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Space systems — Relative motion analysis elements after LV/SC separation

Systèmes spatiaux — Éléments d'analyse de mouvement relatif après séparation du LV/SC

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Foreword

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The committee responsible for this document is ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Introduction

Relative motion analysis predicts the relative distance after launch vehicle (LV) and spacecraft (SC) separation. The analysis result offers support to the mission design and operation.

This International Standard provides LV and SC operators and manufacturers with specific elements and procedures for performing relative motion analysis after LV and SC separation. The intent is to regulate a common basis and offer a direction.

Space systems — Relative motion analysis elements after LV/SC separation

1 Scope

This International Standard provides relative motion analysis elements after LV/SC separation, including analysis input, analysis principle, analysis method and analysis output. It is applicable to the mission design and verification for the prediction of relative motion after LV/SC separation.

This International Standard focuses on the relative motion between the objects involved in one launch mission. It does not cover the issues about the collision avoidance between newly launched objects and on-orbit ones.

2 Normative reference

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14303, *Space systems — Launch-vehicle-to-spacecraft interfaces*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 14303 and the following apply.

3.1
LV/SC separation
event of disconnection between LV/SC under the control of LV

3.2
relative motion analysis
analysis to predict the relative distance of spacecraft(s) to objects (end stage of LV and others generated during the separation) after the LV/SC separation

3.3
separation velocity
relative speed to LV when separation is completed instantly

4 Abbreviated terms

LV	launch vehicle
SC	spacecraft
ICD	interface control document
RMS	root mean square

5 Input for analysis

The following information shall be included as analysis input.

a) Theoretical velocity, position, attitude of LV and (each) spacecraft at the separation moment, which shall be presented in pre-determined coordinate system. Velocity and position vectors shall be offered in the format as Vx, Vy, Vz, X, Y, Z. The potential reference frames are offered in Annex C.

b) Separation velocity, mass and inertia characteristics of separation bodies.

c) Deviations of LV and separation parts [mass, thrust, impulse, moment-inertial characteristics (optional), tailed-effect, etc.].

d) Manoeuvres or other operations which shall affect LV end-stage orbit, related parameters and sequences.

e) Manoeuvres or other operations which shall affect SC orbit, related parameters and sequences (optional).

6 General process

In actual flight, relative motion after LV/SC separation is affected by many factors, including certain operations, deviations, mission profile, etc. on both sides. However, in order to simplify collaborations in applications of launch services, LV and SC parties shall perform the following processes:

a) LV conducts relative motion analysis without taking into account SC manoeuvre, attitude control, etc. into account,

b) SC evaluates it does not collide with LV orbital stage or other SC (for multi-SC launch mission) after separation due to its manoeuvre, attitude control, etc., based on the result of LV relative motion analysis.

The general process is described in Figure 1, where Party A represents LV and Party B represents SC.

The final safety evaluation should be performed based upon LV's and SC's analysis. If necessary input can be offered, the aforementioned processes a) and b) can be incorporated.

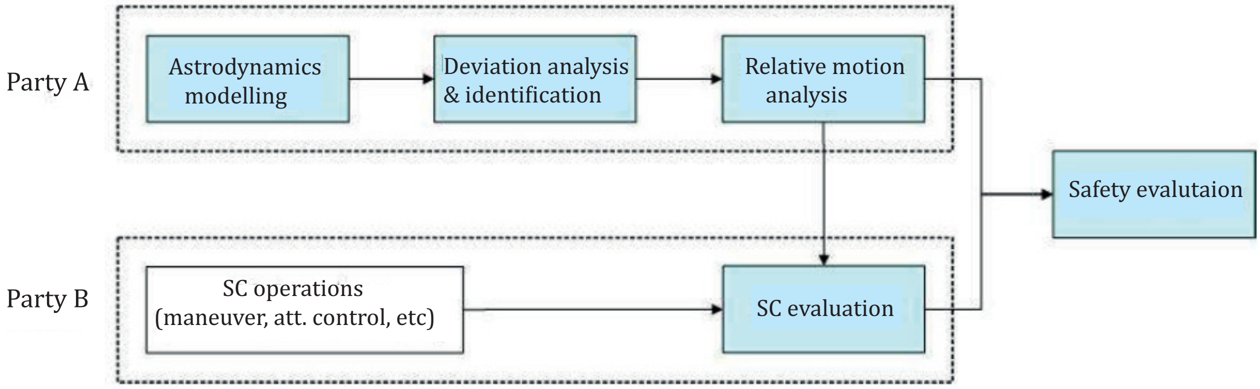

Figure 1 — Flow for relative motion analysis after LV/SC separation

7 Analysis principle

In the analysis principle, safety deserves priority. The analysis shall be in accordance with general principles for trajectory/orbit analysis (perturbations, astrodynamics, etc.) and shall cover deviations status.

8 Analysis method

8.1 General

The following content shall be included for relative motion analysis:

- astrodynamics modelling;
- deviation analysis and identification;
- relative motion simulation;
- safety evaluation.

8.2 Astrodynamics modelling

The astrodynamics modelling can be achieved in different coordinate systems. One alternative centroid motion model in an Earth-fixed coordinate system is offered in Annex A for information. Motion analysis of different objects should be conducted in the same coordinate system.

Gravity, atmosphere force models and related parameters shall be dealt in accordance with the trajectory/orbit calculation.

8.3 Deviation analysis and identification

Theoretical parameters shall be applied in normal analysis while deviation status shall be considered to cover the deviations existing in actual flight. The possible deviations have to be included and necessary items have to be identified for the relative motion analysis.

Typical deviations for LV shall include the following:

- separation velocity;
- separation attitude (pitch, yaw);
- mass of orbital stage;
- other factors, de-orbit thrust, de-orbit attitude control precision, etc.

8.4 Relative motion simulation

8.4.1 Relative motion analysis period

Relative motion analysis period should be a period of time agreed upon with the SC contractor. It should be no less than one orbit period.

8.4.2 Deviation

Deviation trajectory calculations are performed to support the analysis on minimum relative distance between orbital stage and spacecraft. Generally, deviations can be generated in 3 typical manners:

- margin status,
- typical combination of deviations, (note that Annex B offers a combination matrix for information) and
- combination of deviations generated by random sampling method.

8.4.3 Relative position calculation

Relative position calculation shall be performed using the steps below.

a) Calculate the orbits of spacecraft.

b) Calculate the deviation trajectory of orbital stage (or other objects generated during separations), according to the choice of deviations.

c) Calculate relative positions, via subtractions of spacecraft's orbit and certain deviation trajectories of orbital stage.

8.4.4 Deviation margin of relative position

Deviation margin of relative position depends on the result obtained in 8.4.3 and varies from different deviation choice.

a) Margin status: deviation margin equals subtraction of spacecraft's orbit and margin status deviation trajectory of orbital stage.

b) Typical combination of deviations: deviation margin equals subtraction of normal result and deviation obtained via RMS method.

c) Combination of deviations generated by random sampling method: deviation margin equals (m-σ) that was obtained via statistics method and represent mean value and standard deviation respectively.

8.5 Safety evaluation

The minimum relative distance shall be obtained on the base of 8.4.4.

The safety evaluation shall be performed according to the minimum safety distance agreed upon with the SC contractor, or the data from similar success flight cases.

The determination of minimum safety distance shall take the following factors into account:

- dimensions of LV orbital stage;
- dimensions of SC;
- margin of clearance and spacing.

9 Analysis output

The output shall include the relative motion analysis result between LV and SC during analysis period, and general requirements shall include the following:

a) data shall be expressed in international unit;

b) present the illustration containing distance versus time curves;

c) conclusion.

Annex D presents a relative motion analysis template for information.

Annex A
(informative)

Relative motion analysis model

Centroid motion formulae are to be built for all objects involved respectively, including SC, LV and other components generated during the separation(s). Numerical simulations will be conducted taking the data at separation point as the initial value to predict the relative motion for objects in the analysis period.

The coordinate system can be selected according to specific requirements, and be confirmed between parties.

The basic motion formulae under Earth-fixed coordinate systems are presented for reference,

$$\begin{gathered}\begin{bmatrix}\dot{V}_x\\ \dot{V}_y\\ \dot{V}_z\end{bmatrix}=\begin{bmatrix}\dot{W}_x\\ \dot{W}_y\\ \dot{W}_z\end{bmatrix}+\begin{bmatrix}g_x\\ g_y\\ g_z\end{bmatrix}+\begin{bmatrix}a_{cx}\\ a_{cy}\\ a_{cz}\end{bmatrix}+\begin{bmatrix}a_{ex}\\ a_{ey}\\ a_{ez}\end{bmatrix}+\begin{bmatrix}\delta a_x\\ \delta a_y\\ \delta a_z\end{bmatrix}\\ \begin{bmatrix}\dot{X}\\ \dot{Y}\\ \dot{Z}\end{bmatrix}=\begin{bmatrix}V_x\\ V_y\\ V_z\end{bmatrix}\end{gathered}\tag{A.1}$$

where

$\left(\dot{W}_\mathrm{x} \quad \dot{W}_\mathrm{y} \quad \dot{W}_z\right)$	is the acceleration vector caused by manoeuvre;
$\left(g_x \quad g_y \quad g_z\right)$	is the earth gravity acceleration vector;
$\left(a_{cx} \quad a_{cy} \quad a_{cz}\right)$	is the Coriolis acceleration vector;
$\left(a_{ex} \quad a_{ey} \quad a_{ez}\right)$	is the centrifugal acceleration vector,
$\left(\delta a_x \quad \delta a_y \quad \delta a_z\right)$	is the perturbation acceleration vector;
$\left(V_x \quad V_y \quad V_z\right)$	is the velocity vector;
$\left(V_x \quad V_y \quad V_z\right)$	is the position vector.

Annex B

(informative)

Typical combination of deviations

A typical combination matrix is listed as shown in Table B.1, different choice of positive and negative are distributed.

Table B.1 — Typical combination of deviations

Dev.	Max. Sep. Vel	Min. Sep. Vel	Max. Sep. att. (pitch)	Min. Sep. att. (pitch)	Max. Sep. att. (yaw)	Min. Sep. att. (yaw)
Sep. Vel	+	—	—	—	—	—
Mass of orbital stage	—	+	—	—	—	—
De-orbit thrust	+	—	—	—	—	—
De-orbit att. (pitch)	—	—	+	—	—	—
De-orbit att. (yaw)	—	—	—	—	+	—
Sep. att. (pitch)	—	—	+	-	—	—
Sep. att. (yaw)	—	—	—	—	+	—

Annex C
(informative)

Coordinate reference frames and variables

Potential coordinate reference frames and variables applied are as follows:

- Earth-centred, Earth-fixed (ECEF) — Orthogonal system from the centre of the Earth with vertical axis through the geographic North Pole and horizontal axis fixed at 90° longitude.
- Body-fixed — Reference frame affixed to a designated satellite with vertical axis in the nadir direction.
- J2000 — x toward mean vernal equinox, z along Earth's mean rotational axis on 1 Jan 2000, 12:00:00.00 UTC.
- Perigee Orbital — Centered on the centre of the Earth, but in the orbital plane of a designated satellite. x toward perigee, y toward the motion direction at perigee.
- Launch centred earth-fixed — A earth-fixed orthogonal system from the launch point with vertical axis pointing upwards along plumb-line and horizontal lies on the horizontal plane, pointing at launch aim direction.
- Launch centred inertial — An orthogonal system superposes launch coordinate system at the lift-off moment, but keeps steady in the inertial space.
- Pitch, yaw and roll angle — A group of Euler angles used in flight dynamics. They describe the attitudes of LV/SC. They have differences in details when applied in engineering field and need explaining when addressed.

Annex D
(informative)

/*-***Preliminary (Final) relative motion analysis report after separation

D.1 Introduction

It is to present a brief introduction to the launch mission and general description on the operations after separations.

D.2 References

It is to list the related documents necessary to the analysis.

D.3 Input conditions

D.3.1 Objects properties

It is to list the related documents necessary to the analysis.

D.3.2 LV's manoeuvre after the separation

Relative separation velocity of SC from LV is **m/s with uncertainty **% at separation time. There is no manoeuvre for LV after the separation. Only J2 perturbation is considered in the analysis.

D.3.3 SC's manoeuvre after the separation

There is no manoeuvre for SC after the separation. Only J2 perturbation is considered in the analysis.

D.3.4 Separation parameters

Parameters at separation are presented as below,

Note the position and velocity are described in ** reference frame and attitude angle in ** reference frame.

D.4 Outputs

D.4.1 Relative distance time-history for short period

Within **s after the separation, the relative distance between end stage of **-** and **** varies with time as shown in Fig. A. It is shown that SC is safe and won't collide with end –stage in this short period.

D.4.2 Relative distance time-history for long-term period

s after the separation, SC completes its 3rd circle around the earth. The relative distance between end stage of **- and **** varies with time as shown in Fig. B. It is shown that SC is safe and won't collide with end –stage in this long-term period.

D.5 Conclusions

After the separation of **-**/**** mission, the distance between SC/LV gradually increases periodically. No collision will occur. Relative motion relations meet the requirements and safety can be guaranteed.

Bibliography

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[2] ISO 10784-2, *Space systems — Early operations — Part 2: Initialization plan*

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