Cowell's Method for Heliocentric Orbits

Written by C. David Eagle

This Windows XP/Vista application (`cowell2.exe`) will numerically integrate the equations of motion of a heliocentric object subject to the point-mass gravitational perturbations of the Sun and all the planets except Pluto. The ephemeris of the Sun and each planet can be computed using either the JPL DE405 or Bureau of Longitudes SLP96 ephemeris.

The second-order heliocentric equations of motion of a satellite or celestial body subject to the point mass gravitational attraction of the Sun and planets are given by

$$\ddot{\mathbf{r}} = \frac{d^2\mathbf{r}}{dt^2}(\mathbf{r},t) = -\mu_s \frac{\mathbf{r}_{s-b}}{\left|\mathbf{r}_{s-b}\right|^3} - \sum_{i=1}^{9} \mu_{p_i} \left(\frac{\mathbf{r}_{(p-b)_i}}{\left|\mathbf{r}_{(p-b)_i}\right|^3} + \frac{\mathbf{r}_{p_i}}{\left|\mathbf{r}_{p_i}\right|^3} \right)$$

where

μ_s = gravitational constant of the Sun

μ_{p_i} = gravitational constant of planet i

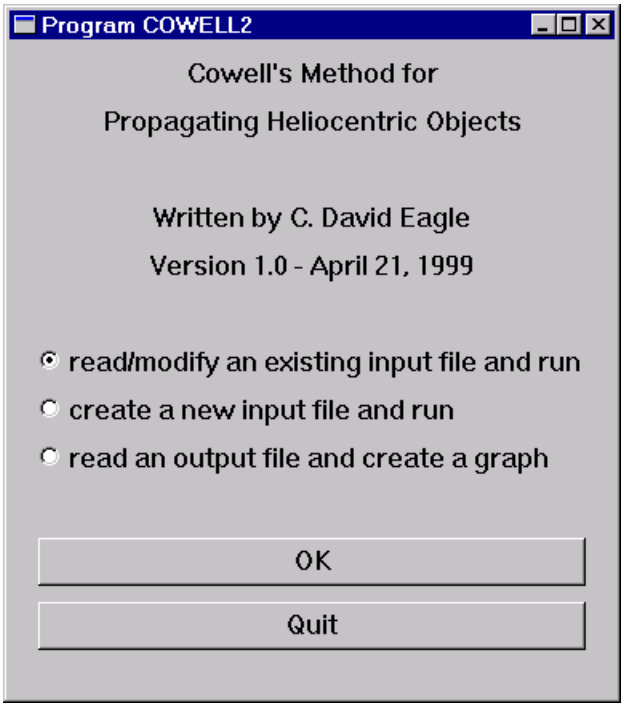
$\mathbf{r}_p$ = position vector from the Sun to planet

$\mathbf{r}_{s-b}$ = position vector from the Sun to the body

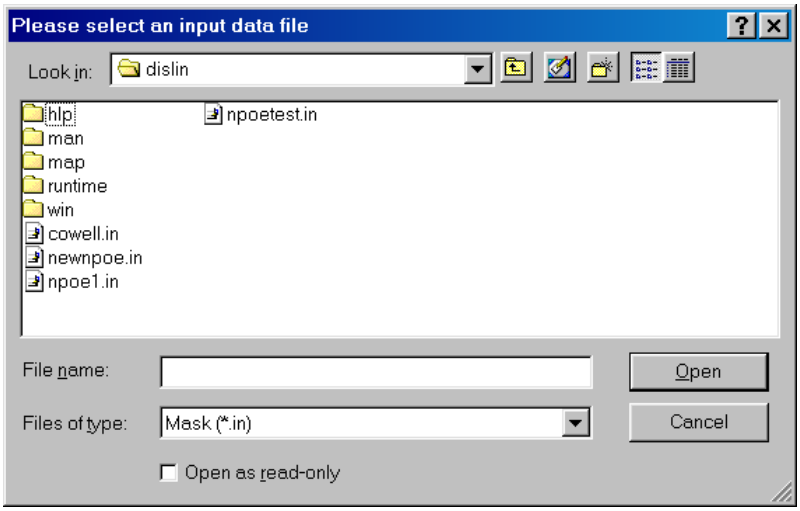
$\mathbf{r}_{p-b}$ = position vector from the planet to the body

These position vectors are related according to $\mathbf{r}_{s-b} = \mathbf{r}_p + \mathbf{r}_{p-b}$.

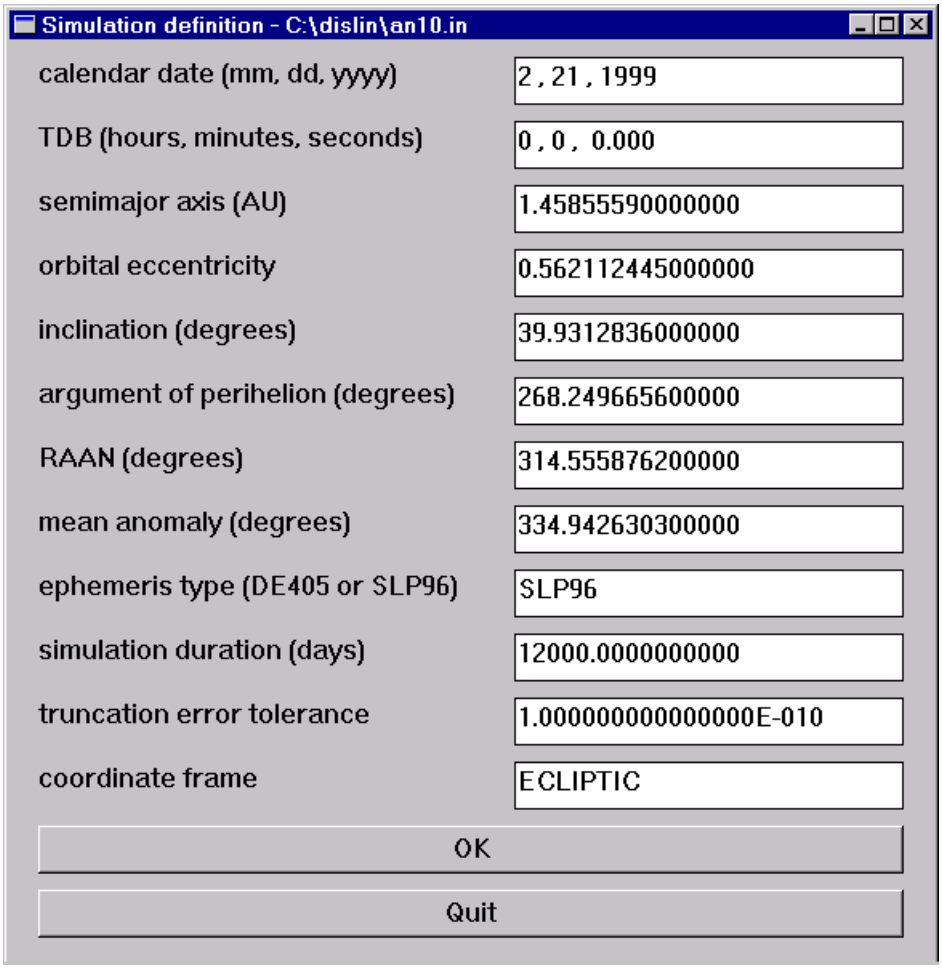
Program options are selected from the following *main menu*.



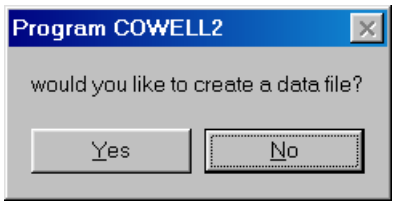
The first selection will allow the user to read and/or modify an existing input data file and run the program. The software will display a file selection screen similar to the following.



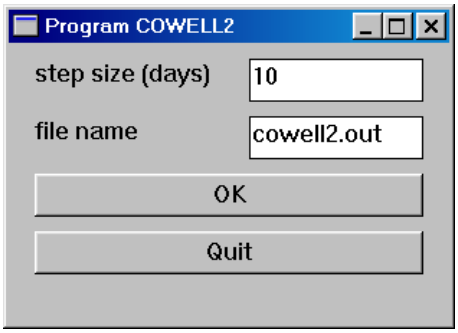
The user can either select an input file using the mouse or type the file name in the File name: field. The default file name extension for input files is `*.in`. However, the software will accept any input file compatible with the `COWELL2` program. After an input file is selected the program will display a *simulation definition* screen similar to the following:



The input fields of this screen allow the user to modify any data item such as the ephemeris source and initial conditions. After clicking the OK button, the program will ask the user if he or she would like to create an ASCII output data file with the following prompt:

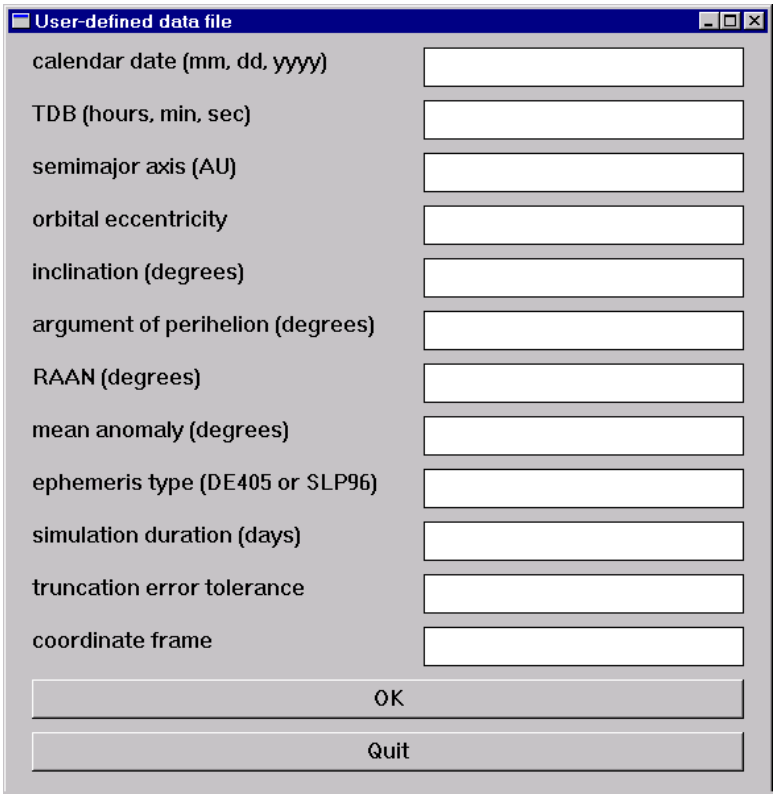


If you select Yes the program will ask for the print step size and output file name with this next interactive screen:



create a new input file and run

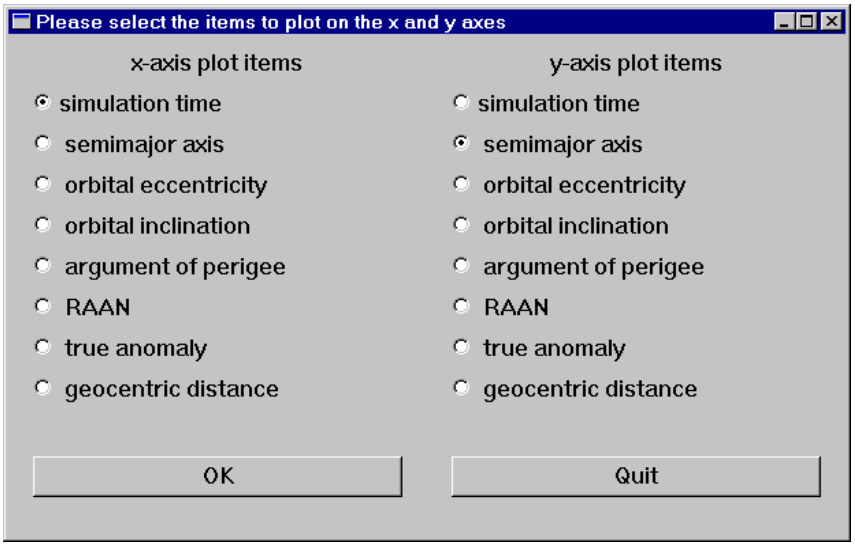
The second item of the main menu will allow the user create a new input file from scratch. The input screen for this option is as follows:



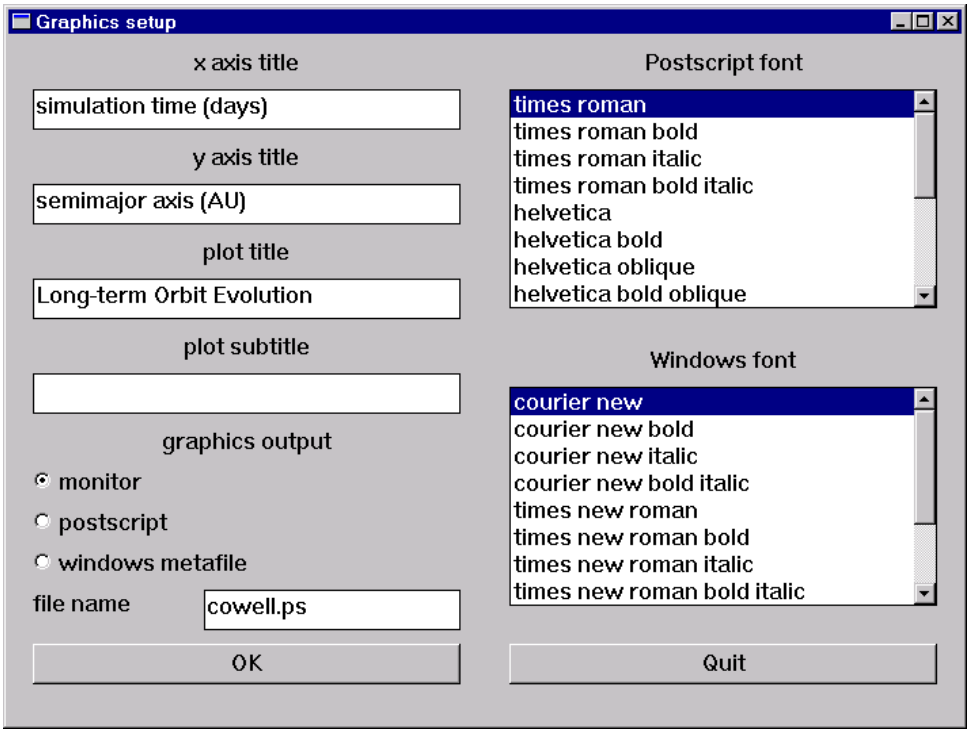
The user simply fills in the input fields, clicks on the OK button to save the file to disk and run the program. Please note that the coordinate frame field must contain either ecliptic or equator. This input is not case sensitive but must be spelled correctly. The same is true for the ephemeris type field.

read an output file and create a graph

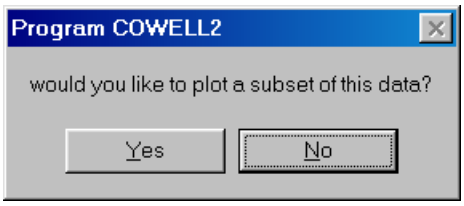
This program option will read an existing output file and create a graph of the data. After the user selects an output file the program will display the following screen which allows the user to select the items to plot on the x and y axes:



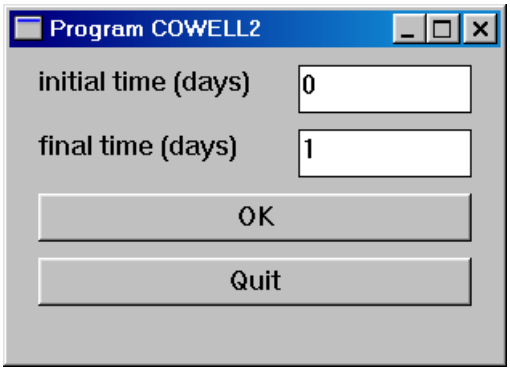
After pressing the OK button, the software will display the following graphics setup screen:



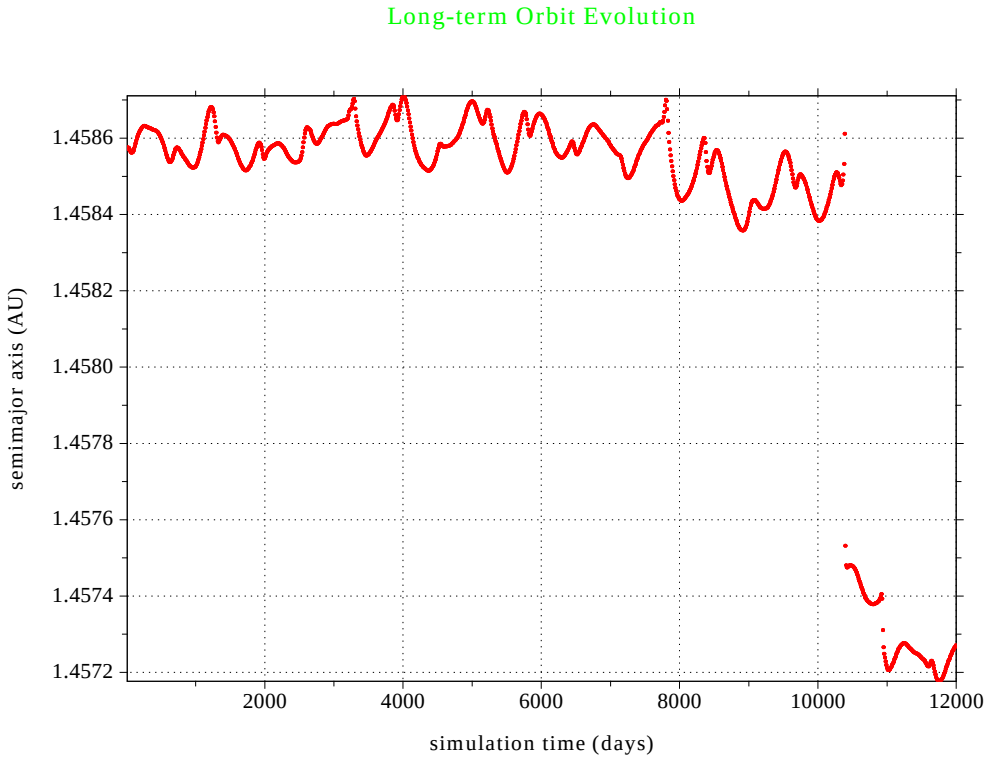
This screen allows the user to define such things as plot titles, fonts and the graphics destination. After the graphics setup is complete the software will ask if you would like to plot a time subset of the data with the following prompt:



If you click the Yes button, the program will display the following screen. With these two data entry fields you can specify the initial and final values of the time subset in days. Please note that the software does not check your input for validity.



The following is a typical graphics screen created with this computer program.

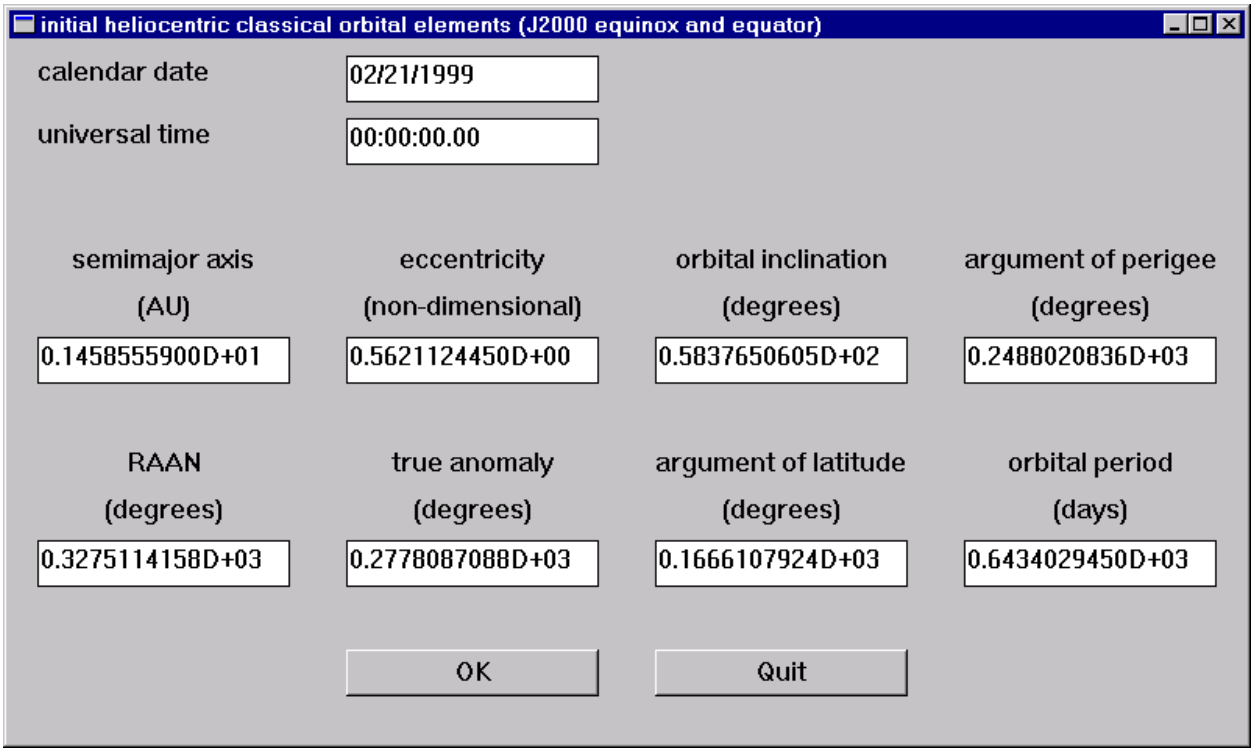


The following is a typical ASCII input data file for this program. It contains the heliocentric orbital elements of the asteroid 1997 XF 11. These coordinates must be relative to the J2000 equinox. The fundamental plane can be either the ecliptic or Earth equator. This data file was created using information available from the Horizons ephemeris system located at http://ssd.jpl.nasa.gov/horizons.html.

```
initial calendar date
(1 <= month <= 12, 1 <= day <= 31, year = all digits!)
10,20,1998

initial TDB
(0 <= hours <= 24, 0 <= minutes <= 60, 0 <= seconds <= 60)
0,0,0

initial semimajor axis (AU)
(semimajor axis > 0)
0.1441779254846407D+01

initial orbital eccentricity (non-dimensional)
(0 <= eccentricity < 1)
0.4836740409964595D+00

initial orbital inclination (J2000 equator and equinox)
(degrees; 0 <= inclination <= 180)
0.2017287833484568D+02

initial argument of perihelion (J2000 equator and equinox)
(degrees; 0 <= argument of perihelion <= 360)
0.3228014264370198D+03

initial longitude of the ascending node (J2000 equator and equinox)
(degrees; 0 <= raan <= 360)
0.3533298230482567D+03

initial mean anomaly (J2000 equator and equinox)
(degrees; 0 <= mean anomaly <= 360)
0.2708752703925974D+03

ephemeris source (SLP96 or DE405)
SLP96

simulation duration (days)
2000

truncation error tolerance (non-dimensional)
1.0d-10

coordinate frame (ecliptic or equator)
equator
```

The user can create input data files for this software using an ASCII text editor or the create a new input file and run option of the main menu. Do not change the total number of lines or the order of annotation and data in this file. The software expects to find exactly 43 lines of information in the input data file.

The software will display the initial date, TDB time and classical orbital elements. The following is a typical screen display of this information:



The software will also display the final time, date and classical orbital elements. The orbital elements in this screen are with respect to the J2000 dynamical equinox and equator when the SLP96 ephemeris is used, and the J2000/ICRF equinox and equator when the DE405 source ephemeris is used.

Output file

The following is part of a typical ASCII output file created with this application.

```
#calendar      TDB        sim time    semimajor axis  eccentricity   inclination   arg perigee      raan      true anomaly   geocentric
#  date        time        (days)          (au)                        (degrees)     (degrees)    (degrees)     (degrees)     distance (au)
02/21/1999, 00:00:00.00,       0.0000,   1.45855590,   0.56211245,   58.37650605, 248.80208361, 327.51141580, 277.80870879,   0.92690571
03/03/1999, 00:00:00.00,      10.0000,   1.45857213,   0.56211457,   58.37610099, 248.80119895, 327.51148114, 290.57031474,   0.31735617
03/13/1999, 00:00:00.00,      20.0000,   1.45857584,   0.56211490,   58.37587742, 248.80094474, 327.51145254, 306.40782376,   0.42647053
03/23/1999, 00:00:00.00,      30.0000,   1.45857483,   0.56211442,   58.37575877, 248.80090957, 327.51139097, 325.83951500,   0.54541158
04/02/1999, 00:00:00.00,      40.0000,   1.45857148,   0.56211340,   58.37569992, 248.80094360, 327.51132187, 348.51270126,   0.66778816
04/12/1999, 00:00:00.00,      50.0000,   1.45856734,   0.56211215,   58.37567935, 248.80099521, 327.51126039,  12.51880282,   0.78561916
04/22/1999, 00:00:00.00,      60.0000,   1.45856390,   0.56211104,   58.37568045, 248.80106365, 327.51121827,  35.07907253,   0.88939772
05/02/1999, 00:00:00.00,      70.0000,   1.45856196,   0.56211020,   58.37568527, 248.80116540, 327.51120344,  54.35231275,   0.97304366
05/12/1999, 00:00:00.00,      80.0000,   1.45856169,   0.56210959,   58.37567774, 248.80130968, 327.51121255,  70.04202859,   1.03522830
05/22/1999, 00:00:00.00,      90.0000,   1.45856317,   0.56210917,   58.37564781, 248.80151034, 327.51123609,  82.68506473,   1.07751469
06/01/1999, 00:00:00.00,     100.0000,   1.45856678,   0.56210896,   58.37558272, 248.80178697, 327.51126802,  92.97465246,   1.10292323
06/11/1999, 00:00:00.00,     110.0000,   1.45857240,   0.56210871,   58.37546657, 248.80217188, 327.51130085, 101.49758163,   1.11445904
06/21/1999, 00:00:00.00,     120.0000,   1.45857894,   0.56210802,   58.37529969, 248.80264696, 327.51132090, 108.69355822,   1.11503558
07/01/1999, 00:00:00.00,     130.0000,   1.45858572,   0.56210678,   58.37508718, 248.80317828, 327.51131755, 114.88044904,   1.10783552
07/11/1999, 00:00:00.00,     140.0000,   1.45859241,   0.56210499,   58.37483260, 248.80374067, 327.51128338, 120.28736375,   1.09581845
07/21/1999, 00:00:00.00,     150.0000,   1.45859878,   0.56210270,   58.37453956, 248.80431325, 327.51121279, 125.08118917,   1.08216953
07/31/1999, 00:00:00.00,     160.0000,   1.45860462,   0.56209998,   58.37421252, 248.80487656, 327.51110182, 129.38541975,   1.07040056
08/10/1999, 00:00:00.00,     170.0000,   1.45860972,   0.56209694,   58.37385761, 248.80540897, 327.51094842, 133.29304126,   1.06383272
08/20/1999, 00:00:00.00,     180.0000,   1.45861387,   0.56209385,   58.37348047, 248.80588420, 327.51075177, 136.87529338,   1.06588530
08/30/1999, 00:00:00.00,     190.0000,   1.45861731,   0.56209102,   58.37307326, 248.80631240, 327.51050396, 140.18763267,   1.07958679
09/09/1999, 00:00:00.00,     200.0000,   1.45862067,   0.56208829,   58.37262923, 248.80674584, 327.51019579, 143.27388736,   1.10708476
09/19/1999, 00:00:00.00,     210.0000,   1.45862386,   0.56208556,   58.37216189, 248.80718006, 327.50983168, 146.16927971,   1.14974859
09/29/1999, 00:00:00.00,     220.0000,   1.45862662,   0.56208301,   58.37168102, 248.80759711, 327.50941579, 148.90248553,   1.20771470
10/09/1999, 00:00:00.00,     230.0000,   1.45862886,   0.56208079,   58.37119061, 248.80799188, 327.50894889, 151.49713292,   1.28015834
10/19/1999, 00:00:00.00,     240.0000,   1.45863055,   0.56207900,   58.37069269, 248.80836666, 327.50843036, 153.97293073,   1.36561717
```