



BSI Standards Publication

Space Engineering — Thermal design handbook

Part 16: Thermal Protection System

National foreword

This Published Document is the UK implementation of CEN/CLC/TR 17603-31-16:2021.

The UK participation in its preparation was entrusted to Technical Committee ACE/68, Space systems and operations.

A list of organizations represented on this committee can be obtained on request to its committee manager.

Contractual and legal considerations

This publication has been prepared in good faith, however no representation, warranty, assurance or undertaking (express or implied) is or will be made, and no responsibility or liability is or will be accepted by BSI in relation to the adequacy, accuracy, completeness or reasonableness of this publication. All and any such responsibility and liability is expressly disclaimed to the full extent permitted by the law.

This publication is provided as is, and is to be used at the recipient's own risk.

The recipient is advised to consider seeking professional guidance with respect to its use of this publication.

This publication is not intended to constitute a contract. Users are responsible for its correct application.

This publication is not to be regarded as a British Standard.

© The British Standards Institution 2021
Published by BSI Standards Limited 2021

ISBN 978 0 55 17018 4

ICS 49.040

Compliance with a Published Document cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 31 August 2021.

Amendments/corrigenda issued since publication

| Date | Text affected |
|------|---------------|
|------|---------------|

TECHNICAL REPORT
RAPPORT TECHNIQUE
TECHNISCHER BERICHT

**CEN/CLC/TR 17603-31-
16**

August 2021

ICS 49.140

English version

**Space Engineering - Thermal design handbook - Part 16
Thermal Protection System**

Ingénierie spatiale - Manuel de conception thermique -
Partie 16 : Protection Thermique des véhicules
spatiaux

Raumfahrttechnik - Handbuch für thermisches Design -
Teil 16: Thermalschutzsysteme

This Technical Report was approved by CEN on 28 June 2021. It has been drawn up by the Technical Committee CEN/CLC/JTC 5.

CEN and CENELEC members are the national standards bodies and national electrotechnical committees of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.



**CEN-CENELEC Management Centre:
Rue de la Science 23, B-1040 Brussels**

Table of contents

| | |
|--|-----------|
| European Foreword | 5 |
| 1 Scope | 6 |
| 2 References | 7 |
| 3 Terms, definitions and symbols | 8 |
| 3.1 Terms and definitions | 8 |
| 3.2 Abbreviated terms..... | 8 |
| 4 Introduction | 9 |
| 4.1 General..... | 9 |
| 4.2 Classification of thermal protection systems | 10 |
| 5 Ablative systems | 14 |
| 5.1 General..... | 14 |
| 5.2 Ablative materials | 14 |
| 5.3 Basic analysis..... | 15 |
| 5.3.1 Surface equilibrium | 16 |
| 5.4 Existing systems..... | 19 |
| 5.4.1 Galileo probe..... | 19 |
| 6 Radiative systems | 23 |
| 6.1 General..... | 23 |
| 6.2 Radiative materials | 23 |
| 6.3 Existing systems..... | 24 |
| 6.3.1 Space shuttle | 24 |
| 6.4 Other developments | 35 |
| 6.4.1 X-38..... | 35 |
| Bibliography | 54 |

Figures

| | |
|---|----|
| Figure 4-1: Velocity-altitude map for the Space Shuttle. Lifting re-entry from orbit..... | 9 |
| Figure 4-2: Summary of re-entry trajectories. From East (1991) [6]. | 10 |

| | |
|---|----|
| Figure 4-3: Sketch of an ablative thermal protection system..... | 11 |
| Figure 4-4: Sketch of a radiative thermal protection system..... | 11 |
| Figure 4-5: Sketch of a transpiration thermal protection system. | 12 |
| Figure 4-6: Typical transpiration cooling system..... | 13 |
| Figure 5-1: Surface energy balance..... | 17 |
| Figure 5-2: Galileo entry probe..... | 20 |
| Figure 5-3: Physical model and phenomena considered in material response analysis..... | 20 |
| Figure 5-4: Temperature history at interfaces. | 22 |
| Figure 5-5: Comparison of mass loss fluxes. | 22 |
| Figure 6-1: Worst case peak predicted surface temperatures. [K] for STS-1. From Dotts et al. (1983) [5]..... | 25 |
| Figure 6-2: Worst case peak predicted structure temperatures. [K] for STS-1. From Dotts et al. (1983) [5]..... | 25 |
| Figure 6-3: Thermal protection subsystems. From Dotts et al. (1983) [5]..... | 26 |
| Figure 6-4: RCC system components. From Curry et al. (1983) [3]. | 27 |
| Figure 6-5: Nose cap system components. From Curry et al. (1983) [3]. | 27 |
| Figure 6-6: Wing leading-edge system components. From Curry et al. (1983) [3]..... | 28 |
| Figure 6-7: Tile attachment and gap filler configuration. From Dotts et al. (1983) [5]. | 29 |
| Figure 6-8: Nose cap RCC surface comparison between prediction and flight data. From Curry et al. (1983) [3]..... | 30 |
| Figure 6-9: Nose cap access door tile surface comparison between prediction and flight data. From Curry et al. (1983) [3]. | 30 |
| Figure 6-10: Wing leading-edge panel (stagnation area). Comparison between prediction and flight data. From Curry et al. (1983) [3]..... | 31 |
| Figure 6-11: STS-1 flight data analysis comparison for lower mid-fuselage location. From Dotts et al. (1983) [3]..... | 31 |
| Figure 6-12: STS-1 flight data analysis comparison for lower wing location. From Dotts et al. (1983) [3]. | 32 |
| Figure 6-13: STS-1 flight data analysis comparison for lower inboard elevon location. From Dotts et al. (1983) [3]..... | 32 |
| Figure 6-14: STS-1 flight data analysis comparison for lower mid-fuselage side location. From Dotts et al. (1983) [3]. | 33 |
| Figure 6-15: Comparison of STS-2 data with analytical predictions. From Normal et al. (1983) [11]..... | 33 |
| Figure 6-16: Comparison of STS-2 data with analytical predictions. From Normal et al. (1983) [11]..... | 34 |
| Figure 6-17: Comparison of STS-2 data with analytical predictions. From Normal et al. (1983) [11]..... | 34 |
| Figure 6-18: In-depth comparison of STS-2 data with analytical predictions for maximum temperatures. From Normal et al. (1983) [11]. | 35 |
| Figure 6-19: X-39 TPS Configuration..... | 36 |
| Figure 6-20: X-38 Reference Heating..... | 36 |

Figure 6-21: CMC Side Panels together with lower CMC Chin Panel37

Figure 6-22: Stand-off Position and Global Design38

Figure 6-23: Stand-off Positions and Global Design39

Figure 6-24: Max. Pressure Load40

Figure 6-25: Max. Thermal Load at Panel Surface40

Figure 6-26: Nose Skirt Assembly with Insulation Blankets41

Figure 6-27: Max. and min. Heat flux time lines applied on the NSK.....41

Figure 6-28: Simplified description of heat transfer modes within the nose skirt
assembly.....42

Figure 6-29: Temperature distribution over a NSK side panel at t = 1100s.....41

Figure 6-30: Carrier Panel TPS Design45

Figure 6-31: X-38 Aeroshell Panel and Blanket Distribution46

Figure 6-32: X-38 Parafoil System.....46

Figure 6-33: Parafoil Line Routing and Acreage Blankets.....46

Figure 6-34: FEI-450 Blanket equipped with Gray FEI-1000High Emissance Coating.....47

Figure 6-35: Typical look of FEI-650 and Blanket with Gray High Emissance47

Figure 6-36: Allocation of Blanket Types to the X-38 Lee-Side Surface.....49

Figure 6-37: Qualification Test Sequence for X-3850

Figure 6-38: Parameters and Results of the Qualification Tests50

Figure 6-39: Computer controlled sewing of FEI blankets.....52

Figure 6-40: FEI-1000 blankets of the Forward Fuselage.....52

Figure 6-41: FEI Blankets Integrated on the X-38 V-20153

European Foreword

This document (CEN/CLC/TR 17603-31-16:2021) 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 17603-31.

This Technical report (TR 17603-31-16:2021) originates from ECSS-E-HB-31-01 Part 16 A.

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).

1

Scope

The thermal protection system (TPS) of a space vehicle ensures the structural integrity of the surface of the craft and maintains the correct internal temperatures (for crew, electronic equipment, etc.) when the vehicle is under the severe thermal loads of re-entry. These loads are characterised by very large heat fluxes over the relatively short period of re-entry.

The design of thermal protection systems for re-entry vehicles is very complex due to the number and complexity of phenomena involved: the flow around the vehicle is hypersonic, tri-dimensional and reactive, and its interaction with the vehicle's surface may induce chemical reactions which are not fully understood.

Two TPS concepts for re-entry vehicles, ablative and radiative are examined and there is also an analysis of existing systems using them.

The Thermal design handbook is published in 16 Parts

| | |
|----------------|--|
| TR 17603-31-01 | Thermal design handbook – Part 1: View factors |
| TR 17603-31-02 | Thermal design handbook – Part 2: Holes, Grooves and Cavities |
| TR 17603-31-03 | Thermal design handbook – Part 3: Spacecraft Surface Temperature |
| TR 17603-31-04 | Thermal design handbook – Part 4: Conductive Heat Transfer |
| TR 17603-31-05 | Thermal design handbook – Part 5: Structural Materials: Metallic and Composite |
| TR 17603-31-06 | Thermal design handbook – Part 6: Thermal Control Surfaces |
| TR 17603-31-07 | Thermal design handbook – Part 7: Insulations |
| TR 17603-31-08 | Thermal design handbook – Part 8: Heat Pipes |
| TR 17603-31-09 | Thermal design handbook – Part 9: Radiators |
| TR 17603-31-10 | Thermal design handbook – Part 10: Phase – Change Capacitors |
| TR 17603-31-11 | Thermal design handbook – Part 11: Electrical Heating |
| TR 17603-31-12 | Thermal design handbook – Part 12: Louvers |
| TR 17603-31-13 | Thermal design handbook – Part 13: Fluid Loops |
| TR 17603-31-14 | Thermal design handbook – Part 14: Cryogenic Cooling |
| TR 17603-31-15 | Thermal design handbook – Part 15: Existing Satellites |
| TR 17603-31-16 | Thermal design handbook – Part 16: Thermal Protection System |