# Trajectory Formats

Overview

In order to perform launch CA, 18 SPCS must receive correctly formatted launch trajectories from the launch entity for all objects that require screening. All launch trajectories should be listed on the Form 22 in accordance with “How to Name Trajectory Files.” Launch CA requires separate trajectory files per launch stage or RCS value. Multiple RCS values for one trajectory file cannot be accommodated and will result in 18 SPCS using the larger RCS value indicated on the Form 22. All trajectory files must be formatted in kilometers; any other unit will compromise the accuracy of the results.

Trajectories should be provided a minimum of 7 days in advance of mission day and at least 30 days in advance of mission day for launch entities who are receiving this service from 18 SPCS for the first time.

System

SuperCOMBO/CALIPER is the launch CA software used by 18 SPCS. It accepts three input file formats: CALIPER Trajectory, Free-Format Ephemeris, and CALIPER Trajectory Covariance V2.0. The CALIPER Trajectory and Free-Format variations are used to input only ephemeris data (position and velocity), whereas the CALIPER Trajectory Covariance V2.0 input file includes both ephemeris and position covariance. The CALIPER Trajectory Covariance V2.0 file format is required for users who request a probability of collision (Pc) metric in addition to a miss distance.

The following sections provide guidance on input file coordinate systems and characteristics that apply to all formats, followed by descriptions of each specific format.

Input Files - Coordinate Systems and Characteristics

SuperCOMBO/CALIPER accepts launch vehicle position and velocity in rotating Earth-Fixed Greenwich (EFG) coordinates. In this system, E is along the line of intersection of the true equator of date and the Greenwich meridian, G is through the true North Pole (normal to the true equatorial plane) and F completes the right-handed coordinate system. SuperCOMBO/CALIPER converts the EFG ephemeris to Earth-Centered Inertial coordinates of date, a frame referred to as “ECI” in the 18 SPCS community. In the conversion from EFG to ECI, SuperCOMBO/CALIPER incorporates UT1-UTC corrections through a timing constants file populated with values from the International Earth Rotation and Reference Systems Service (IERS) Bulletin A.

EFG differs from the crust-fixed Earth-Centered Rotating (ECR) frame in that EFG does not incorporate polar motion. Differences between the EFG and ECR frames are small, on the order of 15 meters or less. Note that EFG is used interchangeably with the NASA “TDR” coordinate system. ECR is terminology used within 18 SPCS; it is equivalent to the Earth-Centered Earth-Fixed (ECEF) and Earth-Centered Fixed (ECF) frames.

Position covariance is entered in a launch vehicle-centered frame, in either UVW or PTW coordinates. In the UVW frame, U (“radial”) is the unit vector in the radial direction, W (“cross-track”) is the unit vector normal to the launch vehicle’s inertial orbit plane, and V (“in-track”) is the unit vector which completes the right-handed coordinate system. (Despite the “in-track” descriptor, V is only coincident with the velocity when the launch trajectory is circular.)

In the PTW covariance frame, T is the unit vector along the launch vehicle’s velocity vector, W is again the unit vector normal to the launch vehicle’s inertial orbit plane, and P is the unit vector that completes the right-handed coordinate system. PTW is the most easily visualized covariance frame for elliptical launch vehicle trajectories because the T direction is aligned with the launch vehicle’s velocity.

The SuperCOMBO/CALIPER launch trajectory input file should have ephemeris/covariance points provided at sufficiently frequent time points that interpolation may be used with negligible error. For boosting launch trajectories, an ephemeris/covariance point spacing of 10 seconds is recommended – although less than 10 second spacing could be needed if the trajectory contains large maneuvers. For non-boosting, non-maneuvering phases of a launch trajectory profile, larger ephemeris/covariance point spacing can be used. Note that SuperCOMBO/CALIPER can accept launch trajectory files with variable ephemeris/covariance point spacing.

Because launch vehicle velocity is used for both interpolation and for identifying potential conjunctions, SuperCOMBO/CALIPER requires that the launch vehicle velocity be realistic such that the EFG velocity represents the derivative of the EFG position. Also, the position and velocity ephemeris points should be relatively smooth and continuous (e.g., real world delta-Vs for maneuvers are acceptable but large deviations particularly those that are discontinuous step functions are not).

For meaningful Pc calculations, the launching entity must provide realistic launch trajectory covariance. For responsible decision making based on Pc, the launching authority must be knowledgeable on the Pc metric and its use/limitations.

Caliper

In the CALIPER trajectory file, one or more launch times/trajectories can be represented in a single file. In the previous version of CALIPER, all launch times in a launch window had to be represented in a single file.

Now, a single trajectory can be input and either run as SuperCOMBO/CALIPER or it can override the launch time and input launch window start/stop/time steps. Since most launch profiles maintain the same earth-fixed trajectory throughout the launch window, this approach is desirable as it requires less processing time. However, if the earth-fixed trajectories do differ with each new launch time (e.g., launch azimuth varies for interplanetary launch opportunities), then all launch times/trajectories will have to be submitted within a single file.

Note that each trajectory file is not screened for its own window if it is grouped into a mission with one overarching launch window (The launch window that is submitted on the Form 22 is used as an override for all trajectory files submitted for that launch screening).

There are several reasons for this, but it comes to system processes and procedures and mission growth. As launch CA has grown and launch screenings have become more system intensive, the trajectory files for missions are screened in a daisy-chain process with their screenings set up to a launch window (that would override a window listed within the trajectory file itself).

This can become an issue with some of the deep space/interplanetary missions if the trajectory files are only viable during a certain limited time within the launch window (i.e. a trajectory file is only valid from 0450-0455 of a launch window/won’t be used after this time, but the file is six hours long and included within the overarching launch window on the Form 22).

Trajectory files must be grouped into a mission and Form 22 based on their respective launch window that they will belong under. A Form 22 could be submitted with all the associated trajectory files for the same launch window as one mission.

If there were a set of additional trajectory files that were only viable for another launch window, they must then be submitted on another Form 22.

Essentially a copy of the Form 22 should be created with just the specific trajectory files listed for that different launch window and all the respective data could remain the same. The additional Form 22s should add a designator of some sort to the mission name to differentiate between the different screenings (i.e. LAUNCH MISSION NAME-A, and the next followed by LAUNCH MISSION NAME-B)

In the example below, two launch times are represented.

LAUNCH TIME: 2019 1 1520 3.000 LAUNCH AZIMUTH: 0.000 DISPERSION FILE:

0.000 -3048.065 -1597.441 5352.179

0.000000 0.000000 0.000000

0.000000000 0.000000000 0.000000000

10.000 -3048.246 -1597.518 5352.450

-0.053000 -0.018000 0.067000

0.000000000 0.000000000 0.000000000

20.000 -3049.416 -1597.747 5353.492

-0.196000 -0.026000 0.141000

0.000000000 0.000000000 0.000000000

30.000 -3052.425 -1598.001 5355.278

-0.417000 -0.023000 0.217000

0.000000000 0.000000000 0.000000000

40.000 -3057.928 -1598.172 5357.776

-0.690000 -0.009000 0.280000

0.000000000 0.000000000 0.000000000

LAUNCH TIME: 2019 1 1521 3.000 LAUNCH AZIMUTH: 0.000 DISPERSION FILE:

0.000 -3048.065 -1597.441 5352.179

0.000000 0.000000 0.000000

0.000000000 0.000000000 0.000000000

10.000 -3048.246 -1597.518 5352.450

-0.053000 -0.018000 0.067000

0.000000000 0.000000000 0.000000000

20.000 -3049.416 -1597.747 5353.492

-0.196000 -0.026000 0.141000

0.000000000 0.000000000 0.000000000

30.000 -3052.425 -1598.001 5355.278

-0.417000 -0.023000 0.217000

0.000000000 0.000000000 0.000000000

40.000 -3057.928 -1598.172 5357.776

-0.690000 -0.009000 0.280000

0.000000000 0.000000000 0.000000000

A line with the launch time separates each EFG trajectory. Launch azimuth and the dispersion file are not used. The first line of each ephemeris point record contains time since launch in seconds followed by the XYZ components of EFG position in km. The second line contains the XYZ components of EFG velocity in km/s. The third line is a placeholder for acceleration of the asset, but acceleration is not currently used.

Any single CALIPER trajectory for a given launch time must contain a minimum of 5 points and a maximum of 25000 points. The maximum number of seconds since epoch is 999999.999 seconds, equivalent to 11.574 days.

Free-Format

The second format is a concise, space-delimited, free-format. An example is provided below.

3896.280 13660.571 2408.228 0.000 2.374 5.095 0.020

3900.000 13669.394 2427.179 0.000 2.369 5.093 0.020

3930.000 13739.930 2579.652 0.003 2.333 5.072 0.030

3960.000 13809.394 2731.493 0.006 2.298 5.051 0.030

3990.000 13877.810 2882.693 0.009 2.263 5.029 0.030

4020.000 13945.204 3033.248 0.012 2.230 5.008 0.040

4050.000 14011.600 3183.149 0.015 2.197 4.986 0.040

4080.000 14077.022 3332.393 0.018 2.165 4.964 0.040

4110.000 14141.495 3480.973 0.021 2.134 4.942 0.050

4140.000 14205.041 3628.885 0.024 2.103 4.919 0.050

4170.000 14267.683 3776.126 0.027 2.073 4.897 0.050

4200.000 14329.444 3922.691 0.030 2.044 4.874 0.050

This EFG file of positions and velocities is independent of launch time. Launch window start/stop/spans are entered within the SuperCOMBO/CALIPER program by 18 SPCS. Numbers are in standard double precision format (not scientific/exponential format).

The first column is time since launch in seconds. The next three columns are the XYZ components of EFG position in km. The last three columns are the XYZ components of EFG velocity in km/s.

CALIPER Trajectory Covariance V2.0

The elements of the CALIPER Trajectory Covariance V2.0 format are shown below:

CALIPER EPHEMERIS V2.0 COVARIANCE UVW (or PTW)

LAUNCH TIME: yyyy ddd hhmm ss.sss…

TimeSinceLaunchInSeconds X Y Z Vx Vy Vz

PosCov(1,1) PosCov(2,1) PosCov(2,2)

PosCov(3,1) PosCov(3,2) PosCov(3,3)

A sample CALIPER Trajectory Covariance V2.0 file is shown next:

CALIPER EPHEMERIS V2.0 COVARIANCE PTW

LAUNCH TIME: 2019 20 1105 35.986inidef

0.000 -15614.190 9512.504 27201.506 -0.031674 -0.511889 -2.511603

0.033489 -0.042779 0.112008

-0.000589 0.000675 0.005907

258.619 -15621.660 9378.301 26541.559 -0.025764 -0.526209 -2.592410

0.033953 -0.045187 0.121013

-0.000573 0.000669 0.006007

510.329 -15627.212 9243.933 25878.882 -0.018003 -0.541701 -2.673392

0.034352 -0.047596 0.130522

-0.000543 0.000660 0.006000

A CALIPER Trajectory Covariance V2.0 file begins with 2 header lines.

Header line 1:

1 2 3 4 5 6 7 8

12345678901234567890123456789012345678901234567890123456789012345678901234567890

“CALIPER EPHEMERIS V2.0 COVARIANCE ccc”

ccc = covariance coordinate system in a launch vehicle-centered frame, specified as either “PTW” or “UVW”.

* In PTW, T is along the velocity vector of the launch trajectory with W out-of plane and P completing the triad.
* In UVW, U is radial with W out-of-plane and V completing the triad.

Header line 2:

1 2 3 4 5 6 7 8

12345678901234567890123456789012345678901234567890123456789012345678901234567890

“LAUNCH TIME: yyyy ddd hhmm ss.sss…”

Launch time formats are self-explanatory. Note that the decimal seconds are actually double precision free-format and thus can contain more than 3 decimals.

Data Record Lines:

Although the ephemeris and covariance data records appear column specific and formatted, they are actually flexible, free-format. Numbers are space delimited and are entered as standard double precision notation (not scientific/exponential notation). The column alignment in the example was added only to aid readability. A data record consists of 3 lines.

The first line consists of both the timestamp and ephemeris data in EFG coordinates. EFG is an Earth-fixed rotating coordinate system related to the true equator/mean equinox of date Earth-Centered Inertial system by a simple rotation about the Z axis (normal to the true equator of date). The second and third lines contain the 6 elements of the lower triangular of the position covariance matrix. Again, despite the appearance of a strict format in the example above, all numbers are free-format double precision, space delimited values, in standard notation (not scientific/exponential notation).

Data record 1:

TimeSinceLaunchInSeconds = time since launch, in seconds

X = X-component of EFG position in km

Y = Y-component of EFG position in km

Z = Z-component of EFG position in km

Vx = X-component of EFG velocity in km/s

Vy = Y-component of EFG velocity in km/s

Vz = Z-component of EFG velocity in km/s

Data Record 2:

The second data record contains 3 of 6 elements of the lower triangular of the position covariance matrix.

PosCov(1,1) = position covariance element in km2

PosCov(2,1) = position covariance element in km2

PosCov(2,2) = position covariance element in km2

Data Record 3:

The third data record contains 3 of 6 elements of the lower triangular of the position covariance matrix.

PosCov(3,1) = position covariance element in km2

PosCov(3,2) = position covariance element in km2

PosCov(3,3) = position covariance element in km2

The CALIPER Trajectory Covariance Format V2.0 can be used to generate Pc and miss distance results, or only miss distance via stand-off radius mode. In this case, SuperCOMBO/CALIPER would use only the ephemeris data. This file could also be used to generate elliptical screening. In this case, SuperCOMBO/CALIPER would again ignore covariance data, using only the ephemeris data in the file.