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Space engineering - Buckling of structures

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Ingénierie spatiale - Flambement des structures

Raumfahrttechnik - Handbuch Knicken und Beulen von Strukturen

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European Foreword

This document (CEN/TR 17603-32-24:2022) has been prepared by Technical Committee CEN/CLC/JTC 5 “Space”, the secretariat of which is held by DIN.

It is highlighted that this technical report does not contain any requirement but only collection of data or descriptions and guidelines about how to organize and perform the work in support of EN 16603-32.

This Technical report (CEN/TR 17603-32-24:2022) originates from ECSS-E-HB-32-24A.

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

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

This document has been developed to cover specifically space systems and has therefore precedence over any TR covering the same scope but with a wider domain of applicability (e.g.: aerospace).

Introduction

The handbook is organised in three parts:

- Part 1: General.

  It includes chapters 4 to 13, and provides general information on the structural stability.

  — Chapter 4 addresses the history of stability problems starting from Euler (1757), who investigated buckling of beams as well as of plates. More recently, during the past 50 years, the discrepancy between experiments and linear buckling analysis as well as the large scatter of the tests stimulated a large amount of research work. The focus was especially on the influence of boundary conditions, of the nonlinear pre-buckling behaviour, of the postbuckling behaviour of the perfect shell and of the buckling and postbuckling behaviour of the imperfect shell.

  — In chapter 5 the occurrence of different types of instabilities are discussed on hand of relatively simple examples. The following topics are addressed: elastic buckling of columns; buckling of thin plates; instability of axially compressed cylindrical panels; structural behaviour of thin shells.

  — The first scope of chapter 6 is to give a survey of all the types of analysis which could be used for the study of stability. A simple descriptive presentation is provided to fix a common language and a clear understanding. For rigorous derivation and comprehensive details, proper reference is indicated. A second scope is to categorize the phenomena of loss of stability, by indicating for each type the appropriate analysis to be performed.

  — Chapter 7 addresses the following topics: linear elasticity and elastic properties; strength properties and hygro-thermal properties; elastic and inelastic material behaviour; plasticity and damage; material testing methods, test data, and evaluation.

  — Chapter 8 describes the design to stability and its verification by analysis. The following topics are included: the design development process; analysis pre-work and load input data; safety concept and factors of safety; dimensioning load cases selection; stability design allowable and knock-down-factors; analyses, modelling, and design aspects; procedure of design verification, including the determination of the margin of safety.

  — Chapter 9 describes the influence of manufacturing and assembly processes on the buckling load.

  — In chapter 10 the use of the finite element method and the numerical procedures applied to perform a buckling or post-buckling analysis are described with a focus on space applications. A guide to select the most adequate solution scheme is provided.

  — This handbook promotes the “Hierarchical High Fidelity Analysis” approach, which is reported in chapter 11. In practice, in order to arrive at a reliable prediction of the critical buckling load and to make an estimate of its imperfection sensitivity which can be used with confidence, the structural analyst should proceed step by step from simple analytical solutions (Level-1) to more complex models and solution procedures (Level-3).

This chapter provides a detailed description of the hierarchical high fidelity analysis approach including a flow chart establishing a strategy to handle buckling phenomena.

— Chapter 12 is dedicated to the buckling experimental methods and design verification by tests. Experiments can explore the physical behaviour near buckling, at buckling and in the post-buckling range and they also yield empirical data upon which design guidelines can be based. The realization of the tests can be done at several levels: tests on elementary sample, tests on structural elements and test on full scale structure.

— The test instrumentation is described in chapter 13. It deals with measurement techniques in structural testing and measurement systems.

- Part 2: Structural elements with examples

  It includes chapters 14 to 17, and it is devoted to structural elements with examples. It reports the mathematical formulae for calculating the buckling loads for the most common structural elements, loads and boundary conditions.

  — Chapter 14 is an introductory chapter covering the following topics: static versus kinematic approach; problems requiring nonlinear analysis; approximate solutions of bifurcation problems; computational tools for bifurcation problems.

  — The remaining chapters 15, 16 and 17, present the solutions with examples for the following structural elements: columns, beams, arches, and rings; flat and curved panels; closed shells.

- Part 3: Structures

  It includes chapters 18 to 23, and addresses the “real world” structures.

  — Chapter 18 is an introductory chapter describing the design, analysis and testing aspects of large aerospace structures, including the approach for the mathematical model correlation and validation. Relevant flow-charts and examples are provided, mainly related to the structure of the European launcher ARIANE 5.

  The remaining chapters 19 to 23 report various “large examples” provided by various European aerospace companies.

  — The buckling analysis and test activities performed on the liquid hydrogen (LH2) tank of the ESC-A ARIANE 5 stage are presented in chapter 19.

  — Chapter 20 describes the Inner Dome of the ARIANE 5 Upper Stage ESC-A. This structure is subjected to compressive loads in case of internal pressure. For this reason the Inner Dome shell has been designed carefully against buckling.

  — The results of the non-linear stability analysis performed on the ARIANE 5 Front Skirt (JAVE) and its adjacent structures are summarized in chapter 21. The chapter presents the main characteristics of the mathematical model, including the definition of material models, loadings, geometric and physical imperfections and analysis technique.

  — Chapter 22 presents the results of the buckling analyses and static strength tests of the Interstage 1/2 for the Vega launch vehicle. The Interstage 1/2 is constructed as monocoque and is buckling critical, hence the need to obtain accurate predictions for buckling strength, including the influence of initial imperfections. The Interstage 1/2 was qualified by a static load test, and then was further loaded to final failure in a rupture test.

  — Finally, chapter 23 reports the results of the stability analysis of the 3rd-stage skirts of the European launcher ELDO-A.

1 Scope

The document recommends engineering practices for European programs and projects. It may be cited in contracts and program documents as a reference for guidance to meet specific program/project needs and constraints.

The target users of this handbook are engineers involved in design, analysis and verification of launchers and spacecraft in relation to structural stability issues. The current know-how is documented in this handbook in order to make this expertise available to all European developers of space systems.

It is a guidelines document; therefore it includes advisory information rather than requirements.

2 References

Due to the structure of the document, each chapter includes at its end the references called in it.

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