Standard (PWI):
Calculation of Orbital Elements at Satellite-Launch Vehicle Separation

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1. Background

Giving an Introduction of a new ISO Preliminary Work Item:

- ISO 10785:2011 Bellows -- Design and operation
- ISO 16458:2004 Unmanned spacecraft transportation -- General requirements
- ISO/DIS 11233 Orbit determination and estimation -- Process for describing techniques
- ISO 14303:2002 Launch-vehicle-to-spacecraft interfaces
- ISO 14303:2002 Launch-vehicle-to-spacecraft interfaces
- ISO 17401:2004 Spacecraft interface requirements document for launch vehicle services
- ISO 17401:2004 Spacecraft interface requirements document for launch vehicle services
- ISO 15863:2003 Spacecraft-to-launch-vehicle interface control document
- ISO 15863:2003 Spacecraft-to-launch-vehicle interface control document
- ISO 22644:2006 Space data and information transfer systems — Orbit data messages
- ISO/PRF 26900 Space data and information transfer systems -- Orbit data messages
- Standards about coordinate system, and their transformation
- Standards or technical documents about gravity model
- Standards or technical documents about telemetry data
- Calculation of Orbital Elements at Satellite - LV Separation
- ISO/AVI 16164 Disposal of satellites operating in or crossing Low Earth Orbit
- ISO/NP 16679 Relative motion analysis elements after LV/SC Separation
1. Background

In the international commercial launch services, the launch vehicle needs to send the satellite accurately into orbit.

The orbital elements at the separation point about satellite and rocket is one of the most important criterion for assessment of successful commercial launch.

It needs a recognized standard about how to calculate the orbital elements at the separation point about satellite and rocket.

Calculation of Orbital Elements at Satellite-Launch Vehicle Separation
2. Scope

- Calculation method of orbital elements at the point of separation
  - Keplerian elements calculation method
  - Transformation method

- Standard
- Application
  - Orbits
    - Low Earth Orbit
    - Sun Synchronous Orbits
    - Medium Earth Orbit
    - Geosynchronous Orbit
    - Transfer Orbit
    - ... Satellites
    - Manned spacecraft
    - Space station
    - ...
- Payloads
- Only separation point
3. Effects

- It can guide the design of the rocket guidance system.
- Providing the basis for the design of the rocket safety margin.
- Assessing the guidance precision in the design.
- Providing the reference for fuel capacity design of launch vehicle and satellite.
3. Effects

- It facilitate international cooperation and communication
- Reducing the risk of loss due to communication problems
- Help to reduce the manufactory cost about rocket and payload
- Help to reduce the space junk to some extent and protect the space environment
4. Calculation method of Orbital elements

—Orbital elements

**Orbital elements**

- Orbit size and shape parameters
- Orbit orientation parameters
- Satellite location parameters

![Diagram showing orbital elements](image)
4. Calculation method of Orbital elements

- Classic Keplerian Orbital elements
  - semimajor axis
  - eccentricity
  - semiminor axis
  - semilatus rectum
  - perigee radius
  - apogee radius
  - perigee altitude
  - apogee altitude
  - period
  - mean motion

- Specific Orbital elements
  - inclination
  - right ascension of the ascending node
  - argument of perigee
  - longitude of the ascending node
  - true anomaly
  - eccentric anomaly
  - mean anomaly
  - mean anomaly
  - time past perigee
  - time past ascending node
  - argument of latitude
4. Calculation method of Orbital elements
—Calculation method

Classic Keplerian Orbital elements Calculation

\[ r = \sqrt{x^2 + y^2 + z^2} \]

\[ V = \sqrt{V_x^2 + V_y^2 + V_z^2} \]

\[ \nu = \frac{rV^2}{GM_e} \]

\[ a = \frac{r}{2 - \nu} \]

\[ \sin \Omega_0 = \frac{h_x}{\sqrt{h_x^2 + h_y^2}} \quad \Omega_0 \in [0, 2\pi] \]

\[ \cos \Omega_0 = -\frac{h_y}{\sqrt{h_x^2 + h_y^2}} \]

\[ \gamma = \arcsin \left( \frac{V_x x + V_y y + V_z z}{Vr} \right) \]

\[ e = \sqrt{1 - (2 - \nu)\nu \cos^2 \gamma} \]

\[ \theta = \begin{cases} \arccos \frac{a(1 - e^2) - r}{er} & (\gamma \geq 0) \\ 2\pi - \arccos \frac{a(1 - e^2) - r}{er} & (\gamma < 0) \end{cases} \]

\[ \omega = u - \theta \]

\[ h = \sqrt{h_x^2 + h_y^2 + h_z^2} \]

\[ i = \arccos \frac{h_z}{h} \]
4. Calculation method of Orbital elements
— Transformation method

Transformation method of other Orbital elements

\[ b = a \sqrt{1 - e^2} \]
\[ p = a(1 - e^2) \]
\[ r_p = a(1 - e) \]
\[ r_a = a(1 + e) \]
\[ h_p = r_p - a_e \]
\[ h_a = r_a - a_e \]
\[ T = 2\pi \sqrt{\frac{a^3}{GM_e}} \]
\[ n = \sqrt{\frac{GM_e}{a^3}} \]

\[ \lambda_N = \Omega - S_0 \]
\[ E = 2 \arctan\left( \frac{1 - e}{\sqrt{1 + e}} \tan \frac{\theta}{2} \right) \]
\[ M = E - e \sin E \]
\[ t_p = t_{SEP} - \frac{E - e \sin E}{n} \]
\[ u = \omega + \theta \]
4. Calculation method of Orbital elements
— Coordinate systems

**Orbital Elements Calculation ------NEED------ Coordinate Systems**

**International Terrestrial Reference Frame (ITRF)**
- Its origin is located at the Earth’s center of mass
- Its unit of length is the SI meter.
- Its X-Y plane is the earth’s equatorial plane.
- Its Z axis coincides with the earth’s axis of rotation and points northward.
- Its positive X axis is directed toward the prime meridian.
- Its Y axis completes a right-handed system.

**Launch Point Geocentric Equatorial InERTial Frame (LGEIF)**

**Possible coordinate frames**
- International Celestial Reference Frame (ICRF)
- International Terrestrial Reference Frame (ITRF)
- Topocentric Horizon Frame (THF)

(frozen at the time of LV take-off)

- **Precession transformation matrix**
- **Nutation transformation matrix**
- **Earth rotation transformation matrix**
- **Polar motion transformation matrix**

ICRF → ITRF

THF → ITRF

angle of Earth Rotation after take-off → ITRF

ITRF → LGEIF

Coordinate Transformation---Needs----The Time Systems
4. Calculation method of Orbital elements
—Time Systems

Greenwich Apparent Sidereal Time (GAST)
Universal Time (UT1)
Coordinated Universal Time (UTC)
International Atomic Time (IAT)
Terrestrial Dynamical Time (TDT)
Barycentric Dynamical Time (TDB)
5. Conclusion

This standard gives the methods about **how to calculate the orbital elements at the separation point** about satellite and rocket, which apply to launch missions of satellites, manned spacecraft, space station and etc.

This standard will **help to provide a unified assessment standards** in the **international commercial launch activities**.

We are planning to **cooperate and coordinate with relevant technical standard systems**, in order to **make synergistic effect to each other**.
6. Normative references

ISO/DIS 11233, Space Systems—Orbit determination and estimation—Process for describing techniques
ISO 14303, Space systems—Launch-vehicle-to-spacecraft interfaces
CCSDS 500.0-G-3, Report Concerning Space Data System Standards—Navigation data-definitions and conventions
CCSDS 502.0-B-2, Recommendation for Space Data System Standards—Orbit data message
CCSDS 503.0-B-1, Recommendation for Space Data System Standards—Tracking data message
CCSDS 504.0-B-1, Recommendation for Space Data System Standards—Attitude data message
Howard D. Curtis, (2005), Orbital Mechanics for Engineering Students, Embry-Riddle Aeronautical University Daytona Beach, Florida.
Thank you!