Achieving Astrodynamics Consistency with STK and ODTK

Updated for STK 12.5 / ODTK 7.5

The following information is meant to serve as guide to configuring STK and ODTK for computational consistency. It assumes you are using STK 12.5 and ODTK 7.5 (or later versions). The main areas of concern are: Earth centered coordinate transformations, and orbit propagation. A necessary first step is ensuring that the same data is used in both products.

1 Dynamic Earth Data

STK and ODTK rely on the following data files:

EOP-v1.1.txt	This file contains the historical daily values for polar motion and UT1-UTC corrections for the previous 5+ years. It also contains predicted values for the next year (measured from your last update). There is another version of this file, EOP-All-v1.1.txt, which contains measured data back to 1962.
SpaceWeather-v1.2.txt	This file contains the historical values for the F10.7, Ap, and Kp parameters for the last 5 years. It also contains predicted values for the next 90 days (measured from your last update). There is another version of this file, SpaceWeather-All-v.1.2.txt, which contains measured data back to 1957.

These files are located under the **C:\ProgramData\AGI\STK 12** directory for STK 12 and **C:\ProgramData\AGI\ODTK 7** directory for ODTK 7. Under each of these directories is a **DynamicEarthData** directory that contains these files.

The parameters in these files change over time so you must update the corresponding files in our products. You can update each set of files using the Data Update utility available from the **Utilities | Data Update** menu. Both of these utilities obtain the necessary updates from the AGI web site.

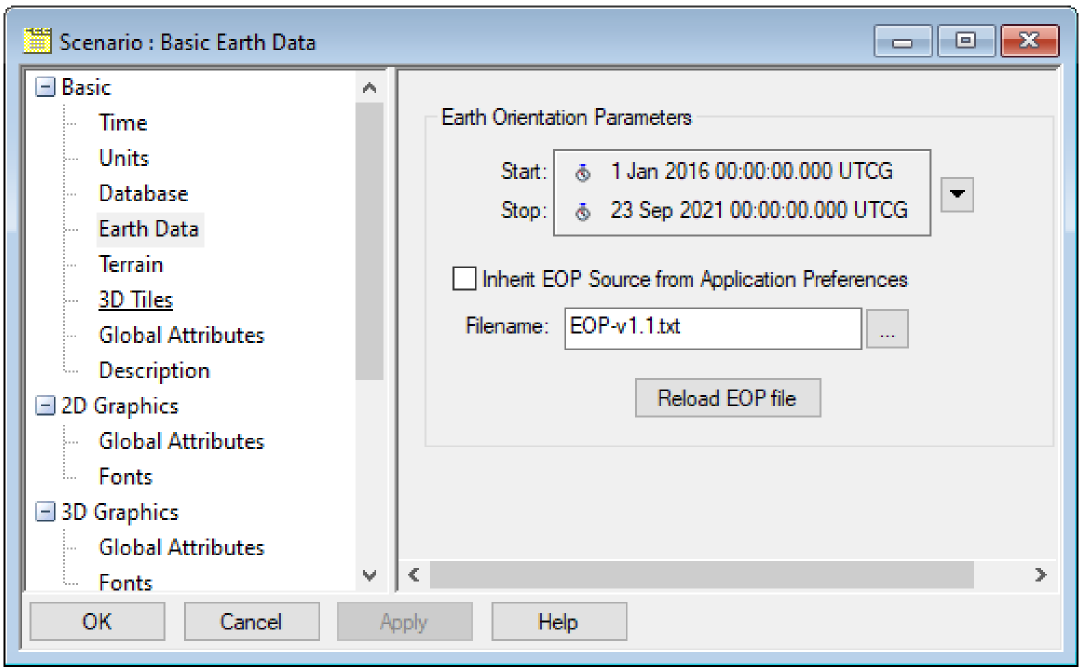
STK and ODTK each use their own set of these files. To achieve consistency between products, the files must be consistent. Alternatively, you may choose to keep one copy up to date and configure both products to use the one copy.

2 Leap Seconds

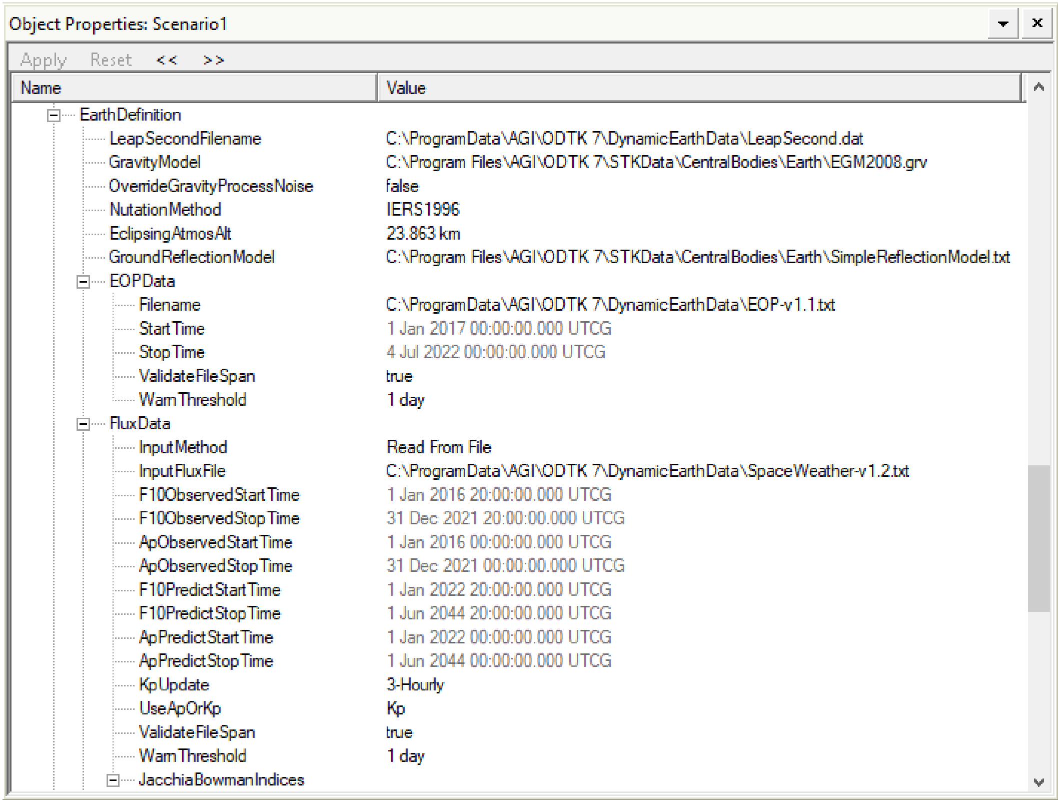
When a new leap second is announced, it must be added to the **LeapSecond.dat** file in the above **DynamicEarthData** directories. The process used to update the dynamic Earth data will also update this file, or it can be added by manually editing the file.

3 Coordinate Transformations

There are several settings for the Earth that must be the same in STK and ODTK in order for the Earth centered coordinate transformations to match. In STK, the specific EOP file to be used may be selected on the **Basic | Earth Data** tab of the scenario property page.



The EOP file in ODTK is specified via the object properties on the scenario, as shown:



Other settings of interest are found in the **Earth.cb** file for both STK and ODTK. The **Earth.cb** file is located in the **<*install dir*>/STKData/CentralBodies/Earth** directory and contains settings that define characteristics of the Earth for each application. It is important that all settings in this file be the same for STK and ODTK – the files as installed should be identical.

The **GravityModel** and **Gm** settings in the **Earth.cb** are overridden in ODTK by the scenario level setting for the Earth gravity field. In STK, these settings are used for analytical propagator definitions and transformations to/for orbital elements. These settings (in both the STK and ODTK **Earth.cb** files) should match the desired gravity field as specified in the scenario level setting in ODTK.

The **NutationUpdateInterval** setting specifies how often (in seconds) the Earth nutation matrix is updated. The default value of the **NutationUpdateInterval** for STK is **0 seconds**. Regardless of the value in the ODTK file, ODTK will read the value from the file but then override it with a value of zero. Therefore, you must verify that the STK value is zero as well.

In ODTK the **IAU1980NutationMethod** is overridden and set to the **IERS 1996** method. This specification indicates that the nutation is computed based on the IAU 1980 theory using the fundamental arguments from the 1996 IERS Conventions. The default value of **IAU1980NutationMethod** for STK is **JPLFile** meaning that nutation is computed based on interpolation of the current JPL DE file (DE430 at time of writing). Both scenarios can be configured to use either method.

To have both products use the **JPLFile** method, change the **NutationMethod** attribute in ODTK (see above screen shot) from **IERS1996** to **JPLFile**. The STK central body file in this case will not need to be modified.

To have both products use the **IERS1996** nutation method, change the **NutationMethod** attribute in ODTK to **IERS1996**, and modify the **Earth.cb** file for STK by uncommenting the line

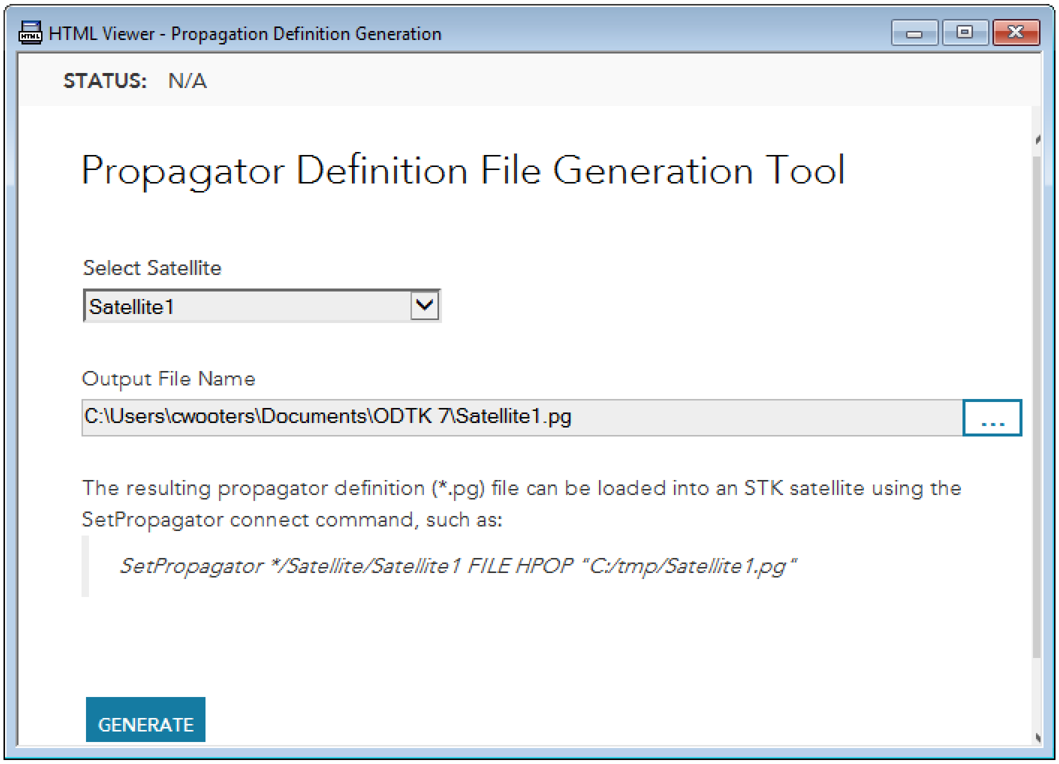
```
#     IAU1980NutationMethod    IERS1996
```

The relevant portion of the **Earth.cb** file is shown below. Proper settings in this block for consistency, assuming the use of the **JPLFile** Nutation Method in ODTK, are

```
# Default settings for ODTK
#      IAU1980NUTATIONMETHOD    IERS1996
#      NutationUpdateInterval   0.0
```

4 HPOP Orbit Propagation

STK and ODTK both use the HPOP propagator for numerical integration of orbit trajectories. In order to propagate trajectories consistently between the two tools, a number of settings must be matched. First, the coordinate system transformations mentioned above must match. Second, the settings for the HPOP integrator must match. The easiest way to achieve consistency in settings for the HPOP integrator is to transfer the settings from ODTK to STK using a propagator definition (.pg) file. This file is similar to the satellite (.sa) file in STK, but contains only the settings for the orbit propagator. There is a utility in the ODTK Launch Pad HTML page to assist with the generation of propagation definition files, **PropagatorDefnFile**. Go to the ODTK **Utilities** tab, expand the **Installed Utilities** folder, and open the **PropagatorDefnFile** Utilities page.



This utility will create a .pg file for you based on your inputs. The resulting propagator definition file may be loaded into an STK satellite using the connect command syntax indicated at the bottom of the html page. The file may also be loaded into an existing STK satellite using the **Load Prop Def File** tool on the Satellite object. The result is that all of your STK HPOP settings will be set correctly to match ODTK.

5 Astrogator Orbit Propagation

Sometimes you need to take a state vector from ODTK and propagate it using STK's Astrogator module (typically if you are using an auto sequence in Astrogator to calculate future maneuvers). This requires you to configure your Astrogator settings to achieve consistency with ODTK and HPOP. Astrogator is more flexible in its configuration options than ODTK, so it is convenient to change its settings rather than ODTK's. We have found it is easiest to configure an HPOP satellite first via the propagation definition file, verify its consistency with your ODTK results, then configure an STK satellite using Astrogator to match the STK HPOP satellite.

Unfortunately, there isn't an HTML tool to automate this for you so you must do so by hand. The process can be divided into two parts – force model configuration and integrator configuration. Both of these are done via STK's **Component Browser** (found under the **Utilities** menu). Under the **Propagator** tab, select the **Earth HPOP Default v10** propagator and duplicate it. This propagator provides a good starting point since it is already configured to match the default STK HPOP settings. Open it up to further configure the following:

5.1 Gravitational Force

Ensure the same gravity field file (*.grv) is selected as the one ODTK is configured for (see the ODTK scenario properties). Ensure the degree, order, and solid and ocean tide settings are consistent with ODTK.

Gravity field files may contain definitions for secular variations in some of the gravity field coefficients. ODTK does not have a setting to control the inclusion of time variation in the coefficients, in this case the use of time variations is enabled if the file contains such information. HPOP has a setting, available on the **Force Model - More Options** panel to enable/disable the use of secular variations in the coefficients. This setting should be configured to **true** to match ODTK. Astrogator has a similar setting, available on the **Propagator** definition panel. This setting should also be configured to **true** to match ODTK.

ODTK does not support the Astrogator option **Modify gravity model below this % of CB surface**, but this should not be an issue since this option is mainly useful during the targeting process in Astrogator.

5.1.1 Solid Tides

Astrogator exposes three solid tide options, while ODTK only exposes two. The solid tide option **None** in Astrogator is equivalent to **false** in ODTK. The solid tide option **Full tide** in Astrogator is equivalent to **true** in ODTK. ODTK does not currently support the Astrogator solid tide option **Permanent tide only**.

5.2 Atmospheric Drag

Determine what density model your ODTK satellite is configured to use. If your Astrogator propagator is using the same one then you can continue, otherwise you will need to remove the default **Jacchia-Roberts** model and insert another drag model into the force model list. Make sure **Use Approximate Altitude** is disabled and ensure you are using the same (or equivalent) input files. Make sure the **Sun Position Type** setting matches your ODTK satellite's **SunPosMethod**. If using a plugin atmospheric density or drag model, make sure the same version of the plugin is being used in both tools.

5.3 Solar Radiation Pressure

Determine what solar radiation pressure model your ODTK satellite is configured to use. If your Astrogator propagator is using the same one then you can continue, otherwise you will need to remove the default **Spherical** model and insert another SRP model into the force model list. Make sure **Use Luminosity** is selected and the value set to **3.828E26** (this is the correct value for a mean solar flux of 1361 W/m^2. Earlier versions of ODTK used 3.839E26 and 3.823e+026 (a mean solar flux of 1365.08 and 1359.388 W/m^2, respectively). You can override this for ODTK and HPOP by editing your **Sun.cb** file in **C:\Program Files\AGI\ODTK 6\STKData\CentralBodies\Sun**. Locate the section that looks like the one below and add the luminosity line (the value below corresponds to a newer number that has come out that corresponds to a mean flux of 1361 W/m^2).

```
BEGIN Sun
	Luminosity 3.828E26
END Sun
```

As of ODTK 7.1 and STK 12.0, both use a default luminosity of 3.828E26.

Make sure the **Sun Position Type** setting matches your ODTK satellite's settings as well. If using a plugin light reflection model, make sure the same version of the plugin is being used in both tools.

5.3.1 Eclipse Shadow Model

ODTK only uses a dual-cone shadow model. STK should be configured to use the same by setting the **Shadow Model** to **Dual-Cone**. The STK choice to use a cylindrical shadow model exists only for backwards compatibility with legacy tools that didn't support a dual-cone model.

Both ODTK and STK provide the option to use eclipse boundary mitigation during the numerical integration process. The mitigation algorithm seeks to minimize the effect of crossing changes in the lighting condition on the numerical integration process. Make sure that the same setting is used in both tools. The STK setting is found under the SRP model settings as a checkbox titled **Include Boundary Mitigation**. The ODTK setting is found under the satellite SRP settings as **BoundaryMitigation**.

Both Astrogator and ODTK allow for specification of an extension of the size of the size of a planetary body for use in eclipse determination to account for the effects of atmosphere. Make sure that the ODTK scenario level setting **EarthDefinition.EclipsingAtmosAlt** matches the Astrogator solar pressure setting **Atmospheric Altitude for Eclipse**.

5.4 Third Body Forces

Determine what third body forces your ODTK satellite is configured to use. If you aren't using the sun and moon, remove the unnecessary one(s) from your Astrogator propagator. The ephemeris source for third bodies in Astrogator should be set to use **DE File** when possible. If the source of the gravitational parameter is set to **Cb File** in ODTK, make sure your gravitational parameter source is set to **Cb File - System** in Astrogator if that option is available and **Cb File** if it is not. The system option is available for planetary objects with moons of significant mass and is compatible with the use of ephemeris for the planet barycenter.

5.5 Finite Maneuvers

Astrogator has a larger selection of options for the specification of finite maneuvers than ODTK. If your maneuvers do not fit into one of the ODTK provided types, you will need to generate an acceleration history file from STK that describes the finite maneuver executed in Astrogator and use the Acceleration History maneuver type in ODTK. Since the acceleration history is a time ordered table of how the maneuver imparts acceleration on the spacecraft, the table must be interpolated during the numerical integration process. The data in the acceleration table must, therefore, be provided in a manner that supports accurate interpolation. Accurate interpolation mainly depends on the sampling rate of the acceleration profile and the specified interpolation order. The sample rate is driven by the step size of the propagator used during the maneuver in Astrogator. Small step sizes, on the order of 1 second or less, are sometimes required for consistency in maneuver results. Use of 3^{rd} order interpolation, specified in the acceleration history file, is typically required to provide accurate interpolation.

It is helpful to control the integration step size during the maneuver. The use of fixed step size integration at small step sizes is helpful.

5.6 Plug-in Acceleration Models

Make sure that you are using the same version of plugin acceleration models between the two tools and that all settings of the plug-ins match exactly.

5.7 Numerical Integrator

Select the same numerical integrator in STK as your ODTK satellite is configured to use. Select the VOP option that is consistent with what is used in ODTK. Configure the step control method, step size, and relative error (if appropriate) to match your ODTK settings. The Fixed-Step settings are the easiest to use to achieve consistency.

6 Consistency Testing

The easiest way to test whether you have achieved consistency is to propagate a state vector forward in time using each tool and compare the ephemeris. The Astrogator steps are only necessary if you will be propagating an ODTK state vector in Astrogator. We typically test in the following manner:

1. Locate an STK external ephemeris file (*.e) containing ephemeris for the orbit you would like to test. We are only going to use the first ephemeris point in the file, so the rest of the contents don't matter. Using a file to obtain the initial state eliminates the potential for error by hand typing in numbers.
2. Perform the following in ODTK:

a. Open up the **InitialState** html page from the **ODTK Launch Pad | Utilities Tab | Installed Utilities**. Set your desired epoch and set your orbit source to use your initial state .e file. Then press **Go** to transfer the initial state from the .e file to your ODTK satellite.

b. Select your satellite in ODTK and press the **Run** button on the tool bar. This will propagator your satellite forward in time and generates a new .e file. This one will be used for comparison purposes.

c. Open up the **PropagatorDefnFile** html page from the **ODTK Launch Pad | Utilities Tab | Installed Utilities**. Select your satellite and generate the .pg file.

3. Perform the following in STK:

a. Create a satellite and call it ODTKtest. Set it's propagator to be **External** and select your .e file you created earlier in ODTK (make sure you have the right one, not the one you used to initialize the state from).

b. Create a satellite and call it HPOPtest. From the **Satellite** menu, select **Load Prop Def File**. Select the .pg file you just created earlier, press the **Load** button and then dismiss the panel. It is now configured to use HPOP as a propagator and all the settings are consistent with ODTK.

c. Select the ODTKtest satellite and generate a **RIC** graph. It will prompt you for the satellite to compare against - choose the HPOPtest satellite. Ensure the results are satisfactory to you. If not, then you have a configuration error somewhere.

d. Create a satellite and call it GatorTest. We are assuming you have done all the steps described earlier to create an ODTK compatible propagator in Astrogator. Open up the satellite's **Basic Properties** and in the **Propagate** segment select your newly configured propagator and set the stopping duration to your desired length of time. In the **Initial State** segment, select the **Initial State Tool** button and use the new panel to load in your initial state .e file. Use the same epoch time as in your HPOPtest satellite. Ok your way out and press the run button to propagate your Astrogator satellite.

e. Select the ODTKtest satellite and generate a **RIC** graph. It will prompt you for the satellite to compare against - choose the GatorTest satellite. Ensure the results are satisfactory to you. If not, then you have a configuration error somewhere, most likely in your Astrogator propagator configuration.

Comparing the RIC results from each graph allows you to determine if the results are satisfactory. You may still see differences between your Astrogator satellite and your HPOP or ODTK satellites. ODTK models the SRP coefficient, drag coefficient, and atmospheric density as Gauss-Markov processes, so in addition to the fixed value for each of these parameters there is also a time-varying component that is added on. When ODTK propagates forward in time, it is using this time-varying component (and decaying it over time). Exporting a propagator definition file from ODTK and importing it into an STK HPOP satellite preserves the time-varying component values, but they are not visible in the HPOP GUI. Propagating the HPOP satellite will result in the same ephemeris as ODTK. Astrogator does not currently support modeling the time-varying components; therefore the Astrogator satellite will not exactly match the same initial conditions as the other two satellites, resulting in ephemeris differences that will grow over time. If you are not importing a propagation definition file from ODTK then you will not have this problem since the default values for the time-varying component in HPOP are zero.

7 Interpolator Settings

If you are generating RIC reports (as opposed to graphs) and seeing jumps in differences which occur between the output ephemeris points, then you may be seeing issues due to two satellites having different interpolation methods.

For a satellite using external ephemeris in STK, the interpolation method is defined in the lines:

```
InterpolationMethod          Lagrange
InterpolationOrder           5
```

When comparing against a satellite propagated in STK using HPOP or Astrogator, it is suggested you change the interpolation method to **LagrangeVOP** and in HPOP under the **Integrator** settings set the interpolation method to **VOP** with **Order** of **5**.