Getting Started Processing Ephemeris Data as Measurements

1 Introduction

ODTK has the capability to process ephemeris position and velocity components as observations. This capability is supported by both ODTK Least Squares and the ODTK Filter/Smoother. A measurement provider plugin is available to read in standard STK ephemeris (*.e) files. You can use ephemeris files using both Earth and non-Earth (Moon, Sun) central bodies. You can use covariance data, if available, to weight the measurements.

2 Processing ephemeris data as measurements

The following are the factors to consider when deciding whether or not to process ephemeris data as measurements.

1. You must add the ephemeris file to be processed as a measurement file to the Scenario.Measurements.Files list. The STK *.e file does not include a tracking or satellite number identifier. To get around this, you must name the *.e file in the form *TrkID(nnnn)*.e, where nnnn corresponds to the ODTK.Scenario1.Satellite.MeasurementProcessing.TrackingID. TrkID(nnnn) may be a subdirectory name, as in *\TrkID(nnnn)*.e, or just part of the filename. The letters "TrkID" are not case sensitive.

2. Ephemeris files using both Earth and non-Earth (Moon, Sun) central bodies are acceptable. However the central body must match the associated Satellite central body. If they do not match, ODTK will bypass the observations.

3. The measurement types associated with ephemeris processing are "Eph Pos" for position components and "Eph Vel" for velocity components. Position components share the same measurement statistical parameters, and the velocity share the same measurement statistical parameters. ODTK can process position and velocity components together, but you may select one without selecting the other. To process these measurement types, you must include them in the ODTK.Scenario1.Satellite.MeasurementProcessing.MeasTypes list as well as ODTK.Scenario1.Satellite.MeasurementStatistics list. You must also include them in the Filter or LeastSquares MeasTypes list.

4. You can also use the ephemeris file covariance data to weight the ephemeris component measurements. To use the covariance data, you must set the Scenario.Measurements.EmbeddedWNSigmas.Use flag to true.

5. You could write a custom Tracking Data Provider to read in non-STK ephemeris files. Refer to the ODTK Help system for information on writing tracking data providers. You must supply the following CAgODGenericObs properties:

   a. Time (in the form of Date string or {JulianDay, MinAfterMidnight})

   b. TrackingIDs (satellite tracking number must be first entry in list)

   c. MeasureType

   d. Value

   e. WNSigma (optional)

   f. CartesianComponent

   g. CartesianCoordSys

   h. EphCentralBody

3   Orbit determination example

Basic knowledge of ODTK and of how to navigate its GUI menus are both assumed for this exercise. For basic ODTK examples, refer to Orbit Determination Process in the Help Training folder..

3.1   Null case A using Earth as central body; the filter produces zero residuals

1. Start ODTK.

2. Create a new scenario, satellite object, and filter object.

3. Rename the satellite "SatTrkID1000".

4. Double-click the satellite to display its properties and in the OrbitState section change CoordFrame to "Fixed". Leave the default CentralBody setting, which is "Earth".

5. Scroll down to the EphemerisGeneration section and change CoordFrame to "Fixed" and CreateFile to "True".

6. Change the STKFileName to "SatTrkID(1000)_EarthFixed_1.e". The parentheses in the filename are required so ODTK can use the file later as an input measurement file. This is a convention that ODTK uses to identify the "tracking ID" of the object that the ephemeris file contains measurements for. See the Ephemeris table entry in the Help documentation on <u>measurement file formats</u>.

7. Generate the ephemeris file by selecting the satellite object and clicking the "Run" button.

8. Repeat step 4 but change the OrbitState.CoordFrame to "ICRF".

9. Repeat step 5 but change EphemerisGeneration.CoordFrame to "ICRF".

10. Repeat step 6 but change STKFileName to "SatTrkID(1000)_ICRF_1.e".

11. Repeat step 7 to generate the ICRF ephemeris file.

12. Add a TrackingInstrument to the Satellite object and rename it to be "T1". Bring up T1's properties page and change its trackingID to be the same as SatTrkID1000's tracking ID. Click to edit the MeasurementStatistics in the TrackingInstrument properties window. Click Remove All to remove all default selections and add "Eph Pos" and "Eph Vel".

13. Bring up the Scenario properties. In the Measurements.Files, click to edit. Click Add and select the file name "SatTrkID(1000)_EarthFixed_1.e", which you generated in step 6 above.

14. Open the Filter properties. Go to Filter.MeasTypes. Then click "Remove All", click "Add", and add "Eph Pos" and "Eph Vel".

15. Run the filter; this should produce an output file Scenario1.filrun.

16. Click View and select Static Product Builder. Click the Inputs tab and click the Add button. Under Objects, click to edit and select Filter1; this automatically adds Scenario1.filrun as the input file. Then in the Outputs tab, select and generate the report style "Residuals with Bias By Satellite"; you should get all zeroes for residuals, as shown below. The measurement types are Eph Pos X CBF, Eph Pos Y CBF, Eph Pos Z CBF, Eph Vel X CBF, Eph Vel Y CBF, and Eph Vel Z CBF. In this case, CB (central body) is Earth.

```
Residuals with Bias

Grouping by ['Satellite Name']


-----------------------------------------------------------------------------------------

Satellite Name: SatTrkID1000

              Date Time [UTCG]      Tracker Name Measurement Type      Pre Fit Residual Residual Units        Residual Sigma         Residual Ratio Edit Flag
       01 Jul 2020 12:00:00.000000  SatTrkID1000.T1   Eph Pos X CBF           0.000000            m             88.118574              0.000000        A
       01 Jul 2020 12:00:00.000000  SatTrkID1000.T1   Eph Pos Y CBF           0.000000            m             51.478445              0.000000        A
       01 Jul 2020 12:00:00.000000  SatTrkID1000.T1   Eph Pos Z CBF          -0.000000            m             25.260357             -0.000000        A
       01 Jul 2020 12:00:00.000000  SatTrkID1000.T1   Eph Vel X CBF           0.000000         m/sec             0.038635              0.000000        A
       01 Jul 2020 12:00:00.000000  SatTrkID1000.T1   Eph Vel Y CBF           0.000000         m/sec             0.059485              0.000000        A
       01 Jul 2020 12:00:00.000000  SatTrkID1000.T1   Eph Vel Z CBF           0.000000         m/sec             0.024409              0.000000        A
       01 Jul 2020 12:01:00.000000  SatTrkID1000.T1   Eph Pos X CBF           0.000000            m             13.950991              0.000000        A
       01 Jul 2020 12:01:00.000000  SatTrkID1000.T1   Eph Pos Y CBF          -0.000000            m             14.046560             -0.000000        A
       01 Jul 2020 12:01:00.000000  SatTrkID1000.T1   Eph Pos Z CBF          -0.000000            m             13.560837             -0.000000        A
       01 Jul 2020 12:01:00.000000  SatTrkID1000.T1   Eph Vel X CBF          -0.000000         m/sec             0.013848             -0.000000        A
       01 Jul 2020 12:01:00.000000  SatTrkID1000.T1   Eph Vel Y CBF          -0.000000         m/sec             0.014152             -0.000000        A
       01 Jul 2020 12:01:00.000000  SatTrkID1000.T1   Eph Vel Z CBF           0.000000         m/sec             0.013594              0.000000        A
       01 Jul 2020 12:02:00.000000  SatTrkID1000.T1   Eph Pos X CBF          -0.000000            m             12.182489             -0.000000        A
       01 Jul 2020 12:02:00.000000  SatTrkID1000.T1   Eph Pos Y CBF           0.000000            m             12.248143              0.000000        A
       01 Jul 2020 12:02:00.000000  SatTrkID1000.T1   Eph Pos Z CBF          -0.000000            m             12.061101             -0.000000        A
       01 Jul 2020 12:02:00.000000  SatTrkID1000.T1   Eph Vel X CBF           0.000000         m/sec             0.012184              0.000000        A
       01 Jul 2020 12:02:00.000000  SatTrkID1000.T1   Eph Vel Y CBF          -0.000000         m/sec             0.012405             -0.000000        A
       01 Jul 2020 12:02:00.000000  SatTrkID1000.T1   Eph Vel Z CBF           0.000000         m/sec             0.012150              0.000000        A
       01 Jul 2020 12:03:00.000000  SatTrkID1000.T1   Eph Pos X CBF          -0.000000            m             11.510067             -0.000000        A
       01 Jul 2020 12:03:00.000000  SatTrkID1000.T1   Eph Pos Y CBF           0.000000            m             11.569451              0.000000        A
       01 Jul 2020 12:03:00.000000  SatTrkID1000.T1   Eph Pos Z CBF          -0.000000            m             11.451494             -0.000000        A
```

17. Repeat step 13 and choose SatTrkID(1000)_ICRF_1.e for Measurements.Files.

18. Rerun the filter and generate another "Residuals with Bias By Satellite" report. It should look similar to the following table. The measurements are now Eph Pos X/Y/Z CBI (Central Body Inertial) and Eph Vel X/Y/Z CBI. Also, the residuals are zeroe,s as in the previous report.

```
Residuals with Bias

Grouping by ['Satellite Name']


-----------------------------------------------------------------------------------------

Satellite Name: SatTrkID1000

              Date Time [UTCG]      Tracker Name Measurement Type      Pre Fit Residual Residual Units        Residual Sigma         Residual Ratio Edit Flag
       01 Jul 2020 12:00:00.000000  SatTrkID1000.T1   Eph Pos X CBI           0.000000            m             50.990195              0.000000        A
       01 Jul 2020 12:00:00.000000  SatTrkID1000.T1   Eph Pos Y CBI           0.000000            m             88.962168              0.000000        A
       01 Jul 2020 12:00:00.000000  SatTrkID1000.T1   Eph Pos Z CBI           0.000000            m             25.260406              0.000000        A
       01 Jul 2020 12:00:00.000000  SatTrkID1000.T1   Eph Vel X CBI           0.000000         m/sec             0.060828              0.000000        A
       01 Jul 2020 12:00:00.000000  SatTrkID1000.T1   Eph Vel Y CBI           0.000000         m/sec             0.037773              0.000000        A
       01 Jul 2020 12:00:00.000000  SatTrkID1000.T1   Eph Vel Z CBI           0.000000         m/sec             0.024408              0.000000        A
       01 Jul 2020 12:01:00.000000  SatTrkID1000.T1   Eph Pos X CBI           0.000000            m             14.051275              0.000000        A
       01 Jul 2020 12:01:00.000000  SatTrkID1000.T1   Eph Pos Y CBI           0.000000            m             13.948248              0.000000        A
       01 Jul 2020 12:01:00.000000  SatTrkID1000.T1   Eph Pos Z CBI           0.000000            m             13.560838              0.000000        A
       01 Jul 2020 12:01:00.000000  SatTrkID1000.T1   Eph Vel X CBI           0.000000         m/sec             0.014161              0.000000        A
       01 Jul 2020 12:01:00.000000  SatTrkID1000.T1   Eph Vel Y CBI           0.000000         m/sec             0.013839              0.000000        A
       01 Jul 2020 12:01:00.000000  SatTrkID1000.T1   Eph Vel Z CBI           0.000000         m/sec             0.013594              0.000000        A
       01 Jul 2020 12:02:00.000000  SatTrkID1000.T1   Eph Pos X CBI           0.000000            m             12.250084              0.000000        A
       01 Jul 2020 12:02:00.000000  SatTrkID1000.T1   Eph Pos Y CBI           0.000000            m             12.181076              0.000000        A
       01 Jul 2020 12:02:00.000000  SatTrkID1000.T1   Eph Pos Z CBI           0.000000            m             12.061096              0.000000        A
       01 Jul 2020 12:02:00.000000  SatTrkID1000.T1   Eph Vel X CBI           0.000000         m/sec             0.012406              0.000000        A
       01 Jul 2020 12:02:00.000000  SatTrkID1000.T1   Eph Vel Y CBI           0.000000         m/sec             0.012183              0.000000        A
       01 Jul 2020 12:02:00.000000  SatTrkID1000.T1   Eph Vel Z CBI           0.000000         m/sec             0.012150              0.000000        A
       01 Jul 2020 12:03:00.000000  SatTrkID1000.T1   Eph Pos X CBI           0.000000            m             11.570192              0.000000        A
       01 Jul 2020 12:03:00.000000  SatTrkID1000.T1   Eph Pos Y CBI           0.000000            m             11.509503              0.000000        A
       01 Jul 2020 12:03:00.000000  SatTrkID1000.T1   Eph Pos Z CBI           0.000000            m             11.451485              0.000000        A
```

3.2 Null case B using the Moon as central body; the filter produces zero residuals

Repeat all the steps in section 3.1. However, add the following after step 3:

3.a Click the Help menu tab and select ODTK LaunchPad -> Installed Utilities ->
ChangeCentralBodyTool.htm.

3.b In the list of satellites, set Desired Central Body to "Moon".

3.c Click "Execute".

3.d Open the satellite properties and change OrbitState.CoordFrame to "Fixed". The
satellite OrbitState properties should look similar to the following:

Continue with the remaining steps. Change ephemeris file name to reflect Moon as the new
central body such as SatTrkID(1000)_MoonFixed_1.e (step 6) or SatTrkID(1000)_MoonICRF_1.e
(step 10). After running the filter, you should be able to generate the following "Residuals with
Bias By Satellite" reports:

```
Residuals with Bias

Grouping by ['Satellite Name']


--------------------------------------------------------------------------------

Satellite Name: SatTrkID1000

            Date Time [UTCG]     Tracker Name Measurement Type    Pre Fit Residual Residual Units      Residual Sigma    Residual Ratio
   01 Jul 2020 12:00:00.000000   SatTrkID1000.T1    Eph Pos X CBF         0.000000              m           50.883657         0.000000
   01 Jul 2020 12:00:00.000000   SatTrkID1000.T1    Eph Pos Y CBF         0.000000              m           98.540199         0.000000
   01 Jul 2020 12:00:00.000000   SatTrkID1000.T1    Eph Pos Z CBF        -0.000000              m           22.852863        -0.000000
   01 Jul 2020 12:00:00.000000   SatTrkID1000.T1    Eph Vel X CBF         0.000000          m/sec            0.060682         0.000000
   01 Jul 2020 12:00:00.000000   SatTrkID1000.T1    Eph Vel Y CBF         0.000000          m/sec            0.040643         0.000000
   01 Jul 2020 12:00:00.000000   SatTrkID1000.T1    Eph Vel Z CBF        -0.000000          m/sec            0.022739        -0.000000
   01 Jul 2020 12:01:00.000000   SatTrkID1000.T1    Eph Pos X CBF        -0.000000              m           14.020165        -0.000000
   01 Jul 2020 12:01:00.000000   SatTrkID1000.T1    Eph Pos Y CBF         0.000000              m           14.103319         0.000000
   01 Jul 2020 12:01:00.000000   SatTrkID1000.T1    Eph Pos Z CBF         0.000000              m           13.441606         0.000000
   01 Jul 2020 12:01:00.000000   SatTrkID1000.T1    Eph Vel X CBF         0.000000          m/sec            0.014064         0.000000
   01 Jul 2020 12:01:00.000000   SatTrkID1000.T1    Eph Vel Y CBF        -0.000000          m/sec            0.013936        -0.000000
   01 Jul 2020 12:01:00.000000   SatTrkID1000.T1    Eph Vel Z CBF        -0.000000          m/sec            0.013444        -0.000000
   01 Jul 2020 12:02:00.000000   SatTrkID1000.T1    Eph Pos X CBF         0.000000              m           12.223720         0.000000
   01 Jul 2020 12:02:00.000000   SatTrkID1000.T1    Eph Pos Y CBF        -0.000000              m           12.247356        -0.000000
   01 Jul 2020 12:02:00.000000   SatTrkID1000.T1    Eph Pos Z CBF         0.000000              m           12.021861         0.000000
   01 Jul 2020 12:02:00.000000   SatTrkID1000.T1    Eph Vel X CBF         0.000000          m/sec            0.012264         0.000000
   01 Jul 2020 12:02:00.000000   SatTrkID1000.T1    Eph Vel Y CBF        -0.000000          m/sec            0.012222        -0.000000
   01 Jul 2020 12:02:00.000000   SatTrkID1000.T1    Eph Vel Z CBF        -0.000000          m/sec            0.012033        -0.000000
```

Similarly, the Moon ICRF residuals should look like:

```
Residuals with Bias

Grouping by ['Satellite Name']


--------------------------------------------------------------------------------

Satellite Name: SatTrkID1000

            Date Time [UTCG]     Tracker Name Measurement Type    Pre Fit Residual Residual Units      Residual Sigma    Residual Ratio
   01 Jul 2020 12:00:00.000000   SatTrkID1000.T1    Eph Pos X CBI         0.000000              m           84.466415         0.000000
   01 Jul 2020 12:00:00.000000   SatTrkID1000.T1    Eph Pos Y CBI        -0.000000              m           59.475484        -0.000000
   01 Jul 2020 12:00:00.000000   SatTrkID1000.T1    Eph Pos Z CBI         0.000000              m           22.809214         0.000000
   01 Jul 2020 12:00:00.000000   SatTrkID1000.T1    Eph Vel X CBI         0.000000          m/sec            0.048386         0.000000
   01 Jul 2020 12:00:00.000000   SatTrkID1000.T1    Eph Vel Y CBI         0.000000          m/sec            0.051032         0.000000
   01 Jul 2020 12:00:00.000000   SatTrkID1000.T1    Eph Vel Z CBI         0.000000          m/sec            0.022712         0.000000
   01 Jul 2020 12:01:00.000000   SatTrkID1000.T1    Eph Pos X CBI         0.000000              m           14.090547         0.000000
   01 Jul 2020 12:01:00.000000   SatTrkID1000.T1    Eph Pos Y CBI         0.000000              m           14.035462         0.000000
   01 Jul 2020 12:01:00.000000   SatTrkID1000.T1    Eph Pos Z CBI         0.000000              m           13.439129         0.000000
   01 Jul 2020 12:01:00.000000   SatTrkID1000.T1    Eph Vel X CBI        -0.000000          m/sec            0.013991        -0.000000
   01 Jul 2020 12:01:00.000000   SatTrkID1000.T1    Eph Vel Y CBI        -0.000000          m/sec            0.014010        -0.000000
   01 Jul 2020 12:01:00.000000   SatTrkID1000.T1    Eph Vel Z CBI         0.000000          m/sec            0.013442         0.000000
   01 Jul 2020 12:02:00.000000   SatTrkID1000.T1    Eph Pos X CBI         0.000000              m           12.260446         0.000000
   01 Jul 2020 12:02:00.000000   SatTrkID1000.T1    Eph Pos Y CBI         0.000000              m           12.211510         0.000000
   01 Jul 2020 12:02:00.000000   SatTrkID1000.T1    Eph Pos Z CBI        -0.000000              m           12.021046        -0.000000
   01 Jul 2020 12:02:00.000000   SatTrkID1000.T1    Eph Vel X CBI        -0.000000          m/sec            0.012271        -0.000000
   01 Jul 2020 12:02:00.000000   SatTrkID1000.T1    Eph Vel Y CBI        -0.000000          m/sec            0.012216        -0.000000
   01 Jul 2020 12:02:00.000000   SatTrkID1000.T1    Eph Vel Z CBI         0.000000          m/sec            0.012033         0.000000
```

3.3 Deviated case using Earth as the central body; the filter retrieves the simulated Ballistic coefficient value

Repeat the steps in Null Case A of section 3.1. However, after step 6, insert the following steps:

6.a In the satellite properties, set ForceModel.Drag.BallisticCoeffCorrHalfLife = 1,008,000 minutes, which is 100 times its default value. This setting essentially makes the ballistic coefficient B a constant.

6.b In the scenario properties, set ODTK.Scenario1.Satellite.SatTrkID1000.ForceModel.Drag.EstimateDensity = false.

After step 14, insert this step:

14.a In the satellite properties, set ForceModel.Drag.Model.CD = 2.1. This setting essentially deviates C_D from the "truth" C_D = 2.2. After this change, the calculated ballistic coefficient in the satellite properties is 0.042. When you run the filter in step 15, it will estimate and recover the "truth" C_D of 0.044 that ODTK used when generating the ephemeris file. The ballistic Coefficient B is:

$$\beta = C_D \frac{A}{m}$$

where:

C_D = drag coefficient

A = area in m^2

m = mass in kg

If all goes well, the filter should accomplish this for you. In the Static Product Builder, change the Output Style to be the "Ballistic Coefficient" graph and generate the graph. It should look like the one below. The initial correction estimate is 0 because the filter has no knowledge of the true ballistic coefficient. As it processes more measurements, it converges to a correction of 0.0476 or 4.76%. This is a correction to the nominal Ballistic Coefficient value it started with of 0.042. We also see the sigma values converging, indicating the filter has good observability of this parameter.
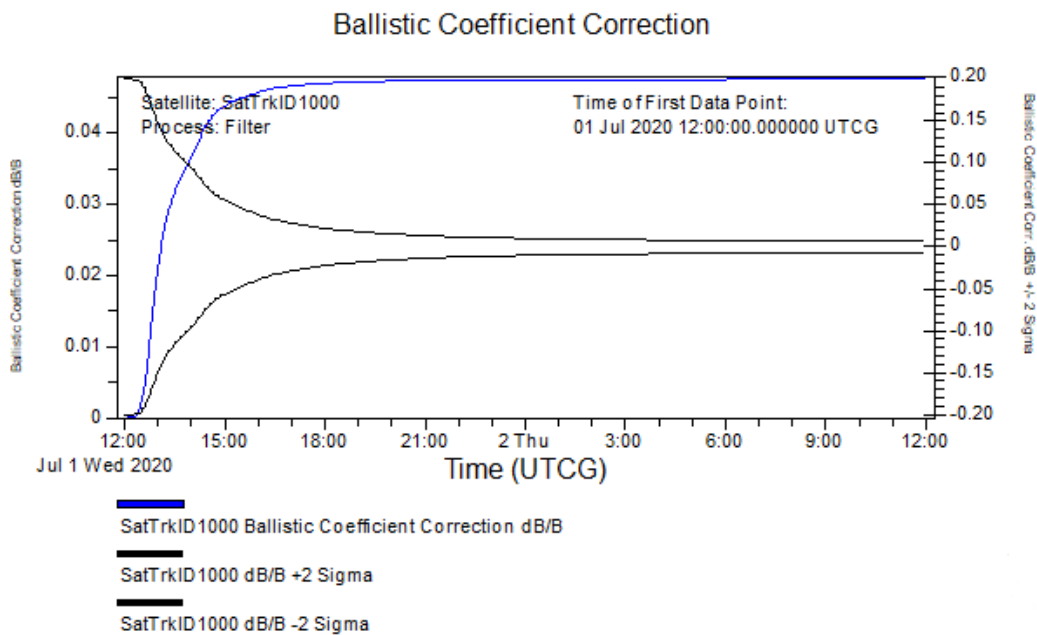
Now select the Output Style "Satellite Summary" report and run it. It should look like the one below. This indicates the satellite state at the end of the run. You can see that the filter has found the true B = 0.044 (see the highlighted value below).

```
Satellite summary at the end of a run



     Satellite: SatTrkID1000
          Date: 02 Jul 2020 12:00:00.000000 [UTCG]
          Mass: 1000.000 [kg]
  Central Body: Earth


          --------------------------------------------------------------------------

          Classical Elements ICRF [km, deg]

                                    Value               Sigma

              Semimajor Axis:     6676.5163906         0.7684669
                Eccentricity:        0.0005788         0.0000004
                 Inclination:       28.4837711         0.0000247
                        RAAN:      352.4761463         0.0000422
              Arg of Perigee:      284.7477971         0.0342773
       True Arg of Latitude:      348.6189779         0.0000411


          --------------------------------------------------------------------------

          Cartesian Elements

                    ICRF [km, km/s]         CBF [km, km/s]

              Pos X:     6335.6352718        -3148.7478849
              Pos Y:    -2004.5590842        -5853.1498378
              Pos Z:     -628.1657652         -615.7494468
              Vel X:        2.3877945            5.4196955
              Vel Y:        6.4013154           -3.3007222
              Vel Z:        3.6130232            3.6176470


          --------------------------------------------------------------------------

          Sigma-Correlation Matrix [m, m/s]

                         Radial    Intrack  Crosstrack     Radial    Intrack  Crosstrack
                           Pos        Pos        Pos         Vel        Vel        Vel

            Radial Pos    1.6170    -0.2915    -0.0010      0.6432    -0.9716    -0.0078
           Intrack Pos              2.0869    -0.0038     -0.3318     0.3040    -0.0023
        Crosstrack Pos                         2.1483      0.0096     0.0024     0.2792
            Radial Vel                                     0.0038    -0.5926    -0.0023
           Intrack Vel                                                0.0018     0.0076
        Crosstrack Vel                                                           0.0035


          --------------------------------------------------------------------------

          Force Model Estimates

                             Parameter    Total      Rel.      Sigma      Add.      Sigma
                                                     Corr.                Corr.

         Atmospheric Density (rho):                 0.00000   0.00000
         Ballistic Coefficient (B):     0.04400    0.04758   0.00343    0.00200   0.00014
           Coefficient of Drag (Cd):                                    0.09992   0.00720
  Solar Radiation Pressure (CrAM):      0.00000    0.00000   0.00000    0.00000   0.00000
     Coefficient of Reflection (Cr):    0.00000                         0.00000   0.00000
```

4 Extra credit

1. Add a Least-Squares object for SatTrkID1000 and run it for Eph Pos and Eph Vel measurements generated in section 3.3. Use this state for the initial state of the satellite when doing the filter run.

2. Run a deviate case using the Sun as the central body; you need to run ChangeCentral-BodyTool.htm first.