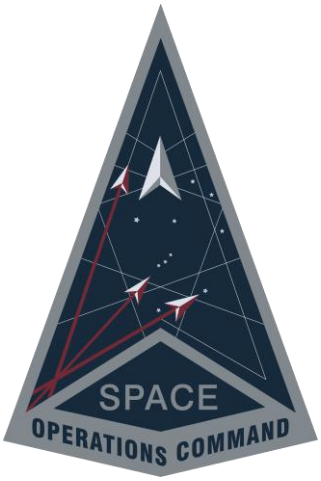
HQ Space Operations Command (SpOC)
DCG-T/S9I
Astrodynamics Standards Engineering Group

Astrodynamics Standards



Release Notes

Version 8.3

April 2022

1. Background

Version 8.3 (v8.3) is a minor release of the U.S. Space Force, Space Operations Command, Astrodynamics Standards software library. The Astro Standards are delivered as a collection of Dynamic Link Libraries (DLLs) for Windows and Shared Objects (SOs) for Linux. The libraries can be run on either 32- or 64-bit platforms, and version releases include wrappers and drivers to support a variety of customer/user preferred languages. Within this document, the term Library is used to refer to either a Windows DLL or a Linux SO. The Library algorithms are designed to be compatible with systems and astrodynamics algorithms implemented into space operations and used by Warfighters and Analysts, including those of the Combined Space Operations Center (CSpOC) Battle Space Awareness (BSA) mission. The Astro Standards are also used to Verify and Validate (V&V) equivalent algorithms of these operational space-domain systems such as those that run at the 18th Space Defense Squadron (18th SDS) at Vandenberg AFB, and other operational locations critical to the National defense.

2. What's New

The most notable change in v8.3 is the introduction of the WinWin Tool. It is a GUI wrapper written in C# that allows users to easily use many of the more popular features of Astro Standards without needing an in-depth understanding of shared libraries. Since it is written in C#, it has only been tested on Windows. WinWin will need to be specifically requested as it is in its own package.

There are also more driver examples for each package, many of which are in Java. Also notable is that there are only three main packages: Sgp4Prop, Astro Standards, and WinWin. Users requesting any of the traditional packages will receive the Astro Standards package which has everything except WinWin.

Octave, Go, and Rust are now fully supported, and all APIs are available. TCL/TK has most of the APIs but is not being automatically generated, so there are some missing. It should be fully supported in a future release, but for now users will need to generate the APIs they need. These languages were all tested on Linux. Some tweaking may be needed for Windows. Some Java/JNI had issues due to a missing .dll on the Windows side. It is now included in the distribution.

For the SGP4/SGP4-XP Propagator:

1. The fastest way to obtain SGP4/SGP4-XP is by creating an account on https://www.space-track.org, and downloading it directly from there. No approval is required, but permissions will need to be granted by the administrators of space-track.org.
2. SGP4 is one unique Astro Standards library in the suite of Astro Standards libraries available in that it is U.S. Space Force, Space Operations Command-approved to "share with the world."

Other Applications within the Astro Standards Library (including SGP4/SGP4-XP):

1. For the balance of the Astro Standard Applications, use https://halfway.peterson.af.mil/SARP. The requestor must have a U.S. Government-issued CAC card and be logged into *NIPRnet*. This website cannot be accessed from the Internet.
2. Once logged-in to https://halfway.peterson.af.mil/SARP obtain additional details by referring to the document, "***Instructions for Requesting Astrodynamics Standards Software.pdf,"*** available upon logging into the SARP website.

Figure 1. Astodynamic Standards Distribution

3. Tally of Bug Fixes / Improvements for Releases 8.2 and 8.1

Item	Current Release 8.3	Previous Release 8.2.1
Bug Fixes	*19*	*35*
New Features /Improvements	*62*	*79*
Target / Final Release Date	*Apr 27, 2022*	*Dec 17, 2021*

4. Astro Standards Bug Fixes and Enhancements, By Library

The following subsections are listed alphabetically by each of the 24 Astro Standards libraries for quick reference. See the AstroJiras_v8.3.html file for full list of changes.

4.1 AOF - Area Overflight

AOF computes when overhead satellites have potential visibility to a geographic location or area on the surface of the Earth. Visibility is defined as a nominal Field of View (FOV), defined by a user-specified half-angle around the satellite's sub-point intersecting the defined points or areas on the surface.

NO CHANGES

4.2 AstroFunc - Astrodynamics Functions

This library includes various Astrodynamics functions for orbital element conversions; coordinate transformations and reference-frame transformations.

NO CHANGES

4.3 BAM – Breakup Analysis Module

The Breakup Analysis Module library uses the last good element set of the parent object along with user-selected best-quality element sets of a few of the breakup pieces. The post-breakup piece element sets are propagated backward in time, and the pre-breakup parent element set is propagated forward in time, to identify the "pinch-point" where the piece and parent element sets converge positionally in time. This convergence point corresponds to the time the breakup of the parent most likely occurred.

NO CHANGES

4.4 BatchDC - Batch Differential Correction (DC) Orbit Determination

BatchDC Performs a least-squares batch differential correction of orbital elements using empirical tracking data (sensor observations). It updates either SGP4 Keplerian elements (18th SPCS TLE) or SP state vectors (from an 18th SPCS VCM) using the appropriate propagator theory.

CHANGES:

- Fix bug in BatchDcSolveSelObs DC object was getting cleared. Users were unable to create vectors or VCMs after a DC. (Jira 791)

NEW APIS:

- ***No New APIs***

4.5 Combo - Computation of Miss Between Orbits

Combo computes close approaches between satellite orbits based on user-specified screening volume, exclusion volume, and warning and alert thresholds expressed in either standoff radius or asset-centered UVW (radial, in-track, and cross-track) miss-distance criteria. Precomputed SGP4, SGP4-XP, or SP-based ephemerides are used in the evaluation. ***Note:*** SGP4 GP-based Combo results are appropriate for general understanding of the frequency of approaches between objects and coarse assessment of expected miss distances between objects, but *not* appropriate for collision-avoidance decisions. Only high-accuracy SP ephemerides that include propagated covariance resulting in computed Probability of Collision P_c should be used for collision-avoidance decisions.

CHANGES:

- Allow combo to work with SP vector in trajectory mode (Jira 773)

NEW APIS:

- ***ComboCompPriSec_MT***: Same as ComboCompPriSec but better for multi thread.

4.6 DllMain - Main Library

CHANGES:

NEW APIS:

- ***TestInterface2***: Allow users to test in and out types
- ***TestInterface3***: Allows users to test arrays with undefined length

4.7 ElComp - Element Comparison, including Computation of Co-Orbital

Combines capabilities of Computation of Co-Orbital (previously the Coco library) into the Element Comparison library (ElComp), with the ElOps Library dependency.

ElComp includes Computation of Coplanar Orbits (COCO). The COCO algorithm calculates the difference in orbital plane between a pair of orbits defined by element sets. COCO includes evaluation of relative nodal rates between the two objects and reports when (how many days hence) the two object's ascending nodes will align.

ElComp performs Element Comparison. Element comparison is used to determine the degree to which two orbits are Same, Close, Similar, or None. Determination of Same, Close, Similar, or None is by user-specified comparison thresholds for the primary orbit versus the secondary for which differences are evaluated in inclination, right ascension of ascending node, perigee height, eccentricity, orbital period, and argument of perigee.

NO CHANGES

4.8 ElOps - Element Operations

Includes various orbital element operations that do not require a propagator.

NO CHANGES

4.9 EnvConst - Environmental Constants Utility

This library is used for loading and manipulating various Earth constants and FK data.

NO CHANGES

4.10 ExtEphem - External Ephemeris

NO CHANGES

4.11 FOV - Field of View

FOV determines times in which orbiting satellites fly through a ground-based observer's conical field of view. The field of view can be defined by a constant azimuth and elevation boresight, a constant right ascension and declination boresight, or as a line-of-site to an orbiting satellite. The input orbit descriptions may be either a SGP4 TLE, a SP VCM, or an externally generated ephemeris file.

NO CHANGES

4.12 Lamod - Look Angle Module

The Lamod Library computes sensor (ground-based or space-based) viewing opportunities ("look angles") for Earth-centered satellite orbits. The input orbit description may be either a SGP4 TLE, a SP Vector, a SP VCM, or an externally generated ephemeris file.

CHANGES:

- New option to accept all passes regardless of visibility

NEW APIS:

4.13 Obs – Observations

This library is used for loading and manipulating observations including observations in B3 format, external TTY ASCII format, or comma-separated value csv format.

NO CHANGES

4.14 ObsOps - Observation Operations

Includes the Initial Orbit Module (IOMOD) capability to compute an initial set of orbital elements (18th SPCS TLE) from as few as three sensor observations, or four observations to include solution for the drag model parameter. The ObsOps library also allows users to manipulate observations

and derive useful information such as Latitude and Longitude from Right Ascension, Declination and Height. Notably, the ObsOps library now has the capability to compute satellite range through a triangulation technique using two simultaneous angles-only tracks. V8.3 adds the ability to do a Lomb-Scargle analysis, which is good for analyzing light curves.

CHANGES:

- No Changes

NEW APIS:

- ***AngleBetweenObs***: Calculate the angle between two observations.
- ***LombLengthOut***: Calculate length of arrays in Lomb
- ***Lomb***: Calculates information for a Lomb-Scargle Periodogram.
- ***LombFalseProb***: Find False Alarm Probability of given power
- ***LombFalseProbInv***: Find power of given False Alarm Probability
- ***LombLengthCoef***: Calculate length of output arrays in LombWaveFit
- ***LombWaveFit***: Fits user defined frequencies to data. Finds magnitudes
- ***LombCalcValueFromTime***: Find a the value from given time within the model from LombWaveFit

4.15 Rotas - Report Association, Observation/Element-Set Association

Associates sensor observations against satellite element sets using the same algorithms used by the 18th SPCS. It computes observation residuals, compares the residuals against delta-height, delta-in-track, and delta-beta residuals and assigns the ASTAT value (association status) to be either 1, 2, 3, or 4. ASTAT 1 corresponds to FULL, meaning observations fall within the un-multiplied height, in-track, and cross-track residuals. ASTAT 2 corresponds to CLOSE, meaning the observations residuals fall inside the cross-track limit and within the multiplied radial and in-track limits. ASTAT 3 corresponds to PLANE meaning the observation residuals meet the cross-track limit but fall outside the multiplied radial or multiplied in-track limits. ASTAT 4 corresponds to NONE meaning the observation residuals fall entirely outside the multiplied association box. The result of ASTAT 4 NONE is the observations cannot be tagged and are reported as Uncorrelated Track Observations (UCTs), meaning those observations must be correlated and tagged to another object.

CHANGES:

- Adds angle between observed and predicted to output

NEW APIS:

- ***No New APIs***

4.16 SAAS - Space Attack Assessment Software

For a specified launch location, profile, and maximum kill altitude, computes the kill ring and identifies all object's orbits that will penetrate the kill ring (entry or exit or both and the corresponding satellite numbers and times). Identified satellites only include those that orbit less than or equal to the maximum altitude of the launch capability for a specified launch forecast period of interest.

CHANGES:

- No Changes

NEW APIS:

- ***No New APIS***

4.17 SatState - Satellite State

The SatState library is used for handling a mix of different types of predictions and for extracting derived information such as semi-major axis, minimum perigee and maximum apogee, or computation of Earth-Centered Inertial (ECI) positions from a ground sensor location (either Latitude Longitude and Height, or Earth-Centered Rotating position).

CHANGES:

- Fix bug in SatStateGenEphFile (Jira 747)

NEW APIS:

- ***No New APIs***

4.18 Sensor – Sensor Processing

The Sensor library is used for loading sensors and defining sensor limits that define the coverage type, Field of Regard and Field of View.

CHANGES:

- No Changes

4.19 Sgp4Prop - SGP4 Propagator, extended to include SGP4-XP Capabilities

The Sgp4Prop library includes analytic propagation methods based on general perturbations (GP) theory. Sgp4Prop is used for generating ephemerides for satellites in Earth-centered orbits. It is the appropriate means for propagating orbital state using input TLEs for sensor-tasking purposes. SGP4 perturbations account for non-sphericity of Earth, Sun and Moon perturbative accelerations, and atmospheric drag according to Jacchia 1970 static density tables. The new "XP" version of SGP4 is appropriate for applications that require SP-level accuracy. The Extended Perturbations version of SGP4 is referred to as "SGP4-XP".

The propagation accuracy now available by SGP4-XP is vastly improved by inclusion of extended perturbations that can be tapped by using the new TLE ephemeris type 4, which replaces the legacy $\ddot{n}/6$ term in columns 45-52 of Line 1 with the object's solar radiation pressure model parameter, *AGOM* [m^2/kg]. The leading decimal point is assumed for the AGOM value in columns 45-52. As previously summarized in Figure 3, extended perturbations includes better lunar perturbation modeling, new and more resonance modeling, solar radiation pressure modelling (in addition to drag modelling), and the Geopotential model has been extended to include the J5 zonal term and legacy WGS-72 terms are replaced with EGM-96 terms to be consistent with SP propagation by the operational ASW. In addition, the static atmosphere model

is replaced with the Jacchia-70 model that uses a generic solar flux and geomagnetic index that predicts future flux based on flux periodics dating back more than 40 years. Therefore, it is not necessary to maintain $F_{10.7}$ and A_p values for running the SGP4-XP propagator.

CHANGES:

- No Changes

NEW APIS:

- ***No New APIs.***

4.20 SpProp - SP Propagator

The SpProp library uses a Special Perturbations (SP) theory to generate ephemerides from ECI state vectors produced by the BatchDC orbit determination library. SP theory includes perturbations accelerations due to Sun and Moon and other third-bodies (planets); non-sphericity of Earth including up to 70x70 zonals and tesserials in the EGM-96 geopotential model; dynamic calibration of the atmosphere (DCA); Earth-tides and ocean tides; and other techniques that improve orbit determination and prediction accuracy.

CHANGES:

- When using the JPL ephemeris file, uses now has the ability to add perturbations due to planets (changes in the 4P). Also added partials due to these perturbations for use in BatchDC. See documentation for usage.
- Lunar/Solar Perturbations when using JPL ephemeris were incorrectly using MEME J2K instead of TEME of Date

NEW APIS:

- ***SpPropDs50UtcPosVel***: Propagate satellite to a time and get position and velocity.
- ***SpGenEphemsVcm_OS***: Generate ephemeris for the input VCM with specified step size.
- ***SpPropAllSats***: Propagate all satellites to a specified time

4.21 SpVec - SP Vector

The SpVec library is used for loading SP Vectors.

NO CHANGES

4.22 TimeFunc – Time Functions

The TimeFunc library manages various time types and conversions among various time types such as Time Atomic International (TAI), Universal Time Corrected, TAI minus UTC offset (leap second), UT1 Rate, and determination of Greenwich hour angle, also known as Theta Greenwich.

NO CHANGES

4.23 TLE - Two-Line Element Set Processing

The TLE library is used for loading operational Two-Line Element sets (TLEs) and comma-separated value (csv) formatted orbital elements.

CHANGES:

- No Changes

NEW APIS:

- ***No New APIs.***

4.24 VCM - Vector Covariance Message Processing

The VCM library is used for parsing and loading information from Vector Covariance Messages (VCMs).

CHANGES:

- Added BIG, MED, SMA, ALL to the Lunar/Solar field. This adds perturbation due to the planets in order of effect. BIG will turn on Jupiter and Venus. MED will turn on BIG and Saturn, Mars, Mercury. SMA will turn on BIG, MED, and Uranus and Neptune. ALL turns on Pluto in addition to the other planets.

5. Future Capabilities and Changes

- Add Position, Partials, and Time Version 3 (PPT3) Navy propagator to Sgp4Prop in a future Release. This will allow Astro Standards to be compatible with the Navy theory. This will also allow creation of PPT3 elements. These will be distinguished by *element set type "3"*.
- Ability to use Right Ascension and Declination Rates in ROTAS and BatchDC.
- Release of unit tests along with the new Release.
- Fully replace the AVL tree with the new DMA mode. This will deprecate some functions.
- Allow observations and sensors to use the new DMA mode.
- More covariance transformations in AstroFunc library

6. Past Releases of the Astrodynamics Standards

- v8.2.1 – Patch release on Windows (32/64) and Linux (32/64): 17 Dec 2021
- v8.2 – Full release on Windows (32/64) and Linux (32/64): 15 Nov 2021
- v8.1 – Full release on Windows (32/64) and Linux (32/64): 26 May 2021
- v8.0 - Full release on Windows (32/64) and Linux (32/64): 09 Nov 2020
- V7.9 - Full release on Windows (32/64) and Linux (32/64): 15 May 2019
- V7.8.1 – Full non-beta release of on Windows (32/64) and Linux (32/64): 24 July 2018
- V7.8 - Full non-beta release of on Windows (32/64) and Linux (32/64): 15 June 2017
- V7.7 - Public Release of SGP4 on Windows (32/64) and Linux (32/64): 15 March 2016
- V7.beta6 - SGP4, SP, LAMOD, COMBO, ROTAS, IOMOD, BATCHDC, Linux (32/64): 28 Oct 2014
- V7.beta6 - SGP4, SP, LAMOD, COMBO, ROTAS, IOMOD, BATCHDC, Windows (32/64): 27 Oct '14
- V7.beta5 - SGP4, SP, LAMOD, COMBO on Windows(32/64): 25 August 2014
- V7.beta4 - SGP4, SP, LAMOD, COMBO on Linux(32/64): 25 September 2012
- V7.beta4 - SGP4, SP, LAMOD, COMBO on Windows(32/64): 17 September 2012
- V7.beta - COMBO on Windows: 28 October 2011
- V7.beta1 - LAMOD on Windows: 28 Jun 2011
- V7.beta - LAMOD on Windows: 02 Jun 2011
- V7.beta3 - SGP4, SP on Windows: 21 March 2011
- V7.beta2 - SGP4, SP on Linux: 06 October 2010
- V7.beta1 - SGP4, SP on Windows: 27 July 2010
- V7.beta - SGP4, SP on Windows: 08 December 2008