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Space systems — Dynamic and static analysis — Exchange of mathematical models

Systèmes spatiaux — Analyse dynamique et statique — Échange de modèles mathématiques

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 14954 was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Space systems — Dynamic and static analysis — Exchange of mathematical models

1 Scope

This International Standard normalizes the exchange of mathematical models between payload contractors (PLC) and launch service providers (LSP). It identifies standard methods for modelling the dynamic behaviour of both launch vehicles (LV) and payload (PL), particularly when they are coupled prior to launch and during the early moments of the launch phase.

In standard mode, the delivered models represent dynamic and static behaviour at the launcher interface. The requirements provided in this International Standard are the minimum necessary for dynamic coupled analysis. They may not be sufficient for stress analysis. The payload models are full integrated models from the different parts of the payload under the payload contractor authority, including also their own adapter to LV interface in the case that the adapter is a part of the payload.

This International Standard does not include the validation of PL models.

2 Normative references

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

ISO/IEC 646, *Information technology — ISO 7-bit coded character set for information interchange*

3 Terms, definitions, symbols, and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1
payload
system that is launched by a launch vehicle

EXAMPLES Satellite, spacecraft, space probe.

3.1.2
payload contractor
organization in charge of a payload

3.1.2
launch service provider
organization that conducts a launch with a launch vehicle

3.2 Abbreviated terms

ATM acceleration transformation matrix

CoG centre of gravity

DoF degree of freedom

DTM displacement transformation matrix

EOF end of file

ICD interface control document

LSP launch service provider

LTM load transformation matrix

LV launch vehicle

OTM output transformation matrix

PL payload

PLC payload contractor

SI International System of Units

3.3 Symbols

$\boldsymbol{A}$ acceleration transformation matrix

$\boldsymbol{C}$ damping matrix

$\boldsymbol{D}$ displacement transformation matrix

$\boldsymbol{K}$ stiffness matrix

$\boldsymbol{K}_\mathrm{R}$ stiffness matrix of rigid body modes, $\boldsymbol{K}_\mathrm{R} = \boldsymbol{\phi}_\mathrm{R}^\mathrm{T} \boldsymbol{K} \boldsymbol{\phi}_\mathrm{R}$

$\boldsymbol{L}$ load transformation matrix

$\boldsymbol{M}$ mass matrix

$\boldsymbol{M}_\mathrm{R}$ mass matrix of rigid body modes, $\boldsymbol{M}_\mathrm{R} = \boldsymbol{\phi}_\mathrm{R}^\mathrm{T} \boldsymbol{M} \boldsymbol{\phi}_\mathrm{R}$

S_e strain energy

q_is internal degrees of freedom

q_j degrees of freedom of the interface

$\boldsymbol{\phi}_\mathrm{R}$ matrix of rigid body modes

η_k modal coordinates

4 General description of models

4.1 Matrices

The mathematical model of a PL shall be made of three matrices [mass matrix ($\boldsymbol{M}$), stiffness matrix ($\boldsymbol{K}$), and damping matrix ($\boldsymbol{C}$)]. It shall be sufficient to characterize the dynamic and static behaviour of the structure, assuming that no external forces are applied to the payload except through the LV-PL interface.

A modal synthesis method is a typical procedure used to generate a reduced mathematical model.

Additional matrices may be provided in order to reconstitute acceleration, displacement or load in the PL.

These matrices are identified as OTMs in the following clauses.

4.2 Types of models

4.2.1 Physical models

Physical models shall be represented by matrices, the dynamic and static behaviour of which is described solely by the DoFs related to physical displacement at nodal points, including all interface points.

4.2.2 Modal models

Modal models shall be represented by matrices, the dynamic and static behaviour of which is described solely by a mix of physical and modal DoFs (representing the modes of the structure fixed at previous physical DoFs). Only interface DoFs are physical DoFs.

4.2.3 Hybrid models

Hybrid models are extensions of modal models for which internal physical DoFs other than the interface DoFs are included.

4.3 Units

All numerical input and output data shall be expressed in SI. Acceleration may be expressed in g, where $g = 9{,}81\ \text{m/s}^2$.

Use of units other than those of SI is an exception that shall be submitted for the approval of the LSP.

5 General requirements

5.1 Modelling codes

The software (name and version) and the type of finite elements used for the modelling of the PL shall be indicated.

The condensation procedure applied to the original dynamic model shall be described.

5.2 Co-ordinate systems

A reference co-ordinate system for the PL model shall be defined. A drawing of the PL ensemble with its co-ordinate system shall be included in the written report.

The orientation of the PL axes with respect to the LV shall be defined by the LSP, based on compliance with requirements of clearance between PL and LV structures, on pad access to the PL, and on mechanical and electrical interfaces as stipulated in the ICD.

The same reference system shall be used for the geometrical description of the PL and for the definition of the DoFs in the mass and stiffness matrices.

The axis system shall be cartesian.

A local co-ordinate system may be used but shall be clearly defined. For interfaces, all reference shall be made to the reference co-ordinate system.

5.3 Theoretical aspects for modelling

5.3.1 General modelling

The model shall describe the complete, dynamic, three-dimensional PL behaviour in free-free conditions and also clamped at its interface with the launch vehicle. The model shall be representative up to a frequency specified by the LSP.

5.3.2 Liquid modelling

If the payload contains significant liquid propellant mass, the model shall describe the slosh motions of these liquids, neglecting the surface tension and assuming that the equilibrium surface is perpendicular to the liquid's quasi-static net acceleration vector, when required by the LSP.

The effects of fluid-structure interaction shall be taken into account in the prescribed frequency range.

Typical values of quasi-static acceleration shall be provided by the LSP for loading cases to be considered.

5.3.3 Damping modelling

Damping is usually based on approximations derived from engineering judgement and tests. It may be defined at the PL level, in which case a PL damping matrix shall be a part of the mathematical model.

Damping may be defined at the system level by agreement between PLC and LSP, in which case no damping matrix is required. However, if necessary, the dependence of damping on frequency may be provided.

5.3.4 Interface modelling

When the interface between the PL and the LV may be considered rigid, as approved by both the PLC and the LSP, the interface can be condensed to one node with six DoFs.

Modelling of the PL-LV interface shall require greater accuracy when the flexibility of the interface might induce higher loads on the PL. This issue shall be discussed by both parties prior to the preliminary coupled analysis cycle.

6 Condensation methods

6.1 Condensed physical model

6.1.1 General

The choice of method of condensation is left to the discretion of the writer of the model. The condensed model shall be compliant with requirements given in Clause 7.

The nodal points and DoF shall be defined as in 6.1.2.

6.1.2 Requirements

6.1.2.1 Unless otherwise specified, each physical nodal point of the interface shall have six DoFs in the reference co-ordinate system:

$$\mathrm{T}_X = \text{DoF 1},\ \mathrm{T}_Y = \text{DoF 2},\ \mathrm{T}_Z = \text{DoF 3},\ \mathrm{R}_X = \text{DoF 4},\ \mathrm{R}_Y = \text{DoF 5},\ \mathrm{R}_Z = \text{DoF 6}$$

where T is translation, R is rotation and X, Y, Z are the axes.

6.1.2.2 The DoFs shall be ordered in the matrices first according to the numbering of the nodes and second according to the numbering of the DoFs as listed in 6.1.2.1.

6.1.2.3 A local co-ordinate system may be used but shall be defined. In general, local co-ordinates are excluded for the interface DoFs.

6.1.2.4 Nodal point co-ordinates shall be expressed in the reference system of the PL.

6.1.2.5 As a result of these rules, the mass, stiffness and damping matrices may have a size less than $6N \times 6N$, where N is the number of nodal points.

6.1.2.6 The OTMs may be supplied with related user instructions. The output parameters shall be linearly dependent on the acceleration and/or displacement of nodal points.

Thus, the OTMs are likely to have the same number of columns as the stiffness and mass matrices and P rows, where P is the number of output parameters.

6.2 Modal model

6.2.1 General

The dynamic behaviour of the PL shall be described by the reduced stiffness, mass and damping matrices, relative to the elastic modes (modal co-ordinates, η_k) and the interface nodes (the interface DoF, q_j).

This size of the stiffness and mass matrices (and the damping matrix if provided) is Q rows × Q columns, such that

$$Q = Q_l + Q_m$$

where:

Q_l = number of degrees of freedom of the interface

Q_m = number of elastic modes

