other option is for an imported database file of contour levels to plot. When this option is selected, the Input Database Name: will activate and the name of the database file should be entered there. To load the database, click the LOAD button and all of the contour levels in the database will appear in the Contour Levels list. If you want to add another level to the list, type the level in the Append Contour Level box and click the Add button. The level will be appended to the end of the list. To delete a level from the list, highlight the level to be removed and click the Delete button. The contour level will be removed from the list. To clear the whole list, click the Clear button and the Contour Levels list will be reset. The Bold Switch option will cause the contour levels to be drawn in bold if it is activated.

Select the proper data type for the file you want to plot. When the contour file is generated, three files are created. One for cumulative coverage (.cc), one for average outage (.ao) and one for maximum outage (.mo). The suffix is appended to the file name specified when the file is generated. By selecting the appropriate Data Type, the suffix will again be appended to the file name specified in the Contour file Name box. DO NOT add .cc, .ao, or .mo to the file name typed in the Input Contour File Name: box. It is automatically added by selecting the appropriate data type to the right of the file name.

When the desired levels appear in the Contour Levels list, the bold switch is set to the desired setting (on/off), the input contour file name is in the input box, and the appropriate data type for the plot has been selected, click the OK button. Select the Plot menu command in the Contours sub menu to draw the contours on the current drawing area. To get back to the main program menu, select the CANCEL button.

To plot the contour lines on the drawing area, select the **Plot** command from the **Contours** sub menu in the **Plot** menu.

5.4.2 Sat. FOV

The **Sat. FOV** option is used to draw the satellite field of view at a particular time.

5.4.2.1 Sat. FOV Options

To plot a satellite field of view (FOV), select the **Options...** command in the **Sat. FOV** sub menu in the **Plot** menu. The Satellite FOV Options dialog shown in Figure 23 will appear. The required input for the satellite FOV are the ephemeris file name for the satellite FOV to be drawn, the time for the satellite FOV, the antenna type and the angle parameter for the antenna. Select the ephemeris file by double clicking on the file name in the Ephemeris File List. If the desired ephemeris file name is not in the list, or no files appear in the list, see section 5.2 on opening ephemeris files. Select the antenna type by selecting the radio button next to the desired type. Input the antenna angle parameter for the antenna being used. Definitions of the antenna angle parameters are contained in appendix A. Select the time for the

FOV by inputting the year (YY), Month (MM), day (DD), hour (HH), Minute (mm) and second (ss.ss) for the desired time of the FOV. When an ephemeris file is double clicked the start time of the selected ephemeris will be displayed in the time boxes. The bold switch allows the user to choose if the satellite FOV will be drawn bold or regular. The FOV is drawn bold when the box is checked.

When the file, antenna, time and bold switch have been set to the desired settings, click the OK button. To plot the satellite FOV for the chosen parameters select the **Plot** command in the **Sat. FOV** sub menu in the **Plot** menu. To get back to the main program menu, select the **CANCEL** button.

Satellite FOV Options

Ephemeris File:

Antenna Type: **Bold Switch**

Elevation **Antenna Angle Parameter:**

Cone

Earth Central

Time

Ephemeris File List: **Year (YY):**

Month:

Day:

Hour:

Minutes:

Seconds:

Figure 23 Satellite Field of View dialog

5.4.3 Sat. Posn

The **Sat. Posn** command allows the user to plot the position of the satellite at a given time.

5.4.3.1 Sat. Posn Options

Draw Satellite Position

Time

Year (YY):

Month:

Day:

Hour:

Minutes:

Seconds:

INPUT FILE NAME:

Sat. Size (pixels):

Figure 24 Draw Satellite Position dialog

To plot a satellite position, select the **Options...** command in the **Sat. Posn** sub menu in the **Plot** menu. The dialog shown in Figure 24 will appear. The required inputs for the satellite position are the ephemeris file name for the satellite position to be drawn, the time for the satellite position, and the size of the position graphic on the plot. Select the desired ephemeris file by double clicking on the file name in the Ephemeris File List. If the desired ephemeris file name is not in the list, or no files appear in the list, see section 5.2 on opening ephemeris files. Select the year (YY), Month (MM), day (DD), hour (HH), Minute (mm) and second (ss.ss) for the desired time of the position. When an ephemeris file is double clicked the start time of the selected ephemeris will be displayed in the time boxes. The Sat Size

box allows the user to choose the size of the square drawn on the map to represent the satellite at the specified time.

When the file, time and satellite size have been set to the desired settings, click the OK button. To get back to the main program menu, select the CANCEL button. To plot the satellite position for the chosen parameters, select the **Plot** command in the **Sat. Posn** sub menu in the **Plot** menu.

5.4.4 Sat. Trks

The **Sat. Trks** command allows the user to plot the satellite ground path (sub satellite point) in three different map projections and the actual path of the satellite in the orthographic projection.

5.4.4.1 Sat. Trks Options

To plot a satellite track, select the **Options...** command in the **Sat. Posn** sub menu in the **Plot** menu. The Draw Satellite Tracks dialog shown in Figure 25 will appear. The required inputs for the satellite track are the ephemeris file name for the satellite track to be drawn, the start and stop time for the satellite track, the step size for the track plotting, bold switch option, and Tick Marks option. Select the ephemeris file by double clicking on the desired file name in the Ephemeris File List. If the desired ephemeris file name is not in the list, or no files appear in the list, see section 5.2 on opening ephemeris files. Select the start and stop time for the track by inputting the year (YY), Month (MM), day (DD), hour (HH), Minute (mm) and second (ss.ss) for the desired time of the track. When an ephemeris file is double clicked the start and stop time of the selected ephemeris will be displayed in the time boxes. Set the step size for the ground track plot. **Note:** This does not have to be the same interval that is in the ephemeris file as the routine uses an interpolator to determine the position of the satellite at any given time.

The bold switch allows the user to choose if the satellite track will be drawn bold or regular on the map. To draw bold lines, the Bold Switch box should be checked. The tick marks switch allows the user to place tick marks on the satellite track at a user specified interval and size. When the tick marks check box is active, the input boxes for the tick size and tick interval will become active.

When the file, times, step size, bold switch and tick switch have been set to the desired settings, click the OK button. To return to the main program menu, select the CANCEL button. To draw the satellite position for the chosen parameters, select the **Plot** command in the **Sat. Trks** sub menu in the **Plot** menu.

Draw Satellite Tracks


| Start Time | Stop Time |
|--|---------------------------------------|
| Year (YY): <input type="text"/> | Year (YY): <input type="text"/> |
| Month: <input type="text"/> | Month: <input type="text"/> |
| Day: <input type="text"/> | Day: <input type="text"/> |
| Hour: <input type="text"/> | Hour: <input type="text"/> |
| Minutes: <input type="text"/> | Minutes: <input type="text"/> |
| Seconds: <input type="text"/> | Seconds: <input type="text"/> |
| Step size (seconds): <input type="text"/> | |
| INPUT FILE NAME:  | |
| <input type="checkbox"/> Bold Switch | |
| <input type="checkbox"/> Tick Marks | |
| Double click on file to activate | |
| Tick Size (pixels): <input type="text"/> | |
| Interval (seconds): <input type="text"/> | |
| <input type="button" value="OK"/> | <input type="button" value="Cancel"/> |

Figure 25 Draw Satellite Tracks dialog

5.4.5 G.S. Posn

The **G.S. Posn** command allows the user to plot ground station positions. Up to twenty ground stations may be plotted at one time. The Ground Station dialog is also used to select ground stations for the coverage routines.

5.4.5.1 G.S. Posn Options

To select ground stations to be plotted, select the **Options...** command from the **G.S. Posn** sub menu in the **Plot** menu. The Ground Station dialog shown in Figure 13 will appear. For information on selecting ground stations, see section 5.3.1.1.

The user is also able to choose the size (in pixels) of the ground station plotted on the map. To set this, type the desired size in the Size of GS box in the dialog box.

When the ground station information to be used in the plot routine is displayed in the dialog box, click the OK button. To return to the main OATS menu click the CANCEL button. To plot the G.S. position, select the **Plot** command from the **GS Posn** sub menu in the **Plot** menu.

5.4.6 G.S. FOV

The **G.S. FOV** command allows the user to plot ground station fields of view (FOV) for the active set of ground stations. Up to twenty ground station FOVs may be plotted at one time.

5.4.6.1 G.S. FOV Options

To plot ground station fields of view (FOV), select the **Options...** command from the **G.S. FOV** sub menu in the **Plot** menu. The Ground Station FOV dialog shown in Figure 26 will appear. The user may plot the FOV of the ground station with either a bold or regular line. To select bold, check the bold switch box in the dialog. The user must also input the altitude of the satellite in kilometers. The ground station FOV will be drawn for all of the ground stations in the active list. These may be checked by selecting the **Options...** command in the **G.S. Posn** sub menu in the **Plot** menu.

When the Satellite altitude and bold switch have been set to the desired settings, click the OK button and then select the **Plot** command from the **G.S. FOV** sub menu in the **Plot** menu. To return to the main menu, Click the CANCEL button.

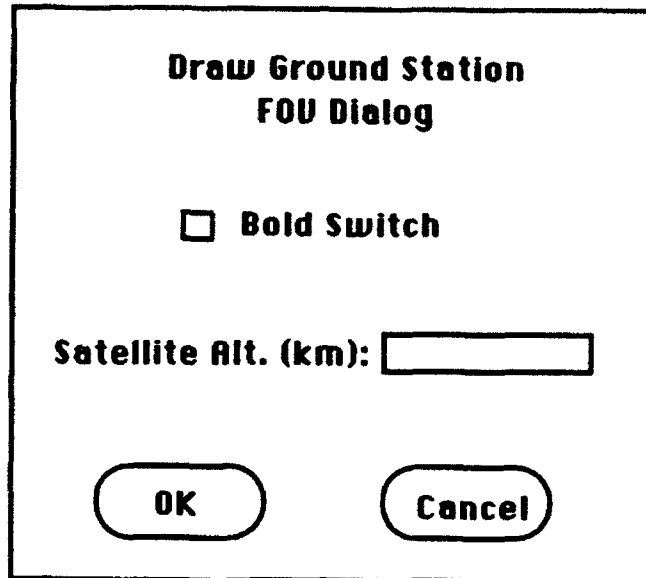


Figure 26 Ground Station Field of View dialog

5.4.7 Map

OATS allows the user to select from four different map projections: Stereographic, Rectangular, Mercator, and Orthographic. The **Map** command allows the user to select the map type and the location of center of the map and then plot the map to the graphics window. The four map types are shown in Figure 27.

5.4.7.1 Map Options

To plot a map, select the **Options...** command from the **Map** sub menu in the **Plot** menu. The Map dialog shown in Figure 28 will appear. The user can choose the resolution of the map, the border size between the edge of the map and the edge of the drawing area, latitude/longitude grid lines and their spacing, the map projection, and the location on the world of the center of the map.

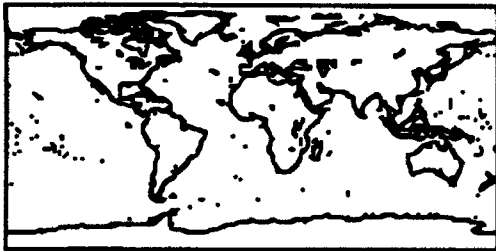
OATS contains two different map databases. The high resolution map contains nearly four times as many points as the low resolution map. It also shows many of the small islands and lakes that are left out of the low resolution map. However, the high resolution map takes approximately four times longer to draw than the low resolution map. The choice of the detail on the map is selected by clicking in the radio box next to the desired resolution of the map.



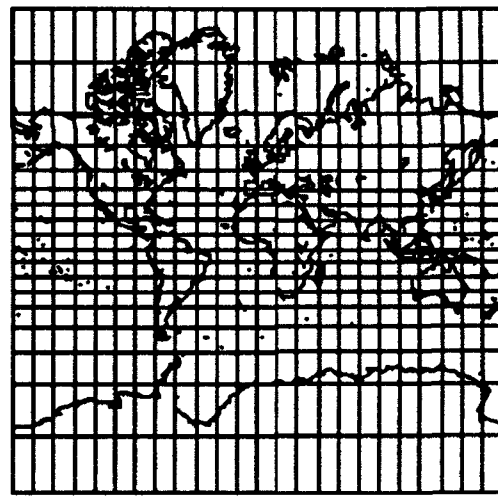
Orthographic



Stereographic



Rectangular



Mercator

Figure 27 Map types

The border size selection was added to OATS to aid in the quality of cutting and pasting of pictures into other applications. The border size is set by typing in the desired border for the drawing into the margin boxes. These margins are in pixels.

The user has the option to include latitude and longitude lines in the drawing of the map. To include lat/lon grid lines on the map, check the box for Draw Lat/Lon Grid and then input the spacing of the grid lines in degrees.

Next the user should select a map projection. Click the radio button next to the desired map projection. The parameters for the map will activate and the other map projection's parameters will grey (deactivate). The parameters for the different map projections are as follows:

-Stereographic

Latitude and longitude of the center of the map are set by the user. The map is scaled according to the drawing area size.

-Rectangular

The user inputs the minimum and maximum for both latitude and longitude. The map is then scaled according to the user specified size (min/max lat/lon) and the size of the drawing area.

-Mercator

The user inputs the minimum and maximum for both latitude and longitude. The map is then scaled according to the user specified size (min/max lat/lon) and the size of the drawing area.

-Orthographic

The user inputs the coordinates (lat/lon) of the center of the map and also a scale factor. The scale factor determines the size of the map. A scale factor of 1 will just fill the drawing area minus the specified borders. A scale factor <1 will draw the entire globe smaller than the drawing area with the size of the globe decreasing as the scale factor decreases. A scale factor >1 will draw a zoomed in projection with the center at the specified coordinates. The larger the scale factor, the closer the map projection.

When the map options have been set for the desired map projection, click the OK button and then select the **Plot** command from the **Map** sub menu in the **Plot** menu. To exit the map dialog, click the **CANCEL** button.

| | | | |
|---|-----------------------------------|---------------------------------------|------------------------------------|
| Map Quality: | | Margins (pixels): | |
| <input type="radio"/> High Resolution | | Horizontal: <input type="text"/> | |
| <input type="radio"/> Low Resolution | | Vertical: <input type="text"/> | |
| <input type="checkbox"/> Draw Lat/Lon Grid | | | |
| Lat. Grid Spacing (deg): <input type="text"/> | | | |
| Lon. Grid Spacing (deg): <input type="text"/> | | | |
| <input type="radio"/> Stereographic | <input type="radio"/> Rectangular | <input type="radio"/> Mercator | <input type="radio"/> Orthographic |
| Latitude: <input type="text"/> | Min Lat: <input type="text"/> | Min Lat: <input type="text"/> | Viewer Lat: <input type="text"/> |
| Longitude: <input type="text"/> | Max Lat: <input type="text"/> | Max Lat: <input type="text"/> | Viewer Lon: <input type="text"/> |
| | Min Lon: <input type="text"/> | Min Lon: <input type="text"/> | Scale: <input type="text"/> |
| | Max Lon: <input type="text"/> | Max Lon: <input type="text"/> | |
| <input type="button" value="OK"/> | | <input type="button" value="Cancel"/> | |

Figure 28 Select Map dialog

6.0 File Formats

This section provides a list and description of all of the input and output files used by OATS. All of the files are ASCII format and sequential access. They may be created manually from a text editor or by another computer program. The map database files are included with OATS.

6.1 Orbital Elements

Three different orbit propagation models are in Version 1.0 of OATS; PPT2 (Brouwer-Lyddane), RUK12 (4th order Runge-Kutta numerical integration), and FOJ2 (first order J_2 analytic). Each model requires a different input vector file format. These orbital element input files may be created by the user with any text editing program, imported from an external source, or created by OATS using the Edit Elements dialogs.

6.1.1 PPT2 Input Files (OLES)

The PPT2 orbit model accepts the NAVSPASUR one-line elements sets (OLES) in Charlie, PME, and Z formats.

6.1.1.1 Charlie

The Charlie format is valid at 0 hours Zulu. The parameters making up the NAVSPASUR Charlie format one-line element set are as follows:

IIIII.AAAAAA.MMMMMM.DDDDD.EEEEE.EWWWWW.NNNNNN.IIIIIIYYMMDD

where,

IIII = satellite SDC number

AAAAAA = mean anomaly, fraction of a revolution

MMMMMM = mean motion, radians/hergs

DDDDD = decay, radians/hergs/hergs

EEEEEE = eccentricity

WWWWW = argument of perigee, fraction of a revolution

NNNNNN = longitude of ascending node, fraction of a revolution

IIIII = angle of inclination, fraction of a revolution

YY = year

MM = month

DD = day

6.1.1.2 PME

The epoch of the PME format one-line element set is specified to the nearest ten minutes. The parameters making up the NAVSPASUR PME format one-line element set are as follows:

IVRRRRRAAAAAAAMMMMMDDDDDEEEEEEEWWWWWNNNNNNNIIIIIIYYMDDHMM

Where,

II = satellite SDC number

V = version number

RRRRR = rev number

AAAAAA = mean anomaly, fraction of a revolution

MMMMMM = mean motion, radians/hergs

DDDDD = decay, radians/hergs/hergs

EEEEEEEEE = eccentricity

WWWWWWW = argument of perigee, fraction of a revolution

NNNNNNNN = longitude of ascending node, fraction of a revolution

IIIIIII = angle of inclination, fraction of a revolution

Y = year

MM = month

DD = day

HH = hours

M = tens of minutes

6.1.1.3 Z

The Z format is valid at 0 hours Zulu. The parameters making up the NAVSPASUR Z format one-line element set are as follows:

IIIIIRRRRRRAAAAAAMMMMMMDDDDDEEEEEEEWWWWWWWNNNNNNNNIIIIIIYYMMDD

Where,

IIII = satellite SDC number

RRRRR = rev number

AAAAAAA = mean anomaly, fraction of a revolution

MMMMMMMM = mean motion, radians/hergs

DDDDD = decay, radians/hergs/hergs

EEEEEEEEE = eccentricity

WWWWWWW = argument of perigee, fraction of a revolution

NNNNNNNN = longitude of ascending node, fraction of a revolution

IIIIIII = angle of inclination, fraction of a revolution

YY = year

MM = month

DD = day

6.1.2 RUK12 Input Files

The RUK12 orbit model accepts an osculating, cartesian state vector as input. The input file format for the RUK12 orbit propagation model is as follows:

x - x position component in kilometers (real)
y - y position component in kilometers (real)
z - z position component in kilometers (real)
xdot - x velocity component in kilometers (real)
ydot - y velocity component in kilometers (real)
zdot - z velocity component in kilometers (real)
i_frame - if i_frame = 0, coordinates are Earth Centered Inertial, if i_frame = 1, coordinates are
Earth Centered Earth Fixed (integer)
int_step - step size in seconds for the numerical integrator (real)
tstep - interval in seconds for the output ephemeris file (real)

6.1.3 FOJ2 Input Files

The FOJ2 orbit model accepts mean Keplerian orbital elements as input. The input file format for the FOJ2 orbit propagation model is as follows:

a - Semi-major axis in kilometers (real)
e - Eccentricity (real)
i - Inclination in degrees (real)
W - Argument of the ascending node in degrees (real)
w - Argument of perigee in degrees (real)
m - Anomaly in degrees (real)
i_frame - if frame = 0, W is right ascension, if frame = 1, W is longitude of ascending node.
(integer)
i_anomaly - if i_anomaly = 0, m is mean anomaly, if i_anomaly = 1, m is true anomaly (integer)

6.2 Ephemeris Files

All of the coverage analysis and orbit propagation functions in OATS assume a common format for the ephemeris files. Each record contains the following space-delimited fields:

YY - The last two digits of the year.
MM - Month (integer)
DD - Day (integer)
HH - Hour (integer)
mm - Minutes (integer)

ss.ss - Seconds (real)

x - Earth Centered Earth Fixed x position component in kilometers (real)

y - Earth Centered Earth Fixed y position component in kilometers (real)

z - Earth Centered Earth Fixed z position component in kilometers (real)

xdot - Earth Centered Earth Fixed x velocity component in kilometers/second (real)

ydot - Earth Centered Earth Fixed y velocity component in kilometers/second (real)

zdot - Earth Centered Earth Fixed z velocity component in kilometers/second (real)

The Earth Centered Earth Fixed coordinate system is a rotating frame fixed to the Earth with its origin at the center of the Earth. The x axis lies in the equatorial plane through the Greenwich meridian. The z axis is through the pole and the y axis completes the right handed system.

6.3 Target Input File

The Target input file allows the user to import a list of target positions into OATS for coverage analysis. The Target Input File may be created by the user using any text editing program. Each record must contain the following space-delimited fields:

TLAT - Target geodetic latitude in degrees (real)

TLON - Target longitude in degrees (real)

TALT - Target height above the geoid in kilometers (real)

6.4 Map Files

Two map database files are included with OATS; a high resolution file "map.dat" and a low resolution file "newmap.dat". These files contain the latitude and longitude pairs that make up continental boundaries, large bodies of water, and major islands. The files are sequential ASCII format. Each record contains a single latitude, longitude ordered pair. Latitude is expressed in radians from $-\pi$ to π , longitude is expressed in radians from 0 to 2π . Pen lifts are indicated by negative longitude values.

6.5 Contour Files

The output files of the graphical coverage program are sequential ASCII. The program uses a file naming convention when creating the output files. The user specifies a file name in the Run Graphical Coverage dialog box, and the program appends characters to this name for each of the three output files based on the data type; ".cc" for the coverage file, ".ao" for the average outage file, and ".mo" for the

maximum outage file. The user specifies N , the grid spacing in degrees of latitude, and M , the grid spacing in degrees of longitude. The number of grid elements on each meridian is then $L + 1$ where, $L = 180/N$, and the number of grid elements on each parallel is $K = 360/M$. The first record in contour file contains the integers K and L . The remainder of the file is made up of the $K \times (L + 1)$ grid points. The grid points are mapped on to the latitude, longitude grid via the following algorithm:

For the p^{th} record in the file (after the record containing the K, L) the latitude is given by:

$$\text{latitude} = (i - 1) \times 180 / L - 90 \text{ degrees.}$$

The longitude is given by:

$$\text{longitude} = (j - 1) \times 360 / K \text{ degrees,}$$

$$\text{where } i = \text{modulus}(p, K) + 1 \text{ and } j = p - (i \times k).$$

The user may wish to use the OATS Plot Contour function to contour data created by some external program. In which case, the first record in the data file to be contoured should be the integers K, L which are, respectively, the number of longitude and latitude elements in the grid. The remaining $K \times (L + 1)$ records in the file should be written in the following order:

```

For j = 1, 2 ..., L + 1
  For i = 1, 2, ..., K
    write latitude i, longitude j,
  End For
End For

```

6.6 Contour Database Files

The Graphical Coverage function of OATS computes files that are intended for use as input files to the OATS Plot Contour function. The Graphical Coverage function computes three output files; a cumulative coverage file, an average outage file, and a maximum outage file. The units of the average outage and maximum outage files are in minutes. The user selects the units of the cumulative coverage file to be average coverage in minutes, total coverage in minutes or percentage coverage.

When the Plot Contour function in OATS creates a contour map it must be told what contour levels are to be drawn. These levels are shown in the Contour Levels scroll box in the Plot Contours Options dialog box. For user convenience, database files are included with OATS that may be loaded into the Contour Levels scroll box. These files are selected based on the coverage data file to be plotted. Therefore, five contour database are provided with OATS. They are:

| | | |
|--------------|--|---------------|
| DBASE.CC_PCT | Cumulative coverage contour database file | (percent) |
| DBASE.CC_TC | Total cumulative coverage contour database | file |
| (minutes) | | |
| DBASE.CC_AC | Average cumulative coverage contour | database file |
| (minutes) | | |
| DBASE.AO | Average outage contour database file | (minutes) |
| DBASE.MO | Maximum outage contour database file | (minutes) |

These free-format sequential ASCII files contain the real-valued contour levels to be plotted. These files may be modified or created by the user using any text editing program.

References:

1. FaceIt™, Programmers Guide, Version 4.0c, May 1989, ©FaceWare 1986-1989, All Rights Reserved.
2. Casten, R. G., and Gross, R. P., "Satellite Cumulative Earth Coverage", AAS Paper 81-125, Presented at AAS/AIAA Astrodynamics Specialist Conference, Lake Tahoe, Nevada, August 3-5, 1981.

APPENDIX A - Antenna Definitions

Version 1.0 of the OATS software supports nadir viewing, conical satellite sensor patterns. The viewing geometry is depicted in Figure A.1. The earth radius is r and the satellite orbital radius is r_s . The angle σ is called the elevation angle, ϕ is the cone angle and θ is the earth central angle. The user can define the sensor pattern by specifying any one of these three angles. This is accomplished by selecting the Antenna Type in the Edit Antenna Dialog Box to be either elevation angle, cone angle, or earth central angle. Based on the antenna type selected, the Antenna Parameter entry will provide the value for σ , ϕ , or ω respectively.

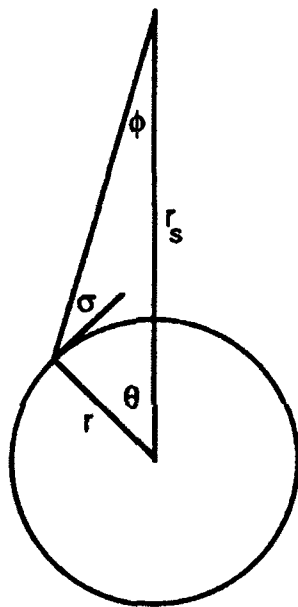


Figure A.1 Satellite Antenna Pattern Geometry

APPENDIX B - Example Session

An example analysis session using the OATS tool is described in which many of the frequently used functions are illustrated. In the following example two orbital elements files are created from which two satellite ephemerides are generated. These ephemerides are used to illustrate the three different types of coverage analyses performed by OATS: Tabular, Look Angles, and Graphical computation. Finally, some of the OATS graphical functions are used to display selected coverage data.

B.1 Computing the Ephemerides

The J2 orbital model will be used to create two satellite ephemeris files. Under the **Propagate** menu item on the main menu bar, select the J2 model. The input dialog for the J2 model will appear. Enter the orbital elements for the first satellite. For this example the input coordinate frame should be set to *ECF*, and the input anomaly should be set to *True*. Enter the following orbital elements:

| | |
|---------------------------|----------------------|
| Semi-major axis: 8000 km | YY: 92 (year) |
| Eccentricity: 0.001 | MM: 1 (month) |
| Inclination: 50.0 degrees | DD: 1 (day) |
| Arg. Asc. Node: 0 degrees | HH: 0 (hours) |
| Perigee: 0 degrees | mm: 0 (minutes) |
| Anomaly: 0 degrees | ss.ss: 0.0 (seconds) |

Save the elements in a file by clicking the **Save As...** button. Enter the file name: *J2.1*. Select **OK**. Next the Edit Interval dialog box will appear. This dialog sets the start and stop times of the ephemeris to be computed. The start time is pre-set to the epoch of the input element set. Set the stop time to equal to the input set plus one day:

| | |
|---------------|----------------------|
| YY: 92 (year) | HH: 0 (hours) |
| MM: 1 (month) | mm: 0 (minutes) |
| DD: 2 (day) | ss.ss: 0.0 (seconds) |

Enter the output file name: *J2.1.xyz*. Select **OK**. Select **Execute** under the **Propagate** menu item to compute the ephemeris.

To propagate an ephemeris for the second satellite follow the procedure above starting with selecting the **J2** model from the **Propagate** menu item. Enter the orbital elements for the second satellite: Set the coordinate frame to *ECF*, and the anomaly flag to *True*. Enter the following orbital elements:

| | |
|----------------------------|----------------------|
| Semi-major axis: 8000 km | YY: 92 (year) |
| Eccentricity: 0.001 | MM: 1 (month) |
| Inclination: 50.0 degrees | DD: 1 (day) |
| Arg. Asc. Node: 90 degrees | HH: 0 (hours) |
| Perigee: 0 degrees | mm: 0 (minutes) |
| Anomaly: 180 degrees | ss.ss: 0.0 (seconds) |

Save the elements in a file by clicking the **Save As...** button. Enter the file name: *J2.2*. Select **OK**. Select the **Edit Interval** command from the **Propagate** menu. This dialog sets the start and stop times of the ephemeris to be computed. The start time is pre-set to the epoch of the input element set. Set the stop time to equal to the input set plus one day:

| | |
|---------------|----------------------|
| YY: 92 (year) | HH: 0 (hours) |
| MM: 1 (month) | mm: 0 (minutes) |
| DD: 2 (day) | ss.ss: 0.0 (seconds) |

Enter the output file name: *J2.2.xyz*. Select **OK**. Select **Execute** under the **Propagate** menu item to compute the ephemeris.

B.2 Coverage Analysis

The two ephemeris files computed above will now be used in a coverage analysis example. Under the **Open Eph.** menu item select **Open...** The Open Ephemeris Files dialog will appear. The two files which were just propagated have automatically been added to the ephemeris file list on the left hand side of the dialog. Move the first ephemeris file into the active list by highlighting *J2.1.xyz* on the left hand side and clicking **ADD**. Move the second ephemeris file into the active list by highlighting *J2.2.xyz* on the left hand side and clicking **ADD**. Click the **Open** button and both ephemeris files will be read into memory. Three coverage analysis examples will now be illustrated using these ephemeris files.

B.2.1 Tabular Coverage

The Tabular Coverage function computes satellite coverage for a system of satellites against a set of ground targets. Ground stations may be used as coverage constraints on the satellites. For example, the satellite may only be operational when it is in view of a ground station. In this example our satellite system will consist of two vehicles and two ground stations. We shall constrain vehicle 1 to operate only while in view of either ground station. Vehicle 2 will operate continuously. Coverage to a single target will be computed.

Select the **Edit Grnd Stns** command from the **Tabular** submenu in the **Coverage** menu. Select two ground stations: Maui and Malabar. If these stations are already in the OATS data base, simply highlight the station names in the left hand box and click the **ADD** button between the two boxes to add the stations to the active list. If the stations are not in the OATS data base, enter the station coordinates and names in the appropriate areas in the dialog box and click the **ADD** button above the left hand box. Use the following coordinates:

Maui

Geodetic Latitude: 20.708 degrees

Longitude: 203.742 degrees

Altitude: 3.059 km

Malabar:

Geodetic Latitude: 28.026 degrees

Longitude: 279.315

Altitude: -0.013 km

Add the station names to the active list. Select **OK**.

Select the **Edit Antennas** command from the **Tabular** submenu in the **Coverage** menu. The Edit Antennas dialog box that appears associates antenna patterns with each satellite ephemeris. The two ephemeris files previously read in appear in the box. Double click on the file *J2.1.xyz*. Select the **Antenna Type, elevation**. Set the **Antenna Parameter** to 0.0 and check the **Ground Station** box. With these selections, the satellite will be able to view the target when it is above 0.0 degrees of the target local horizon and it is within view of either Maui or Malabar. Double click on the file *J2.2.xyz*. Select the **elevation Antenna Type**, set the **Antenna Parameter** to 0.0 and uncheck the **Ground Station** box. With these selections, the satellite will be able to view the target when it is above 0.0 degrees of the target local horizon with no ground station constraints. Select **OK**.

Select the **Edit Targets** command from the **Tabular** submenu in the **Coverage** menu. There may already be several target locations in the data base. These are indicated by numbers in the left hand box. Any or all of these targets may be transferred to the active box on the right by selecting them in

the left hand box and clicking the **ADD** button between the boxes. In this example, we shall add a new target. Enter the following coordinates in the appropriate areas at the top of the dialog box:

Geodetic Latitude: 34.8 degrees

Longitude: 239.5 degrees

Altitude: 0 kilometers

Click the **ADD** button above the left hand box to add the new target to the list. The new target will be represented in the left hand box at the bottom of the existing list with a number equal to one plus the previous last element of the list. Highlight this new element in the left hand list and click the **ADD** button between the boxes. The target is now in the active list. Select **OK**.

Bring the Tabular Output window to the front by selecting **Tabular Output** under the **Window** menu item on the main menu bar. Execute Tabular Coverage by selecting **Run Tabular** under the **Coverage** menu item on the main menu bar. The Tabular Coverage dialog will appear. Set the Start time to 92, 1, 1, 0, 0, 0.0, the Stop time to 92, 1, 2, 0, 0, 0.0 and the interval to 60.0 seconds. Also, input a name for the output file. Select **OK**. The following Tabular Coverage data will appear in the window:

```

COMPUTE SATELLITE COVERAGE
Start time (Y,M,D,h,m,sec):
92, 1, 1, 0, 0, 0.00000000
Stop time (Y,M,D,h,m,sec):
92, 1, 2, 0, 0, 0.00000000
Time Increment:      60.00000000000000    seconds
Tolerance for up/down time bisection algorithm:  1.0000000000000000D-03 seconds
Ground Station(s):
  [DEG]  [DEG]  [KM]  [DEG]
#   LAT   LON   ALT  MIN EL
  1  20.71  203.74   3.06   0.00
  2  28.03  279.31  -0.01   0.00
SATELLITE EPHEMERIS FILES
  1                                           j2.1.xyz
SATELLITE SENSOR PATTERN:
ELEVATION ANGLE
ANGLE=      0.0000000000000000    DEG
Ground Station Flag      1
  2                                           j2.2.xyz
SATELLITE SENSOR PATTERN:
ELEVATION ANGLE
ANGLE=      0.0000000000000000    DEG
Ground Station Flag      0
TARGETS:
  [DEG]  [DEG]  [KM]
#   LAT   LON   ALT
  1  34.80  239.50   0.00

```

TARGET: 1
 LAT: 34.80 LON: 239.50 ALT: 0.00 KM
 PASS STATISTICS (MINUTES)

| UP | DOWN | COVERAGE | OUTAGE | REVISIT |
|-------------------|-------------------|----------|--------|---------|
| 92 1 1 1 37 6.7 | 92 1 1 1 59 53.5 | 22.8 | 97.1 | 0.0 |
| 92 1 1 7 58 0.0 | 92 1 1 8 15 28.5 | 17.5 | 358.1 | 380.9 |
| 92 1 1 9 55 18.2 | 92 1 1 10 21 29.4 | 26.2 | 99.8 | 117.3 |
| 92 1 1 12 1 37.6 | 92 1 1 12 27 7.4 | 25.5 | 100.1 | 126.3 |
| 92 1 1 12 50 57.4 | 92 1 1 13 6 17.8 | 15.3 | 23.8 | 49.3 |
| 92 1 1 14 9 28.7 | 92 1 1 14 21 0.0 | 11.5 | 63.2 | 78.5 |
| 92 1 1 14 22 0.0 | 92 1 1 14 34 24.9 | 12.4 | 1.0 | 12.5 |
| 92 1 1 14 49 22.4 | 92 1 1 15 14 32.3 | 25.2 | 15.0 | 27.4 |
| 92 1 1 16 15 53.5 | 92 1 1 16 42 3.1 | 26.2 | 61.4 | 86.5 |
| 92 1 1 16 53 51.7 | 92 1 1 17 19 58.3 | 26.1 | 11.8 | 38.0 |
| 92 1 1 18 21 17.8 | 92 1 1 18 46 46.4 | 25.5 | 61.3 | 87.4 |
| 92 1 1 19 1 22.8 | 92 1 1 19 26 19.6 | 24.9 | 14.6 | 40.1 |
| 92 1 1 20 29 8.2 | 92 1 1 20 45 43.9 | 16.6 | 62.8 | 87.8 |
| 92 1 1 21 8 42.9 | 92 1 1 21 34 12.4 | 25.5 | 23.0 | 39.6 |
| 92 1 1 23 14 22.6 | 92 1 1 23 40 42.9 | 26.3 | 100.2 | 125.7 |

COVERAGE STATISTICS (MINUTES):

| | | |
|----------------|-----------------|----------------|
| NCOV: 15 | NOUT: 16 | NREV: 14 |
| COVMIN: 11.52 | OUTMIN: 1.00 | REVMIN: 12.52 |
| COVMAX: 26.34 | OUTMAX: 358.11 | REVMAX: 380.89 |
| COVAVG: 21.83 | OUTAVG: 69.53 | REVAVG: 92.66 |
| COVSTD: 5.30 | OUTSTD: 82.10 | REVSTD: 87.56 |
| COVTOT: 327.50 | OUTTOT: 1112.50 | PCTCOV: 22.74 |
| AVGCOV: 327.50 | AVGOUT: 1112.50 | MINUTES/DAY |

B.2.2 Look Angles:

The Look Angles function computes ground station to satellite pass parameters for a single ground station / satellite pair. In this example we shall compute pass parameters for vehicle 1 and the Malabar ground station.

Select the **Select GS** command from the **Look Angles** submenu in the **Coverage** menu. The Look Angles Ground Station dialog box will appear. The Malabar ground station should appear in the Ground Station box. If the station is not in the OATS data base, enter the station coordinates and name in the appropriate areas in the dialog box and click the **ADD** button. Use the following coordinates:

Malabar:

Geodetic Latitude: 28.026

Longitude: 279.315

Altitude: -0.013 km

Double click on the Malabar station name to select it. Select **OK**.

Select the **Select Eph. file** command from the **Look Angles** submenu in the **Coverage** menu. The Select Ephemeris for Look Angles dialog box will appear. Highlight the *j2.1.xyz* ephemeris

file which was computed in the Tabular Coverage example above. If the filename *j2.1.xyz* does not appear in the dialog box, it must first be read in with the **Open Eph.** function. After highlighting the ephemeris filename, select **OK**.

Bring the Tabular Output window to the front by selecting **Tabular Output** under the **Window** menu item on the main menu bar. Under the **Coverage** menu item select **Run GS Look Angles**. The Look Angles Run Parameters dialog box will appear. Next set the start and stop times, the step size and the output file name. Set the Start time to 92, 1, 1, 0, 0, 0.0, the Stop time to 92, 1, 2, 0, 0, 0.0 and the interval to 60.0 seconds. Also, input a name for the output file. Select **OK**. The following Look Angles data will appear on the Tabular Output Window:

```

COMPUTE PASS STATS
Start time (Y,M,D,h,m,sec):
92, 1, 1, 0, 0, 0.00000000
Stop time (Y,M,D,h,m,sec):
92, 1, 2, 0, 0, 0.00000000
Time Increment:      60.0000000000000    seconds
Ground Station:
  [DEG]  [DEG]  [KM]  [DEG]
#   LAT   LON   ALT  MIN EL
 28.03 279.31 -0.01  0.00
SATELLITE EPHEMERIS FILE

                                j2.1.xyz
YR MO DY HR MI  SEC      AZ(DEG)  EL(DEG)  RG(KM)  RR(M/S)  RR(PPM)
92 01 01 03 54 29.61  153.1190  0.0000  4871.5855 -2655.8627 -8.8590 !AOS
92 01 01 03 55  0.00  151.0052  0.6858  4792.8108 -2520.4168 -8.4072
92 01 01 03 56  0.00  146.6311  1.8082  4650.0213 -2227.1365 -7.4289
92 01 01 03 57  0.00  141.9942  2.8810  4525.8577 -1899.7144 -6.3367
92 01 01 03 58  0.00  137.1095  3.8398  4422.3305 -1539.7402 -5.1360
92 01 01 03 59  0.00  132.0056  4.6291  4341.3026 -1150.5958 -3.8380
92 01 01 04 00  0.00  126.7260  5.2055  4284.3761 -737.5883 -2.4603
92 01 01 04 01  0.00  121.3275  5.5378  4252.7794 -307.8247 -1.0268
92 01 01 04 02  0.00  115.8774  5.6085  4247.2702  130.2081  0.4343
92 01 01 04 03  0.00  110.4481  5.4130  4268.0722  567.3268  1.8924
92 01 01 04 04  0.00  105.1106  4.9605  4314.8571  994.4761  3.3172
92 01 01 04 05  0.00  99.9288  4.2740  4386.7774 1403.5229  4.6817
92 01 01 04 06  0.00  94.9550  3.3896  4482.5408 1787.8627  5.9637
92 01 01 04 07  0.00  90.2269  2.3568  4600.5128 2142.7426  7.1474
92 01 01 04 08  0.00  85.7682  1.2368  4738.8309 2465.2971  8.2234
92 01 01 04 08 58.86  81.6658  0.0000  4892.3822 2749.1837  9.1703 !LOS

```

(In the interest of space, the output table has been truncated after the first pass).

B.2.3 Graphical Coverage

The Graphical Coverage function computes world wide coverage on a global grid for a system of satellites and ground stations. Satellites may operate out of view of the ground stations, or they may be constrained to operate only while in view of a ground station. In the following example we shall compute global coverage for a vehicle constrained to operate while in view of the Malabar or Maui ground stations.

Under the **Open Eph.** menu item select **Open....** The Open Ephemeris Files dialog will appear. Delete any files in the right hand box. Move the vehicle 1 ephemeris file into the active list by highlighting *J2.1.xyz* on the left hand side and clicking **ADD**. Click the **Open** button and the ephemeris file will be read into memory.

Select the **Edit Grnd Stns** command from the **Graphical** submenu in the **Coverage** menu. Select two ground stations: Maui and Malabar. If these stations are already in the OATS data base, simply highlight the station names in the left hand box and click the **ADD** button between the two boxes to add the stations to the active list. If the stations are not in the OATS data base, enter the station coordinates and names in the appropriate areas in the dialog box and click the **ADD** button above the left hand box. Use the following coordinates:

Maui

Geodetic Latitude: 20.708 degrees

Longitude: 203.742 degrees

Altitude: 3.059 km

Malabar:

Geodetic Latitude: 28.026 degrees

Longitude: 279.315

Altitude: -0.013 km

Add the station names to the active list. Select **OK**.

Select the **Edit Antennas** command from the **Graphical** submenu in the **Coverage** menu. The Edit Antennas dialog box that appears associates antenna patterns with each satellite ephemeris. The ephemeris file previously read in appears in the box. Double click on the file *J2.1.xyz*. Select the elevation Antenna Type, set the Antenna Parameter to 0.0 and check the Ground Station box. With these selections, the satellite will be able to view the target when it is above 0.0 degrees of the target local horizon and it is within view of either Maui or Malabar. Select **OK**.

Under the **Coverage** menu item select **Run Graphical**. The Graphical Coverage dialog box will appear. Set the Start time to 92, 1, 1, 0, 0, 0.0, the Stop time to 92, 1, 2, 0, 0, 0.0 and the interval to 60.0 seconds. Set the output file name to *TEST*. Select the Output Units to be % Coverage. Select **OK**. The graphical percent cumulative coverage file will be written to the file named: *TEST.cc*. Graphical display of this data on a world map is illustrated below in the plotting examples.

B.3 Plotting

To illustrate some of the plotting functions of OATS, an example will be discussed in which a map, ground station locations, and graphical coverage data are plotted.

Under the **Plot** menu item select **Map, Options...** Select the rectangular Map Projection radio button. Set the minimum latitude to -90, the maximum latitude to +90, the minimum longitude to -180, and the maximum longitude to +180. Under the **Plot** menu item select **Map, Plot**. A rectangular map will be plotted in the Graphics Window. Under the **Plot** menu item select **GS Posn, Options...** Select two ground stations: Maui and Malabar. If these stations are already in the OATS data base, simply highlight the station names in the left hand box and click the **ADD** button between the two boxes to add the stations to the active list. Under the **Plot** menu item select **GS Posn, Plot...** The positions of the two ground stations will be drawn on the map.

To plot the graphical coverage file created in the previous example, select **Contours, Options...** from under the **Plot** menu item. Select the **% Coverage** radio button under the Contour Levels Data Base heading. Click the **Load** button. Levels from 0 to 100 percent will appear in the Contour Levels box. Indicate the data type to be plotted by selecting the **Cumulative Coverage** radio button. Enter the file name *TEST*. OATS will automatically append *.cc* to this name based on the data type selected. Select **OK**. Under the **Plot** menu item select **Contours, Plot**. The drawing shown in Figure B.1 should now be in the graphics window:

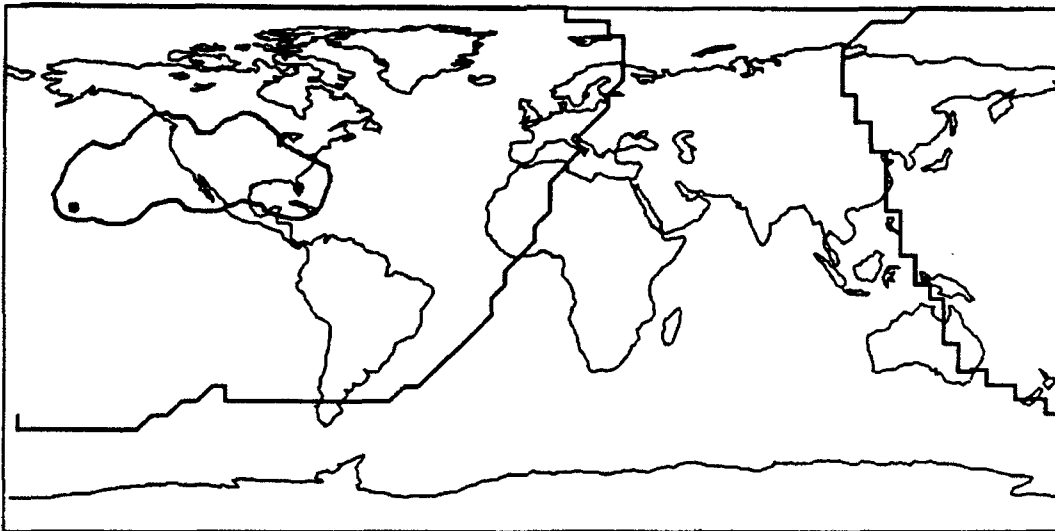


Figure B.1 Example coverage contour map

In this example the contour closest to the ground stations happens to be the 10 percent contour line. The other contour is the 0 percent contour line. The picture is interpreted such that the region between the two contour lines receives between 0 and 10 percent coverage per day from the 1 satellite, two ground station system. That these are indeed the 0 and 10 percent contour lines may be verified by manually loading only the 0 percent contour line in the **Contours, Options** Contour Levels box and plotting only that single contour. This can be repeated for the 10 percent contour line.

The remaining graphical functions of OATS all operate by first the setting the **Options** then updating the drawing selecting **Plot**.

Acronyms

AO - Average Outage

AOS - Acquisition of Signal

CC - Cumulative Coverage

ECF - Earth Centered Fixed

ECI - Earth Centered Inertial

EPH - Ephemeris

FOV - Field of View

GS - Ground Station

LOS - Loss of Signal

MO - Maximum Outage

OATS - Orbit Analysis Tools Software

OLES - One Line Element Set

WGS84 - World Geographical Survey 1984