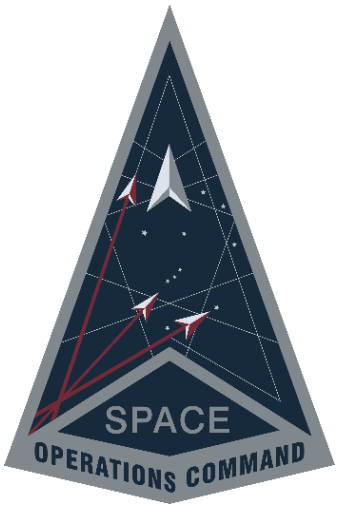
Astrodynamics Standards
Shared Library



Two Line Element Set
(TLE)

Version 9.4

May 2024

Contents

1. Introduction

TLE provides many library functions to load and manage satellite element sets in two line element set format. The element sets are defined as Keplerian (North Aerospace Defense (NORAD) 2-Line MU-15) Two-Line Elements (TLE) including mean motion instead of the semi-major axis that is typical to a standard Keplerian element set. The two satellite element set formats that work with this library are the mean NORAD Keplerian element set and the osculating NORAD Keplerian element set (see section 7). Both types are referred to as a Two-Line Element set or a TLE in the documentation.

TLE allows users to load/delete/update/parse two-line element sets.

TLE is publically releasable and can be distributed/redistributed without the any license agreement.

If you are on Windows, the shared library files will end in ".dll". For example, "AstroFunc.dll". If you are on Linux, the shared library will begin with "lib" and end in ".so", and will be all lowercase. For example, libastrofunc.so.

2. Prerequisites

The following libraries MUST be loaded and initialized before using TLE:

- DllMain
- EnvConst
- TimeFunc
- AstroFunc

To load SGP4, you need to have the **SGP4_Open_License.txt** license file located in the directory from which you are running the application. This can also mean the libraries that depend on SGP4. By default the libraries look for this license file in the same directory as the libraries. For Windows, you will also need the directory of the libraries in your PATH environment variable. For Linux, you will need to set the LD_LIBRARY_PATH environment variable to the directory of the libraries.

3. Getting Started

To get started, please read the README.txt file that came in the root directory of your distribution. In addition to an overall description contained in the distribution, it has a description of a "**wrapper**".

To get started with **TLE**, there is a "wrapper" specific to TLE, under the **SampleCode** directory. Under your language of choice, you will see a "**DriverExample/wrapper**" subdirectory. The files under this directory will have all the Application Programming Interfaces (APIs) available. For TLE specific APIs, you should see a source file labelled with "TLE" in the file name. This will be where you will find all the APIs for that specific library. The "DriverExample" directory will also contain several examples of applications that should run by simply running the runExample.bat or runExample.sh script. You can use these examples as a starting point for building your application.

If you do not see your programming language under "SampleCode", look in the HTML documentation for the APIs. Open a browser to the "Documentation/APIDocs/index.html" file. This document will show all the APIs regardless of programming language.

The Astrodynamics Standards libraries should work with any language capable of using Dynamic Link Library (on Windows) or Shared object (on Linux) files.

4. Terminology

Mean Keplerian element sets are referred as General Perturbations (GP) TLEs. GP TLEs include Simplified General Perturbations (SGP) TLEs (ephemeris type 0), and Simplified General Perturbations #4 (SGP4) TLEs (ephemeris type 2). Osculating Keplerian element sets are referred as Special Perturbations (SP) TLEs (ephemeris type 6).

In the SAA documentation, the terms "GP TLE", "SGP4 TLE", and "SGP4 satellite" are used interchangeably. Moreover, the terms "SP TLE" and "SP satellite" are used interchangeably. The term "satellite" is used to refer to satellites in general, and sometimes context is needed to know which type is being referred to.

5. Understanding TLE

This library stores each loaded TLE internally. Each TLE, when loaded successfully, will receive a unique key. This unique key is commonly called 'satKey' in the documentation since TLE's represent satellites. The satKey is used to retrieve the TLE data.

Any library which work with TLEs, such as Sgp4Prop and SpProp, have access to the loaded data. Therefore, the associated TLE data can be retrieved throughout the Library code via its satKey.

6. Working with Propagators

SGP and SGP4 TLEs only work with SGP4 propagator.

SP TLEs only work with SP propagator.

7. Two-Line Element Set (TLE) Data Description

7.1. NORAD 2-Line (MU-15) Element Set Format – SGP/SGP4

This section presents the format of the Two-line (also known as 2-Card) element set format as contained in CMOC MU15 messages. It is important to note that there are SP element sets which have superficially similar formats, but some of whose data fields (the drag terms, in particular) have different meanings than the MU15 case.

This MU15 format for an element set is widely used to contain SGP and SGP4 element sets. Only ephemeris types 0 (SGP) and 2 (SGP4) are allowed; this is the differentiation from the otherwise indistinguishable osculating Keplerian elements format described in the next section (for which ephemeris type is 6).

Element Set Line 1:

Column	Range	Format	Description
1	1	I1	element set line number 1
2		1X	blank column
3-7	1-99999	I5	satellite number
8	U, C, S	1X	security classification where: U = unclassified

			C = confidential S = secret
9		1X	blank column
10-17		A8	internal designator
18		1X	blank column
19-20		I2	year of epoch, where; 50-99 = years 1950-1999 00-49 = years 2000-2049
21-32		D12.0	decimal day and time of epoch
33		1X	blank column
34-43		D10.0	n-dot/2 (for SGP, eph-type = 0)
44		1X	blank column
45-52		D8.0	n-double-dot/6 (for SGP, eph-type = 0)
53		1X	blank column
54-59		F6.5	B* drag component (to right of decimal)
60-61	(-)1-9	I2	B* exponent
62		1X	blank column
63	0, 2	I1	ephemeris type 0 = SGP 2 = SGP4
64		1X	blank column
65-68		I4	element set number
69		1X	checksum (not used)
70		I1	FK4/FK5 flag; where 4=FK4; else = FK5

71-79		9X	not read (can be used to identify elset)
80		A1	blank (mandatory)

Key elements of this card are the B* drag term and the ephemeris type. The B* drag term is input in abbreviated notation in columns 54 through 61. This is short-hand notation for 0.nnnnnn x 10se, where nnnnnn is the data in columns 54 through 59, s is the exponent sign in column 60, and e is the exponent digit in column 61. Column 63 specifies the ephemeris type; the element set must have ephemeris type "0" (for SGP theory) or "2" (for SGP4 theory) in column 63. NORAD element sets are compatible with both SGP and SGP4. All element sets are transmitted by NORAD with "0" in column 63, but also include the SGP4 drag term (B*) in columns 54-59. The SGP4 library will automatically transform the SGP elements to SGP4 elements as follows:

(1) n-dot/2 and n-double-dot/6 are discarded;

(2) no is de-Kozai'd to compute a Brouwer mean motion.

All other orbital elements are used directly. Because column 80 is not used, but is an identifier, it must be blank, or SGP4 may mistakenly identify the line of data as another type of data card.

Element Set Line 2:

Column	Range	Format	Description
1	2	I1	line number (must be "2")
2		1X	blank column
3-7	1-99999	5X	satellite number (not used) (See Note 1.)
8		1X	blank column
9-16	0.0-180.0	D8.0	orbit inclination (degrees)
17		1X	blank column
18-25	0.0-360.0	D8.0	right ascension of ascending node (degrees)
26		1X	blank column
27-33	0-0.9999999	F7.7	eccentricity (leading decimal assumed)
34		1X	blank column
35-42	0.0–360.0	D8.0	argument of perigee (degrees)
43		1X	blank column

44-51	0.0-360.0	D8.0	mean anomaly (degrees)
52		1X	blank column
53-63		D11.0	mean motion no (revs/day)
64-68		I5	epoch rev (not used)
69		1X	checksum (not used)
70-79		10X	not read
80		A1	blank (mandatory)

As in the format for line 1, column 80 must be blank to keep SGP4 from incorrectly identifying this line as another type of input card.

Note 1: The satellite number in lines 1 and 2 are not required to match. In the past, these were used to keep pairs of physical punch cards together. Once this became obsolete, this field and the adjacent blank columns in line 2 began to be used by other applications for other purposes. For this reason, the satellite number field in line 2 is simply not looked at by SAAs input routines. The output routines will populate the line 2 field to match that in line 1.

Example of a TLE (SGP):

Copy

```
1 90021U RELEAS14 00 51.47568104  .00000184      0 0  -1234-4   814
2 90021   0.0222 182.4923 0000720  45.6036 131.8822  1.00271328 1199
```

Example of a TLE (SGP4):

Copy

```
1     5U 58002B   00081.96390402 +.00000364 +00000-0 +43727-3 2 0460
2     5 034.2549 288.8006 1858938 253.4906 085.4246 10.8236544440306
```

7.2. NORAD 2-Line (MU-15) Element Set Format – SGP4-XP

Element Set Line 1:

Column	Range	Format	Description
1	1	I1	element set line number 1
2		1X	blank column
3-7	1-99999	I5	satellite number
8	U, C, S	1X	security classification where: U = unclassified C = confidential S = secret
9		1X	blank column
10-17		A8	internal designator
18		1X	blank column
19-20		I2	year of epoch, where; 50-99 = years 1950-1999 00-49 = years 2000-2049
21-32		D12.0	decimal day and time of epoch
33		1X	blank column
34-43		D10.0	N/A
44		1X	blank column
45-52		D8.0	agom (m2/kg)
53		1X	blank column
54-59		F6.5	ballistic coefficient (m2/kg) (B term)
60-61	(-)1-9	I2	B term exponent

62		1X	blank column
63	0, 2	I1	ephemeris type (must be 4) 4 = SGP4-XP
64		1X	blank column
65-68		I4	element set number
69		1X	checksum (not used)
70		I1	FK4/FK5 flag; where 4=FK4; else = FK5
71-79		9X	not read (can be used to identify elset)
80		A1	blank (mandatory)

Element Set Line 2:

Column	Range	Format	Description
1	2	I1	line number (must be "2")
2		1X	blank column
3-7	1-99999	5X	satellite number (not used) (See Note 1.)
8		1X	blank column
9-16	0.0-180.0	D8.0	orbit inclination (degrees)
17		1X	blank column
18-25	0.0-360.0	D8.0	right ascension of ascending node (degrees)
26		1X	blank column
27-33	0-0.9999999	F7.7	eccentricity (leading decimal assumed)
34		1X	blank column
35-42	0.0–360.0	D8.0	argument of perigee (degrees)

43		1X	blank column
44-51	0.0-360.0	D8.0	mean anomaly (degrees)
52		1X	blank column
53-63		D11.0	mean motion no (revs/day) (Brouwer)
64-68		I5	epoch rev (not used)
69		1X	checksum (not used)
70-79		10X	not read
80		A1	blank (mandatory)

Example of a TLE (SGP4-XP):

	Copy

```
1 41085U GPDC     19001.16111410 +.00000000  64817-1  25579 0 4 0001
2 41085  98.8405  84.6159 0030231 128.2631 288.8143 14.1732257715999
```

7.3. Osculating Keplerian Elements

This section presents the format of the osculating Keplerian elements. The format to input osculating Keplerian elements is nearly identical to the two-line element set format used for SGP and SGP4. The primary differences are:

- the osculating Keplerian element format is ephemeris type 6
- a true ballistic coefficient is used and is read from the SGP n-dot/2 location.

The following text elaborates on the format where necessary to explain the corresponding osculating Keplerian element format.

Osculating Element Set Line 1:

Column	Range	Format	Description
1	1	I1	element set line number 1
2		1X	blank column

3-7	1-99999	I5	satellite number
8	U, C, S	1X	security classification where: U = unclassified C = confidential S = secret
9		1X	blank column
10-17		A8	internal designator
18		1X	blank column
19-20		I2	year of epoch, where; 50-99 = years 1950-1999 00-49 = years 2000-2049
21-32		D12.0	decimal day and time of epoch
33		1X	blank column
34-43		D10.0	ballistic coefficient (m2/kg) (BTerm)
44		1X	blank column
45-52		D8.0	outgassing parameter/Thrust Acceleration (m/s2)
53		1X	blank column
54-59		F6.5	agom (m2/kg)
60-61		I2	agom exponent
62		1X	blank column
63	6	I1	ephemeris type (must be 6)
64		1X	blank column
65-68		I4	element set number

69		1X	checksum (not used)
70		I1	FK4/FK5 flag; where 4=FK4; else = FK5
71-79		9X	not read (can be used to identify elset)
80		A1	blank (mandatory)

Key elements of this card are the ephemeris type and the ballistic coefficient. The ballistic coefficient (BTerm) used by SP is not the SGP4 B-star. The true ballistic coefficient in columns 34-43 is CDA/m where CD is the coefficient of drag, and A and m are the average cross-sectional area (m2) and the mass (kg) of the satellite, respectively. Column 63 specifies the ephemeris type; osculating Keplerian element sets must have ephemeris type "6" in column 63 to be compatible with SP format. The solar radiation pressure coefficient in m2/kg (agom) can be input via columns 54-61. Because column 80 is not used, but is an identifier, it must be blank, or SP may mistakenly identify the line of data as another type of data card.

Osculating Element Set Line 2:

Column	Range	Format	Description
1	2	I1	line number (must be "2")
2		1X	blank column
3-7	1-99999	I5	satellite number (not used)
8		1X	blank column
9-16	0.0-180.0	D8.0	orbit inclination (degrees)
17		1X	blank column
18-25	0.0-360.0	D8.0	right ascension of ascending node (degrees)
26		1X	blank column
27-33	0-0.9999999	F7.7	eccentricity (leading decimal assumed)
34		1X	blank column
35-42	0.0–360.0	D8.0	argument of perigee (degrees)
43		1X	blank column
44-51	0.0-360.0	D8.0	mean anomaly (degrees)

52		1X	blank column
53-63		D11.0	mean motion (revs/day)
64-68		I5	epoch rev (not used)
69		1X	checksum (not used)
70-79		10X	not read
80		A1	blank (mandatory)

Unlike the averaged orbital elements of SGP and SGP4, the elements listed above are osculating elements; they describe the true state of the satellite at epoch. As in the format for line 1, column 80 must be blank to keep SP from incorrectly identifying this line as another type of input card.

Example of a TLE (SP):

	Copy

```
1 17302U          90 85.76554416 0.00000000  00000 0  00000 0 6  486
2 17302   6.3392 234.9188 3057446 205.3727 135.9681  9.52061962 4853
```

8. TLE comma-separated-value (csv) Field Order/Description

Astro Standards have been updated to accept various fundamental data types in comma-separated value format. This includes Observations and Element Sets. External ephemeris files will also be accepted in csv format. Figure 1 provides the listed data order and data descriptions for csv Element Sets.

Field Order #	Short Description	Range of Values	Type	Extended Description and Units of Measure
1	Classification of Element Set	U	String	Unclassified
		C	String	Confidential
		S	String	Secret
2	Satellite Catalog Number (Current)	1 to 999999999	Integer	9-digits, also known as the Space Control Center Identifier SSCID
3	International Designator, 4-digit Year	0000- to 9999-	String	The Intenational Designator is comprised of three contiguous fields, containing the 4-digit launch year, followed by a "-",
	International Designator, Launch Number of Year	000 to 999	String	followed by the launch number of that year, followed by the object Piece Identifier. A correctly formated International
	International Designator, Piece Identifier	A to ZZZ	String	Designator looks something like this sample: 2018-001A
4	Element Set Epoch Time, Year	Positive	Integer	Four digit year
5	Element Set Epoch Time, Julian Day	Positive	Real	3-Digit Julian Day of the year and the fractional portion of the day
6	First Time Derivative of the Mean Motion	Any	Real	Revolutions per day squared [revs/day^2], also known as "n-dot over 2"
7	Second Time Derivative of Mean Motion	Any	Real	Revolutions per day cubed [revs/day^3], also known as "n-double-dot over 6"
8	B* Drag Term	Any	Real	[1/(Earth Radii)], also known as "B Star"
9	Element Set Type / Extrapolation Theory Used	0	Integer	0 = Kozai, Simplified General Perturbations (SGP)
		2		2 = Brouwer, Simplified General Perturbations Version 4 (SGP4)
		4		4 = Brouwer, SGP4 Extended Perturbations (SGP4-XP)
10	Element Set Number	Positive	Integer	[Unitless]
11	Inclination	0-180	Real	[Deg]
12	Right Ascension of the Ascending Node	0-360	Real	[Deg]
13	Eccentricity	Non-negative	Real	[Unitless]
14	Argument of Perigee	0-360	Real	[Deg]
15	Mean Anomaly	0-360	Real	[Deg]
16	Mean Motion	Positive	Real	Revolutions per day [revs/day]
17	Revolution Number at Epoch	Non-negative	Integer	Revolutions [revs]
18	Original Satellite Catalog Number	1 to 999999999	Integer	Related to analyst satellites promoted to Cataloged Objects with International Designators
19	Solar Radiation Pressure Coefficient (AGOM)	Any	Real	Meters squared per Kilogram [m^2/kg]
20	Ballistic Coefficient (B Term)	Any	Real	Meters squared per Kilogram [m^2/kg]
21	Time of Last Observation used in Orbit Determination -or- Offset Relative to Epoch	Any	Real	In +/- fractional Days
22	Last Computed Error Growth Rate (EGR)	Positive	Real	Kilometers per Day [km/day]
23	Energy Dissipation Rate (EDR)	Any	Real	Watts/Kilogram [W/Kg]
24	Median Visual Magnitude Brightness of Object	Any	Real	Visual Magnitude [mv] - Measurement scaled to standard distance of 35,786 km (elevation to GEO at zenith)
25	Median Radar Cross Section	Positive	Real	Centimeter-diameter equivalent size [cm], represents apparent size of the object expressed as the diameter of a disk of equivalent apparent size
26	Object Type	Payload	String	Payload includes active and inactive payloads
		Rocket Body		Rocket Body includes Apogee Kick Motor (AKM), Perigee Kick Motor (PKM), or Payload Assist Module (PAM)
		Platform		
		Debris		
		Unknown		

Figure 1: TLE comma-separated-value (csv) Field Order/Description