Astronomical Definitions :

The "Two-Line Elements"

The *North American Aerospace Defense Command* (NORAD) is a joint organization between the United States of America and Canada established in 1957 in full during the « Cold War » , for the purposes of the surveillance of the North American airspace. Its headquarters are located at Peterson Air Force Base Son in Colorado. With dozens of radars, NORAD can detect any object in space greater than 1 meter in size (this limit is 10 cm up to an orbital altitude of 8000 km) whose movement is calculated with propagation models, the orbital parameters of the objects are coded in the TLE, *Two-Line Elements*, presented below. For « un-classifed »satellites, the TLEs are updated 1-3 times per day.

NORAD records objects in orbit and provides, in the form of two lines of 69 characters (number, letter, sign, white), their orbital elements. This data, named NORAD Two-Line Element Set Format (abbreviated as TLE), are constantly updated and can be used as initial conditions of an orbiting object's movement, which must then be propagated. For each satellite, the data is in the following format :

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AAAAAAAAAAAAAAAAAAAAAAAA
1 NNNNNU NNNNNAAA NNNNN.NNNNNNNN +.NNNNNNNN +NNNNN-N +NNNNN-N N NNNNN
2 NNNNN NNN.NNNN NNN.NNNN NNNNNNN NNN.NNNN NNN.NNNN NN.NNNNNNNNNNNNNN
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General format of TLE

Line 0 gives the name of the object in orbit (satellite, rocket element), in 24 characters. Lines 1 and 2 of the TLE hold the remaining information.

Line 1 contains date information and various information on atmospheric friction. The orbital parameters are in line 2. The exact description of the information with lines 1 and 2 is described in Tables 1 and 2 (extracted from *Celestrak report*).

Decoding the NORAD TLE

Their is a direct relationship between the size classic Keplerian elements and the six NORAD elements for the i, e and the angular elements Ω, ω, M. The semi-major axis a is obtained from the mean motion n.

In order to practically use the orbital element information, two calculations are required.

[a] The semi-major axis a does not appear directly in the NORAD elements, but is given through the number of revolutions per day via the anomalous period T_a. By an iterative calculation using the successive values of Δn, the value of a can be obtained, which requires the use of orbital software.

[λ_0] The angle Ω, the right ascension of ascending node, is measured in a Galilean reference relative to the direction of the point vernal.

In practice, we want to know λ_0, the longitude of the ascending node of the orbit. That is, we are interested in the angular elongation of that point in a terrestrial reference, counted from the Greenwich meridian with the direction of the vernal point, at midnight UTC on the day considered.

This angle corresponds to the mean sidereal time GMST (Greenwich Mean Sidereal Time), at 0 h TU, noted q_{G00}, measured in seconds. It is obtained through the relation :

$$\begin{aligned} q_{G00} =& 24110.54841 + 8640184.812866\ T_u \\ &+ 9.3104\ 10^{-2}\ T_u^2 - 6.2\ 10^{-6}\ T_u^3 \end{aligned} \tag{1}$$

with T_u, which measured the *Julian time*, defined by $T_u = d_u/36\,525$, where d_u represents the number of integer days represents the integer number of days since January 1, 2000 at 12 noon (the origin date, called DJ2000, corresponds to the Julian date DJ 2 451 545.0)

With ΔJ, the fraction of a day that has elapsed since 0 h (given in line 1 of the TLE), the sideral time (GMST) is calculated at the instant t (TU) considered by :

$$q_{Gt} = q_{G00} + 86\,400\ \dot{\theta}\ \Delta J\ [\text{ mod } 86\,400\ ] \tag{2}$$

where $\dot{\theta}$ represents the rotational angular velocity of the Earth expressed in revolutions/day, that is, $\dot{\theta} = 1,0027379$ revs/day. We obtain the equivalent q_G (given in seconds) in degrees, through the quantity Ω_{Gt} defined as :

$$\Omega_{Gt} = \frac{q_{Gt}}{240} \tag{3}$$

which is the angle made by the Greenwich meridian with the direction of the vernal point, at the time TU considered. The positions of the ascending node of the Greenwich orbit and of the meridian, respectively denoted by Ω and Ω_{Gt}, are measured with respect to the same origin, at the same time. The longitude λ_0 of the ascending node of the orbit in a terrestrial reference is then obtained.

Practical Limits of Use

The use of NORAD data in the form of TLEs requires the use of orbitography software, particularly for the usage of n and a. If we then input the 6 orbital parameters relative to a given day into the software, we can obtain very precise

results on the position of the satellite (with accuracy of the order of 100 meters).
For ultra-precise operations, such as orbital rendezvous maneuvers, NORAD TLE data is insufficient.

Online Propagation and TLE Utilization Tools

All or part of the public part of the NORAD catalog can be found on the internet and on several specialized websites such as the IMCCE website. Some trace the history of the entire population of artificial satellites (including space debris) since 1957, containing several tens of thousands of objects. A large number of applications on tablets and smartphones use the TLEs to foresee satellite visibility conditions and closures with natural celestial objects (such as the Moon), by regularly connecting to remote data bases to « Refresh »the initial conditions. In particular, the following tools :

- IXION, web address, + history of orbital elements
- IMCCE and its ephemeris server
- Stellarium and other online applications, including smartphones (like ISS trackers)

Finally, other types of catalogs (based on alternative theories of artificial satellites) exist only marginally, but most still use the format of the TLEs which has fully established itself in the astronomy and astrodynamics communities.

Column	*Description*
01	Line Number of Element Data
03-07	Satellite Number
08	Classification (U=Unclassified)
10-11	International Designator (Last two digits of launch year)
12-14	International Designator (Launch number of the year)
15-17	International Designator (Piece of the launch)
19-20	Epoch Year (Last two digits of year)
21-32	Epoch (Day of the year and fractional portion of the day)
34-43	First Time Derivative of the Mean Motion
45-52	Second Time Deriv. of Mean Motion (decimal point assumed)
54-61	Drag term (decimal point assumed), " B* " model
63	Ephemeris type
65-68	Element number
69	Checksum (Modulo 10)

TABLE 1 – Description Line 1 of the « NORAD Two Line Elements ». Document NORAD.

Column	*Description*	
01	Line Number of Element Data	
03-07	Satellite Number	
09-16	i	Inclination (Degrees)
18-25	Ω	Right Ascension of the Ascending Node (Degrees)
27-33	e	Eccentricity (decimal point assumed)
35-42	ω	Argument of Perigee (Degrees)
44-51	M	Mean Anomaly (Degrees)
53-63	n	Mean Motion (Revolutions per day)
64-68	Revolution number at epoch	
69	Checksum (Modulo 10)	

TABLE 2 – Description Line 2 of the « NORAD Two Line Elements ». Document NORAD.

