Find Orb Reference Guide

Applies to the Find Orb release 8 Aug 2014

This document is a reference guide to the installation and operation of Find Orb (there being no user guide or help system with the program). Descriptions of how to use Find Orb for particular tasks, such as generating residuals, can be found in the Using Find Orb notes.

The document was originally written to help students install and use Find Orb in the course of tracking, imaging, measuring and making astrometric and photometric reports to the Minor Planet Centre. Not all usages of Find Orb are covered in particular those related to artificial satellites.

This version includes a number of updates suggested by Bill Gray and has been updated for the 2014 release of Find Orb.

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CONTENTS

1 INTRODUCTION

The Minor Planet Centre (MPC) continually refines and updates the orbits of comets and minor planets based on observations supplied by worldwide observers. However there are some times when we may wish to determine orbits for ourselves. The program Find Orb provides the ability to calculate orbital elements from observations and to generate ephemerides from those elements.

It is assumed the reader is familiar with the concepts of orbits and elements. If not, here is a place to start.

2 INSTALLATION

2.1 Program

The Find Orb application can be found at:

http://www.projectpluto.com/find_orb.htm.

This web page contains notes about installation and use of the program together with some sample exercises. Any new user is urged to read the notes on this web page and try the demonstrations.

MS Windows users can download the package from here and extract it into any convenient folder (which I will refer to as the Find Orb folder). It is useful to create a shortcut for *Find_Orb.exe* on the desktop. The program will now run and the demonstrations can be executed. However, before using Find Orb "seriously", there are some set-up considerations in Installation Files (2.1) and Settings (2.2).

For non-Windows users, the source code is provided and installation guidance is provided here.

2.2 Installation Files

2.2.1 Observatory codes

It is important that the observatory locations are correctly defined for all observations. The file *ObsCodes.html* contains the names and locations associated with observatory codes. The latest version of this file should be retrieved from the MPC and placed in the Find Orb folder, overwriting the existing file. Find Orb will remind you to do this again if it comes across an observatory code it does not recognise.

2.2.2 JPL DE Ephemerides

The Find Orb package comes with files that enable it to calculate the positions of the Moon and planets. These are adequate for casual use of the program but a set of JPL Development Ephemerides (DE) will improve both performance and accuracy.

A full set of DE422 ephemerides can be downloaded as follows:

- Click on this link: ftp://ssd.jpl.nasa.gov/pub/eph/planets/Linux/de422/
- Right click on file lnxm3000p3000.422 and save it in the Find Orb folder.

This file is big (532Mb) and it covers years 2999BC to 3001AD. A small version of the DE405 ephemerides that covers 1970 to 2020 is available here and is only 4.7MB.

2.2.3 Asteroid Ephemerides

When calculating orbits, the program can take into account the gravitational effects of up to 300 of the most massive asteroids. If you wish to use this facility then a set of asteroid ephemerides are needed. They can be obtained from:

ftp://cfa-ftp.harvard.edu/pub/MPC/BC405/asteroid_ephemeris.txt

Log in as "anonymous", using your e-mail address as a password. Save the file to your Find Orb folder.

Using all 300 asteroids does slow the program somewhat and you can limit the processing to a few of the most massive asteroids by placing the following statement in the *environ.dat* file, where N is the number of asteroids to be included:

```
BC405_ASTEROIDS=N
```

2.3 Settings

In the Find Orb window press "Settings" to see a dialog containing several fields. There is a complete description of the available settings in section 3.3 but the following initial settings are recommended:

2.3.1 Element precision

This sets the display precision for elements. The default is 5 but you may prefer to extend this to 8 for consistency with the precision shown in *MPCORB.DAT* and other material from the MPC.

2.3.2 Use Sigmas file

This should be selected so that the sigma.txt file is used. See discussion about "sigmas" in the Find_Orb website and Appendix VI.

2.3.3 Alternative element format

Select this for a more readable format of the elements including error estimates.

2.3.4 Heliocentric orbits only

This controls whether Find Orb can generate a geocentric orbit (or orbit centred on another planet). If *Settings/Heliocentric orbits only* is <u>not</u> selected and the object is close to Earth at the epoch then Find Orb may propose a Geocentric orbit. For comets and asteroids this option should normally be selected.

2.3.5 Physical model

This should be set to "Standard".

2.3.6 Comet magnitudes

This should normally be set to Nuclear so that the elements will include an absolute nuclear magnitude M(N) that will be used to generate magnitudes for ephemerides. However, if nobody has yet reported any nuclear magnitudes you can try setting this to Total and Find Orb will then try to establish an absolute total magnitude M(T).

2.3.7 Filtering

Observations that differ from their calculated value by more than a certain amount are "switched off" by Find Orb when you use the "Filter" button. For approximate consistency with the way the MPC treats observations "Max residual" should be selected and the value set to 1.5 sigmas.

2.4 Input Files

The input to Find Orb is in the form of an observation file such as provided by the MPC, NEODyS or ASTDyS. It does not matter if the file contains some other information (such as MPC Report headers) because Find Orb will ignore anything that does not look like an observation.

The most readily available source of observations is the MPC Observations Database. Enter the object's name, number or designation and click "Show". The resulting page includes a link to the observations. If an asteroid has a number then you must use it to retrieve all the observations. Using a provisional designation may only return the observations reported when it had that designation. If a comet has a number, or has had multiple designations (e.g. due to a re-discovery) then you may have to assemble a complete set of observations from each of its designations.

Selecting ephemerides for an object on the NEOCP page will provide a link to its observations.

Save the observations to a local file.

Observations from the MPC are in the same format as those generated by Astrometrica, so you can "copy & paste" your own observations from Astrometrica and add them to those from the MPC. (You cannot do that with NEODyS observation files which are in a different format).

Windows users are advised that, if they want to edit an observation file, use WordPad initially (not Notepad). This is because MPC files are produced by a UNIX system and WordPad will convert them to a Windows format. Once the file has been saved by WordPad, Notepad can be used as normal. (Find Orb is happy to accept the file in either format).

3 OPERATION.

3.1 Main Window

The main window is presented when you open Find Orb. The following describes each part of the window:

3.1.1 Open

Click the *Open* button and select an input file.

Alternatively you can "copy & paste" a list of observations into Find Orb. To do this, open the observations in an editor or in your browser, select and copy the observations, right-click in the Find Orb window (in the *Orbital elements* area) and select "Open from clipboard".

If the file contains observations for more than one object then double-click the required object in the object list below the *Open* button.

When you first open a file of observations Find Orb will search for a set of orbital elements that will fit the observations and looks "reasonable". In the author's words:

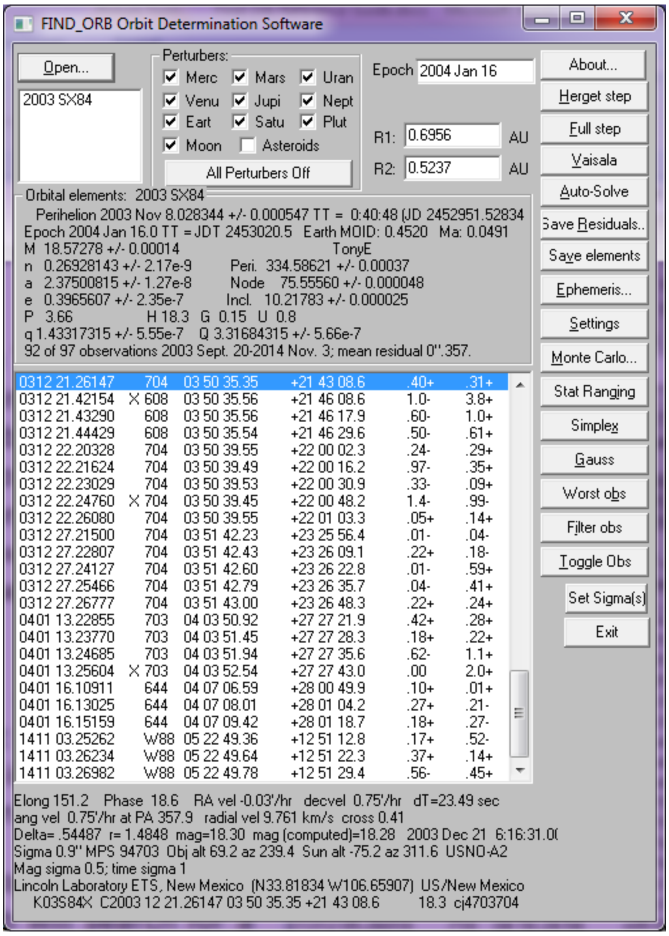

Figure 1 Main window.

"*When Find Orb loads up astrometry for an object, it tries dozens or hundreds of possible orbits, including those found by the method of Gauss and a slew of Väisälä orbits at assorted distances from the sun. Each orbit is given a "score" based on how "likely" the orbit seems. High residuals, a hyperbolic orbit, or an orbit that doesn't match the sort of elements normally observed all result in a poor score. If the arc is long enough, then the method of Herget and/or the "full improvement" method result in improved scores. After all this, the initial orbit shown by Find Orb is the one with the best score.*"

3.1.2 Object List

Below the *Open* button there is a list of objects for which observations have been found in the input file. Double click the one you are interested in. If there is only one object you do not need to select it.

3.1.3 Perturbers.

In the upper central part of the window there is a group of check-boxes called *Perturbers*. A tick in a box means that perturbations caused by that object are taken into account. Find Orb will switch "on" those perturbers it considers important but for best accuracy press the *All perturbers* button. Switching off some perturbers may save a bit of computer time but this is hardly noticeable on a modern PC.

The installation default is that *All perturbers* does not include asteroids. If you want *All perturbers* to include asteroids then insert the following statement in the *environ.dat* file that resides in the Find Orb folder.

```
DEFAULT_PERTURBERS=7007fe
```

When Asteroids are selected then up to 300 of the most massive asteroids are included in the perturbations. The *asteroid.ephemeris* file must be installed (see 2.2.3). Most of the time, the inclusion of asteroid perturbers makes no difference to the orbit, and including 300 asteroid perturbers slows down even a fast machine! However, there are notable exceptions and if you are seeing unexplained high residuals try switching on the asteroid perturbers.

3.1.4 Epoch

This field shows the epoch of the orbital elements currently being displayed. Find Orb will select an epoch close to the time of the observations it used to determine the initial orbit. In the case of an object with a long history *Epoch* may be many years in the past.

If you want to work with a different epoch enter the date (e.g. 2013 07 29) in the *Epoch* field and press *Full step*. Do not press enter when the cursor is in the *Epoch* field as this can cause unpredictable results!). The orbital elements will change to the requested epoch.

If a completely irrational orbit appears (or the *Orbital elements* turn red) then Find Orb has not been able to achieve the requested epoch (probably because there are too few observations). You may need to start again by re-opening the file.

3.1.5 R1: R2:

These fields are the distances (in AU) of the object from the observer for the first and last observation in the list. Normally, Find Orb will place its own estimate of the distances in these fields but if you are using the *Herget step* (see below) for orbit determination then you must first enter your own best guess into these fields (or accept the estimates provided by the initial automatic process).

3.1.6 Orbital elements

In this area of the window, Find Orb displays details of the orbit it has determined. The data includes the usual elements plus other information. A complete list of the data items is shown in Appendix I. If Find Orb fails to determine an orbit, the elements turn red. However, just because the elements are not red it does not mean the orbit is accurate. It is always up to you to decide whether the elements displayed here are reasonable.

If the option *Alternative element format* is selected in Settings, the elements will include error sigmas for example "e=0.4865924 ± 2.1e-7". If the error sigmas are all small it means Find Orb has probably found a good orbit. If they are high then beware the orbit may not be good.

3.1.7 Observation List

The central pane lists all the observations found in the input file for the chosen object. The list is sorted by observation date/time, oldest at the top.

Each line shows:

- Date/time of the observation.
- Observatory code.
- RA and Dec reported.

- RA and Dec residuals (the difference between the reported observation and the RA/Dec calculated from the orbital elements).

If there is an "X" immediately to the left of the observatory code this means the observation is "toggled off". That means it is being ignored. You can change the status of an observation by selecting it and pressing the "Toggle Obs" button. As in normal Windows practice, you can use the Shift or Ctrl keys to select blocks of observations or multiple individual observations.

Observations may also be toggled on/off by Find Orb during its initial search for an orbit or by using the *Filter* button (see below).

3.1.8 Observation Detail

The area under the observation list initially displays information about the version of Find Orb that is running and whether JPL DE files are being used to determine planet positions.

If an observation is selected in the list then this region shows details of that observation. Many data items are shown and these are listed in Appendix II. If multiple observations are selected then their mean residual is shown, together with program version information and DE file usage. If just two observations are shown then the mean residuals, angular distance, time difference and motion are shown.

3.1.9 About Button

This shows information about Find Orb and the current version.

3.1.10 Herget step

This causes one step of the Herget method to be run.

Herget is useful if you have a few days or weeks of observations. It relies on you to provide a reasonable guess as to the distance of the object from the observer for the first and last observations. These distances must be placed in the fields R1 and R2 before pressing the *Herget step* button.

Each time you press *Herget step* the program will look for improved values of R1 and R2 that reduce the mean residual. If your guess is good then each step will improve the values of R1 and R2 and converge towards a solution. If R1 and R2 are bad estimates then an unrealistic orbit will appear or the elements will turn red. In that case try again with different R1/R2 values (or try another method).

If several Herget steps converge to a sensible orbit then you can try *Full step* to improve it further.

3.1.11 Full step

This method is used to improve an orbit already discovered by one of the other methods. The *Full step* method seeks to reduce the mean residual by modifying the orbital elements using a "least squares" approach.

When you have a reasonable orbit by any method (or as proposed initially by Find Orb) press *Full step* several times until little or no change is being made to the elements and the residual is at its lowest value. If pressing *Full step* causes no (or extremely small) change to the elements then you probably have a firm orbit. If the elements jump around then the orbit could be unreliable – more observations are needed. (Don't forget to switch the perturbers on first!) .

Beware!

- *Full step* may rapidly diverge to an impossible solution especially if there are few observations so make sure you remember how you obtained the original orbit.
- If there are few observations, *Full step* may confidently provide an orbit but it may be completely wrong!

3.1.12 Väisälä

It must be recognised that, if you have very few observations you cannot compute a good set of orbital elements. However, you do need a clue as to where to look for the object tomorrow night. This is where the Väisälä method comes in. It relies on you providing a reasonable guess as to the perihelion and aphelion distances for the object. (The MPC uses Väisälä to provide ephemeris for NEOCP objects).

Press the *Väisälä* button and enter your best guess as to the perihelion and aphelion distances of the object (e.g. 1.1/2.5). If a reasonable orbit is computed then you may try using it to predict coordinates for the next mission. You may also try to improve it using *Herget step* or *Full step*, but there is a risk that it may diverge into an impossible solution (so remember which peri/aphelion distances you used).

If no reasonable orbit can be found the *Orbital elements* box will turn red. Try again with a different combination of peri/aphelion distances.

The orbit produced by this method is almost certainly <u>completely wrong</u> but it may well provide usable coordinates for the following night.

3.1.13 Auto-Solve

With *Auto-Solve*, Find Orb will try to work out which method to use and which observations to include. This process is executed automatically when a new observation file is opened and is generally quite successful at providing a reasonable initial orbit.

Pressing the *Auto-solve* button will cause Find Orb to re-try its strategy for finding an orbit. If multiple uses of *Auto-solve* result in approximately the same result then you may have an orbit that is sufficiently well defined that you should apply *All perturbers* and *Full step*. If *Auto-solve* keeps resulting in a different orbit then it is probably not correct – nevertheless it may well be usable to predict tonight’s coordinates.

3.1.14 Save residuals

This button saves the observation list, with residuals, to a file.

3.1.15 Save elements

This button saves the elements to a file. Note that the file contains some additional information not shown in the window – see Appendix I.

3.1.16 Ephemerides

This button opens the Ephemerides window, described in Section 3.2.

3.1.17 Settings

This button opens the Settings window, described in section 3.3.

3.1.18 Monte Carlo

When you press this button Find orb will make random small alterations to the observations and re-generate the elements to provide a collection of different orbits. The orbits are saved in a file *mpcorb.dat* which can be found in the Find Orb folder. The elements are formatted in the same way as the *MPCORB.dat* file from the MPC.

You may imagine that that the file contains a set of "clones" of the object distributed in terms of their probability density. That is to say that there will be more or less clones with a given orbit depending on the probability of that orbit being correct.

Press the Monte Carlo button and a number will appear on the button. This is the number of clones generated. Press it again when you have enough clones.

The set of clone orbits can be used:

- In planetarium software to see the spread of probable positions of the object on future nights.
- To analyse their future movement to see the probability of a collision with another object.
- To analyse the past history of asteroid families or divorced binaries.

In addition to *mpcorb.dat*, the file *state.txt* is produced which contains the state vectors (heliocentric, ecliptic, J2000 positions and velocities) and detailed elements for each of the clones at the epoch. If the orbit is geocentric, and some of the clones will impact the Earth then impact information is written to the *virtual.txt* file.

If you place the following statement in the *environ.dat* file then the *elements.txt* file will include state vectors for all the planets and Moon at the same epoch.

```
PLANET_STATES=y
```

The above two files will therefore contain all the necessary information to initiate a simulation of the paths of the main Solar System objects including the clones.

If there are very few observations, *Monte Carlo* may not work because slight alterations of the observations result in unacceptable orbits. In this case you can try *Start Ranging*.

3.1.19 Start Ranging

This works very much the same way as Monte Carlo and has the same purpose. Clones are generated by a statistical ranging technique. Some would consider this a less mathematically correct way to calculate the probability distribution of clones but it is much more likely to work when there are only a few observations, However, it may not work at all if there are many observations over a long period.

Mpcorb.dat, state.txt and virtual.txt files are produced as for Monte Carlo.

3.1.20 Simplex

The downhill simplex method is worth a try if *Herget step* and/or *Full step* diverge to unreasonable solutions.

Simplex looks for combinations of R1 and R2 that will produce reasonable orbits. In addition to looking for a small mean residual it will also look for a solution that gives a reasonable combination of eccentricity and semi-major access based on main belt and Trojan asteroid statistics.

Set R1 and R2 values to your best guess. Press *Simplex* several times and accept a solution with a low residual. If a reasonable orbit appears then try *Full step* to improve it.

3.1.21 Gauss

This is a classical mathematical approach to determining orbits. It usually works best when there are a few weeks or months of data. It may come up with no solution (in which case there will be a message) or up to three solutions. Pressing *Gauss* repeatedly will cycle through the solutions it has found. It is for you to choose which one you think is best. If one solution has a low residual then it may be the "best". Alternatively consider what you know about the object and which orbit is most likely to be true.

If *Gauss* comes up with a reasonable orbit, use *Full step* to improve it.

3.1.22 Worst obs

Press this button to select the observation with the highest residuals (not considering those already toggled off).

3.1.23 Filter obs

When you press this button Find Orb will toggle "off" all those observations that have residuals greater than the Filtering parameter in *Settings* and toggle "on" all those with lower residuals. It will then run a *Full step*. If there are no remaining observations that have their status changed a message will come up "No changes made".

Repeated use of the *Filter* button can be a strategy to optimise which observations are being used. However, it can lead to blocks of perfectly good observations being excluded and an inaccurate orbit. If you see a block of observations excluded then turn them "on" using the *Toggle obs* button and run a *Full step* to see if the orbit will adjust to include them with reasonable residuals.

3.1.24 Toggle obs

Press this button to toggle the status of selected observations between "on" or "off".

3.1.25 Set Sigma(s)

A dialog opens in which you can set the position, timing and/or magnitude sigma (standard deviation) for selected observations. This will override the rules in the *sigma.txt* file.

- To set a position sigma press Set sigma(s) and enter the required sigma value.
- To set a magnitude sigma press Set sigma(s) and enter the required value preceded by "m" (e.g. m.5).
- To set a time sigma press Set sigma(s) and enter the required value preceded by "t" (e.g. t.5).

Press the See Appendix VI for a discussion about sigmas.

3.1.26 Exit

This closes the program.

3.2 The Ephemerides Window

The Ephemeris button in the main window opens the Ephemeris window.

3.2.1 Start

This is the start date for the set of observable coordinates or orbit epochs you want to produce. It can be in any of the formats generally recognised by Find Orb. Alternatively it can be relative to now, for example +0.5 means starting in 12 hours time.

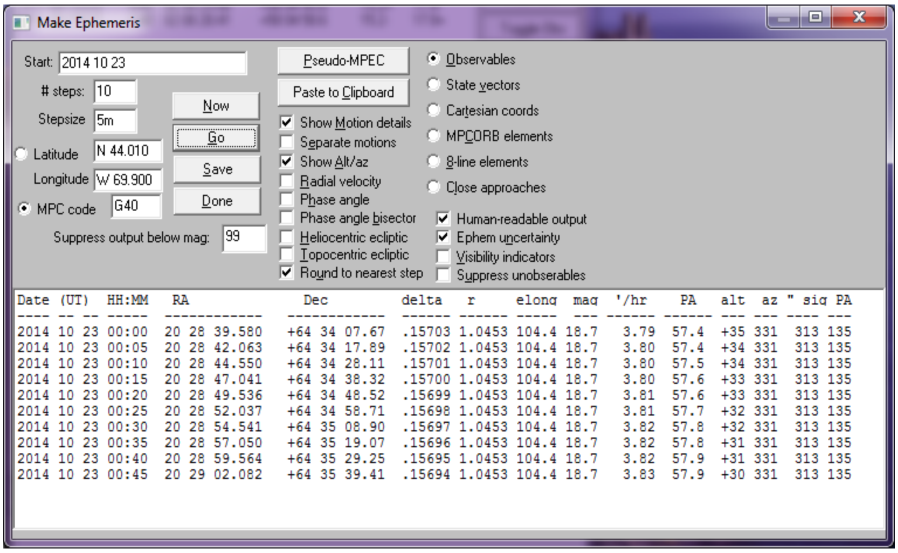

Figure 2 Ephemeris window

3.2.2 # steps and Stepsize

These are the number of steps to be generated in the ephemeris and the time difference between each step. The *Stepsize* is assumed to be in days/decimal days unless otherwise stated. If you place a colon (:) at the end of the *Stepsize* the ephemeris times will include hours, minutes and seconds, otherwise they will be in decimals. You can also specify *Stepsize* as hours or minutes (e.g. 2h, 30m).

3.2.3 Latitude & Longitude

If no observatory code is available the latitude and longitude of the observer is placed here for topocentric ephemerides.

3.2.4 MPC Code

Any MPC observatory code will be recognised. In addition you can use "Sun" "Mer", "Ven", "Mar", "Lun" (Moon) etc., to place the observer at the centre of a planet or put "500" in this field if you want geocentric results.

3.2.5 Suppress output below mag.

Output is suppressed when the object is fainter than given magnitude. (Best set this to 999 except when you really need to set a limit).

3.2.6 Now

This button resets the start time to "now" (+0).

3.2.7 Go

This button generates the requested data according to the options.

3.2.8 Save

This button saves the displayed ephemerides or orbits in a file.

3.2.9 Done

Press this button to close the Ephemerides window. The values of the various fields and options are saved for the next time you open the Ephemerides window. Closing the window using the close button (x) does not save the value of fields.

3.2.10 Display Options (radio buttons)

These determine what kind of data is displayed:

- Observables: Time, RA and Dec plus additional data as set by the checkboxes.
- State vectors: position and velocity vectors (J2000, heliocentric, ecliptic).
- Cartesian coordinates: position vectors (J2000, heliocentric, ecliptic)
- MPCORB elements: Orbits with epochs at each of the time steps in the format of the MPC's *MPCORB.dat* file.
- 8-line elements: Orbits in "8-line" format (similar to those displayed in the main window) with epochs at each of the time steps.
- Close approaches: A list of close approaches to the observer that occur during the period of the time steps requested. Use an appropriate observatory code to determine which body the close approach relates to (500 is best for Earth). You can set the altitude (meters) at which a collision is deemed to happen by putting a statement in the *environ.dat* file:

```
COLLISION_ALTITUDE=50000
```

3.2.11 Data options (check boxes)

The check-boxes control the details of which data are displayed.

- Show motion details: show the rate and direction of movement.
- Separate motions: show the rates of movement in RA and Dec.
- Show Alt/az: Show altitude and azimuth.
- Radial velocity: Show rate of movement towards or away from the observer.
- Phase angle: Show the phase angle presented by the object to the observer.
- Phase angle bisector: Ecliptic latitude/longitude of the PAB.
- Heliocentric ecliptic: Ecliptic latitude/longitude viewed from centre of Sun.
- Topocentric ecliptic: Ecliptic latitude/longitude viewed from observer.
- Round to nearest step: Ephemeris times are forced to integer × stepsize of a day.
- Human readable: Format is for display (alternative is machine readable).
- Ephem uncertainty: Show 1-sigma uncertainty in arcseconds and position angle of the long axis of the uncertainty ellipse.
- Visibility indicators: Indicates presence of Moon etc.
- Suppress unobservables: Suppress ephemeris when object not observable.

3.2.12 Pseudo MPEC buttons

This will show a document formatted similar to a Minor Planet Centre Electronic Circular (MPEC). It contains an extensive summary of the data you are working with including observations, residuals, the requested ephemerides, orbital elements and details of the observing stations. Some parts are blanked out due to MPC copyright.

3.2.13 Paste to Clipboard button

This places all the displayed information in the clipboard.

3.3 Settings Dialog

The *Settings* button on the main window opens the Settings window.

3.3.1 Constraints

If you wish to force a certain type of orbit you can enforce constraints on the elements by specifying their value(s). For example e=1.0 will force an orbit with eccentricity of 1.0, a=2.5 will force a value for the semi-major axis. Values can be specified for *a, e, i, P, q and Q*.

If constraints are set then *Full step* will try to converge towards an orbit that meets them. If it fails to do so that implies the constraints are inconsistent with the observations.

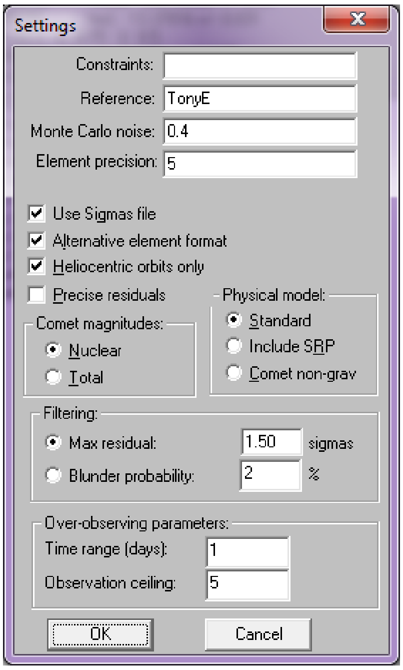

Figure 3 Settings window

3.3.2 Reference

This sets a "source reference" for orbit and element files.

3.3.3 Monte Carlo noise

This controls the amount by which observations are varied during Monte Carlo clone-generation. It should be of a similar order of magnitude to the mean residuals of the observations.

3.3.4 Element Precision

This sets the precision for the display of elements. A precision of 8 is consistent with most MPC output, but the default of 5 leaves the *Orbital elements* area less cluttered. This does not affect the underlying precision of calculations.

3.3.5 Use Sigmas file

This determines whether the *sigma.txt* file is used to specify the positional, magnitude and time error standard deviations (sigmas). This should normally be selected. For a discussion o sigmas see the document Using Find Orb.

3.3.6 Alternative element format

The alternative format shows element uncertainties and no P and Q vectors. It is generally best to select this option.

3.3.7 Heliocentric Orbits

When this box is checked, orbits will always be Heliocentric. This will prevent Find Orb assigning a geocentric orbit to a close passing object. Uncheck this box if you are dealing with a satellite or investigating a potential Earth impact where a geocentric orbit is required.

3.3.8 Precise residuals

This causes residuals to be calculated to 3 significant figures – generally unnecessary.

3.3.9 Comet Magnitudes

This is used to select which kind of magnitudes (nuclear or total) are to be used to calculate the absolute magnitude of a comet. Nuclear is the normal default, but if an object only has T magnitudes observed than set this option to "total".

3.3.10 Physical Model

The *Standard model* is Newtonian gravity including corrections for relativity and the oblateness of planets.

When *Include SRP* is selected *Full step* will attempt to reduce residuals by assigning a value to a parameter “area to mass ratio” (AMR) that accounts solar radiation pressure. This may be relevant for small objects with a long observational history.

When *Comet non-grav* is selected *Full step* will attempt to reduce residuals by assigning values to parameters (A1, A2) that account for the effects of comet out-gassing. This may be relevant for comets with a long observational history or during a close approach to the Sun.

3.3.11 Filtering

This controls the action of the *Filter obs* button. The *Max residual* method sets a statistical sigma (standard deviation) value. If an observation has a residual outside this value then the *Filter* button will cause it to be toggled off. A value of 1.5 might be suitable for an asteroid with a long history of observation – with lots of observations we can afford to discount the doubtful ones. A value of 2.0 is more suitable for an object with fewer observations or a comet.

The *Blunder probability* method allows you to set a percentage. This percentage of observations, with the highest residuals is assumed to be bad and they are toggled off.

3.3.12 Over observing parameters

These parameters can be set if you see that one observatory has supplied an excessive number of observations. If one observatory supplies more than *ceiling* observations during *time range* then their observations are reduced in weight (in a manner proportional to the degree of over-observation).

3.3.13 OK

This button saves the settings and closes the window.

3.3.14 Cancel

This button closes the window without saving any changes.

APPENDIX I - ORBITAL ELEMENTS

The *Orbital elements* area of the main window contains details of the orbital elements as currently established by Find Orb, together with some additional data items. In the table below the column "Field" has the name and symbol used by Find Orb. The column "Alt" has alternative names and symbols as may be found in MPC files, JPL Horizons and other sources.

Note that, when *Settings/alternative element format* is selected then each element is followed by ±uncertainty and the P/Q vector values are omitted.

Field	**Alt**	**Description**
(name or designation)		The name, number or designation of the object.
Perihelion, TT, (JD)	TP, *Tp*	Date and time the object passed through perihelion followed by the same date/time in Julian date form. In some cases this can be replaced by time of perifocal passage round one of the planets but this will not happen if you select "Heliocentric orbits only" in the Settings.
A1: A2:		If *Setting/Comet non-grav* is selected then these parameters appear. They are the comet's non-gravitational parameters that are adjusted to account for the effects of outgassing on its orbit.
Epoch, JDT=		The date for which this set of orbital elements is true, followed by the same date and time in Julian form.
Earth MOID		The Minimum Orbit Intersection Distance (AU). The closest distance of the Earth's orbit from the object's orbit. MOIDs for other planets may also be shown here and MOIDs for all planets are included in the *Save elements* and *elements.txt* files.
AMR		Area to Mass Ratio. This will appear when *Settings/Include SRP* is selected. The number is expressed in square meters per kilogram and is a parameter that is adjusted to account for the effects of solar radiation on an orbit.
M	MA, M_0	Mean anomaly at Epoch (degrees). If the object travelled round its orbit at a uniform angular rate then it would be this angular distance round its orbit at the date/time of the epoch. (Of course it does <u>not</u> travel round at a uniform rate, but this value can be used to calculate the True Anomaly (TA, ν) that is the actual position of the object at that time.)
n	N, *n*	Mean motion (degrees per day). The average angular velocity of the object round its orbit as seen from the Sun.
Peri.	W, ω	Argument of Perihelion (degrees). The angle round the orbit between the direction of the perihelion and the direction of the ascending node.
a	A, *a*	Semi-major axis (AU). This is half the longest diameter across the ellipse and also represents the average distance between the Sun and the object. (Not shown for a comet with ***e***≥1.)

Node	OM, Ω	Longitude of the ascending node. The angle between the reference direction (a line drawn from the Sun towards the direction of 1st point of Aries on 2000 Jan 01.5) and the point where the object rises up through the plane of the ecliptic.
e	EC, *e*	Eccentricity (dimensionless). A measure of how elongated the orbit is. e=0 for a circle. 0<e<1 for an ellipse, e=1 for a parabola and e>1 for a hyperbola.
Incl.	IN, *i*	Inclination (degrees). The angle between the plane of the object's orbit and the plane of the ecliptic.
P	PER	The period of the orbit (years).
H, M(T) M(N)	H, M1, M2	Absolute magnitude. H for an asteroid is the magnitude it would have if placed 1 AU from the observer and 1 AU from the Sun and with a phase angle of zero (i.e. fully illuminated). M(N) is a similar definition for the nucleus of a comet and M(T) is for the total comet. You can select whether to see nuclear or total comet magnitudes in *Settings*.
G or K	G, K1, K2	Slope parameter for the magnitude. Assists in calculating the apparent magnitude when it is not simply a case of distance and phase angle. (G for asteroids, K1 and K2 for comets.)
Q	ADIST	Aphelion distance (AU). Greatest distance from the Sun.
q	QR, *q*	Perihelion distance (AU). Minimum distance from the Sun. This parameter is used instead of semi-major axis in the case of eccentricity >= 1.0.
(observation count)		Number of observations used in the production of these elements and their date range.
Mean residual		The Root Mean Square (RMS) value of the residuals of the observations. Each residual is the difference between the observed position and the position calculated from the orbital elements. This is the primary indicator of how well the orbit fits the observations.
P and Q		P and Q vectors are unit vectors pointing in the direction of the perihelion and at right angles to P in the plane of the object's orbit. These are used in the calculation of positions and are not normally of interest. (Not shown if *Settings/alternative element format* is selected.)
Perturbers		In the *Save elements* file this lists which perturbers were switched on when the elements were calculated.
Tisserand		The *Save elements* file also records the value of the Tisserand parameter relative to various planets. This is a parameter that (among other things) can help identify which family of asteroids an object belongs to or what kind of orbit a comet has.

APPENDIX II - OBSERVATION DETAILS

When the program first opens, this area contains the program version number and a message as to whether a JPL DE Ephemerides file has been found. If an observation has been selected in the main window then details of the observation are shown:

Name	Description
Elong	Elongation. Angular distance between the Sun and the object (degrees). 180° is opposition.
Phase	Phase angle of illumination of the object. The Earth-Object-Sun angle. Near 0° implies full illumination and near 180° implies no illumination.
RA vel dec vel	Angular velocity in RA and Declination in arcminutes per hour (which also equals arcseconds per minute).
dT	Time residual. Difference between the time reported in the observation and the time the reported position was closest to the track implied by the orbit described in the *Orbital elements* area.
Ang vel	Angular velocity. Total angular velocity in arcminutes/hour.
PA	Position angle. Direction in which the object is travelling in degrees. (Angle is measured anticlockwise from North=0°)
Radial vel	Radial velocity in km/s. Negative is coming towards us.
Cross	Cross-track residual. How far away the observation is from the track predicted by the orbital elements. (High values of dT with low values of Cross can point to timing errors).
nn.n days ago	Time since this observation was made (recent observations only).
Delta	The distance of the object from the observer in AU.
r	The distance of the object from the Sun in AU.
mag	Magnitude reported (band is not shown but can be seen to the right of the magnitude in the original observation record at the bottom of the message/observation area.)
Mag(computed)	The magnitude calculated from the absolute magnitude (if available).
(date/time)	The reported date and time of the observation.
Sigma x.x Mag sigma x.x Time sigma x.x	The positional, magnitude, and time sigmas assigned for this observation. If Sigma is not shown then the default is used.
MPS=nnnn	Minor Planet Centre Circular Supplement number in which the observation was published. If the observation was published in some other journal its initials and volume number may appear here.
Obj alt, az	Altitude and azimuth of the object for the observer at the time and place of the observation. (Find_Orb checks this and ignores observations if the object is below the horizon for that observer.)
Sun alt, az	Altitude and azimuth of the Sun for the observer at the time and place of the observation. (Find_Orb checks this and ignores observations if the Sun is above the horizon for that observer.)
(observatory)	Full name of the observatory and its latitude and longitude.
(observation)	The final line is the observation record in its original form.

APPENDIX III - #COMMANDS

There are some commands that can be added to the input file.

The #command should be placed in a separate line before the observation(s) to which it refers.

#coord epoch 1950.0	use epoch B1950.0 for the observations that follow.
#coord epoch 0	use mean coordinates of date for the observations that follow.
#coord epoch 2000	use epoch J2000 for the observations that follow.
#suppress_obs	load the following observations toggled "off". (Putting an "x" in column 65 also means toggle this observation off).
#include_obs	load the following observations toggled "on".
#Posn sigma n.n	assign positional uncertainty n.n to the following observations.
#Mag sigma n.n	assign magnitude uncertainty n.n to the following observations.
#Time sigma n.n	assign time uncertainty n.n seconds to the following observations.

In the above, if n.n = 0 the uncertainty of that type returns to the default

#time date/time	overrides time for the next observation.

APPENDIX IV - ENVIRON.DAT

The file *Environ.dat* is in the Find Orb folder and controls some functions. Most of the information is set up by Find Orb, but you can add the following lines:

`EPOCH=2455600.5`	Forces the epoch always to be the specified Julian date.
`JPL_FILENAME=path/name`	Tells Find Orb where to find a JPL DE Ephemeris file if it is not in the Find Orb folder.
`DEFAULT_PERTURBERS=7007fe`	Sets the *All perturbers* button to include asteroids.
`PLANET_STATES=y`	Save all planets' state vectors in *elements.txt*.
`COLLISION_ALTITUDE=50000`	Collision is defined as this number of meters above the surface.
`BC405_ASTEROIDS=N`	Use the most massive N asteroids as perturbers. (N up to 300 if *asteroid.ephemeris* file is installed.)
`FIX_OBSERVATIONS=1`	Observations sent via e-mail frequently end up with spaces added or removed. Add this line and Find_Orb will be less strict about parsing astrometry, and will usually figure out which lines contain valid data.
`GREENLIT=703 G96`	By default, all NEOCP astrometry is "redacted" in pseudo-MPECs (shown in black; highlight the astrometry in question, and you just see pseudo-random characters). This is because not all observers want their NEOCP astrometry being redistributed without permission. The folks at CSS are fine about redistribution, so NEOCP data from (703) and (G96) is "greenlit" and therefore not redacted. If you want your NEOCP astrometry to show up in pseudo-MPECs, add your observatory code to this line.

APPENDIX V - OTHER FILES

Some other files may be found in the Find Orb folder:

sdesig.txt	Can be used to set up equivalent designations as, for example when you have a mix of observations using temporary and provisional designations.
jpleph.txt	Information about where to obtain JPL DE files.
rfindorb.dat	Text for buttons and fields in the windows (if you want to translate them, but Italian and French versions are already provided).
elements.txt	The current set of elements produced by Find Orb. Can also contain planet state vectors.
virtual.txt	Impact locations for clones generated by Monte Carlo in a format readable by the Project Pluto Guide program.
odd_name.txt	Cross references between packed names and normal names for selected objects.
rovers.txt	Observatory codes for people who do not have “real” observatory codes.
state.txt	The orbital elements and heliocentric ecliptic J2000 state vectors of each of the clones created by Monte Carlo.
mpcorb.dat	The set of Monte Carlo clone orbits in MPCORB.DAT format.
observer.txt	Contains links to observers’ websites.