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Vesoljska tehnika - Priročnik za toplotno zasnovo - 16. del: Sistem toplotne zaščite

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

Raumfahrttechnik - Handbuch für thermisches Design - Teil 16: Wärmeschutzsystem

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

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ICS:

49.140	Vesoljski sistemi in operacije	Space systems and operations

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

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Raumfahrttechnik - Handbuch für thermisches Design - Teil 16: Wärmeschutzsystem

This draft Technical Report is submitted to CEN members for Vote. It has been drawn up by the Technical Committee CEN/CLC/JTC 5.

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Rue de la Science 23, B-1040 Brussels

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Table of contents

Figures

European Foreword

This document (FprCEN/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.

This document is currently submitted to the Vote on TR.

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 16603-31.

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

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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).

This document is currently submitted to the CEN CONSULTATION.

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, tridimensional 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 anlyisis 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

2 References

EN Reference	Reference in text	Title
EN 16603-00-01	ECSS-S-ST-00-01	ECSS System - Glossary of terms

All other references made to publications in this Part are listed, alphabetically, in the **Bibliography**.

3
Terms, definitions and symbols

3.1 Terms and definitions

For the purpose of this Standard, the terms and definitions given in ECSS-S-ST-00-01 apply.

3.2 Abbreviated terms

The following abbreviated terms are defined and used within this Standard.

CAD	computer aided design
CFD	computational fluid dynamics
CMC	ceramics matrix composite
C/SiC	carbon reinforced silicon carbide
FEI	flexible external insulation
FRSI	flexible reusable surface insulation
HTI	high temperature insulation
HRSI	high-temperature reusable surface insulation
IFI	internal flexible insulation
LRSI	low-temperature reusable surface insulation
RCC	reinforced carbon-carbon
RSI	reusable surface insulation
SIP	strain isolation pad
SOML	structural outer mold line
TOML	TPS outer mold line
TPS	thermal protection system

4 Introduction

4.1 General

The thermal protection system (TPS) of a space vehicle consists of those elements needed to protect the structural integrity of the vehicle's surface and maintain the appropriate internal temperatures (for crew, electronic equipment, etc.) when the vehicle is under the severe thermal loads of re-entry. These loads are mainly characterised by very large heat fluxes during relatively short times.

The heat fluxes acting on the TPS are so large because of the great speeds of re-entry vehicles. The velocity-altitude map for the Space Shuttle is represented in Figure 4-1.

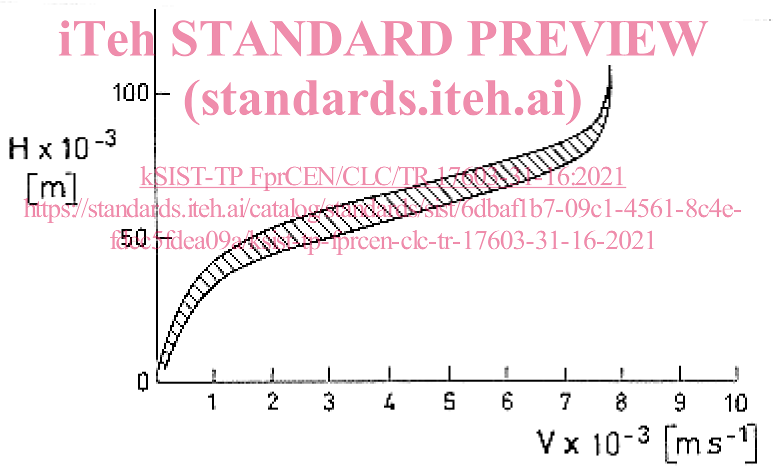

Figure 4-1: Velocity-altitude map for the Space Shuttle. Lifting re-entry from orbit.

The heat fluxes and the time of re-entry are basically determined by the re-entry orbit. These orbits are designed so that the vehicle is captured by the planet and the payload is not damaged by the accelerations; these factors greatly restrict the number of valid trajectories. However, for lifting vehicles which can be manoeuvred those restrictions are alleviated, and re-entry trajectories, other than ballistic, can be achieved. In Figure 4-2 the heat fluxes and re-entry times for different trajectories are summarised.

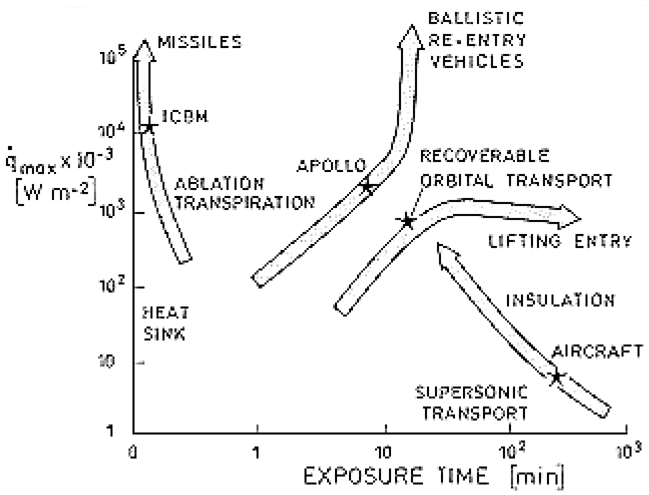

Figure 4-2: Summary of re-entry trajectories. From East (1991) [6].

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

4.2 Classification of thermal protection systems

Generally speaking the TPS consists of a material system (shield and/or load carrying member) operating on a given heat dissipation principle. There are several TPS concepts for re-entry vehicles (Hurwicz & Rogan (1973a) [9]):

- Ablative thermal protection
- Radiative thermal protection
- Heat sinks
- Transpiration cooling

ABLATIVE SYSTEMS

Ablative systems operate dissipating the incident thermal energy through the loss of material: these systems lose mass as a consequence of the ablation of the external surface material. They have good thermal characteristics since phase changes absorb a large amount of energy. These systems are not reusable. See Figure 4-3 for a sketch of an ablative system.

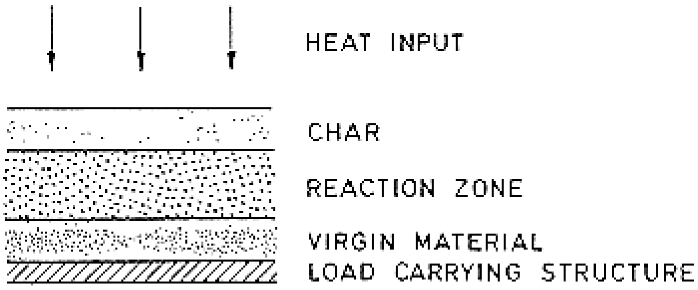

Figure 4-3: Sketch of an ablative thermal protection system.

The ablation process is quite complex and is described in some detail in clause 5.2. One important consequence of the analysis of these systems is that their efficiency is particularlysensitive to material performance. Therefore, it is necessary to treat the subject of materials in detail. In the absence of a universally acceptable ablative material a wide variety of ablative compositions and constructions have been produced, usually tailored to satisfy the requirements of a specific vehicle for a specific mission. A detailed description of ablative materials is given in clause 5.3.

RADIATIVE SYSTEMS

Radiative systems operate re-emitting by radiation the energy received from the surrounding environment. They are composed of two layers: an outer layer which consists of a material that can stand the radiation equilibrium temperature and an inner layer which insulates the outer layer from the structure in order to minimise the heat flow between the two, see Figure 4-4.

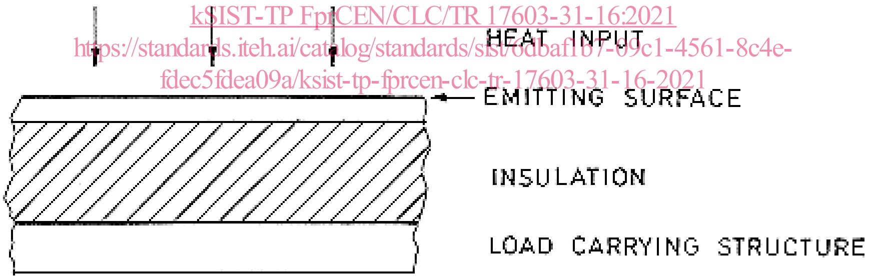

Figure 4-4: Sketch of a radiative thermal protection system.

It will be seen in clause 6.1 that the effectiveness of a radiative system increases very rapidly with increasing surface temperatureand surface emissivity. Consequently, the primary development efforts have been concerned with the improvement of high emissivity, high temperature coatings, and with increasing the material service temperatures (including that of the internal insulation). A detailed description of materials used in radiative systems is given in clause 6.2.

These systems can be designed including a cooling subsystem: this is a fluid loop where the working fluid transports heat from the areas where the heat flux is stronger to those where the heat flux is weaker. The actual mechanism for heat transport can be the same as in heat pipes, the fluid is vaporised in areas of higher temperatures, and it is condensed in areas of lower temperatures. However, even though the characteristics of these systems are good, they are not used in practice.

HEAT SINK THERMAL PROTECTION SYSTEM

A heat sink is the simplest type of absorptive thermal protection system. It was used in the design of the early re-entry vehicles (e.g. the first two manned Mercury vehicles).

These systems are composed of an outer layer, comparatively thick, which consists of a material of high conductivity and capacitance. The function of this layer is to absorb the heat input. Since the material heats up, the storage capability is limited by the melting temperature.

Its use is limited to relatively low heating rates and therefore may not be practical for the high heat loads encountered in short re-entry times.

Heat sinks have the advantages of simplicity, dependability, and for reusable vehicles, ease of refurbishment. Their outstanding disadvantage is their low efficiency, this would cause a heat sink sized to satisfy most current re-entry missions to be excessively heavy.

Materials commonly used as heat sinks are

- beryllium
- beryllium oxide (beryllia)
- copper.

Graphite has many desirable heat sink characteristics, but begins to oxidise at temperatures far below those required for best efficiency.

TRANSPIRATION COOLING

Transpiration systems are systems where fluid is injected through a porous medium into the boundary layer. The structure is maintained cool by two basic mechanisms: heat is conducted to the coolant as it flows through the structure, and as the coolant is ejected out the surface it reduces the surface heat transfer rate by cooling and thickening the boundary layer. See Figure 4-5 for a sketch.

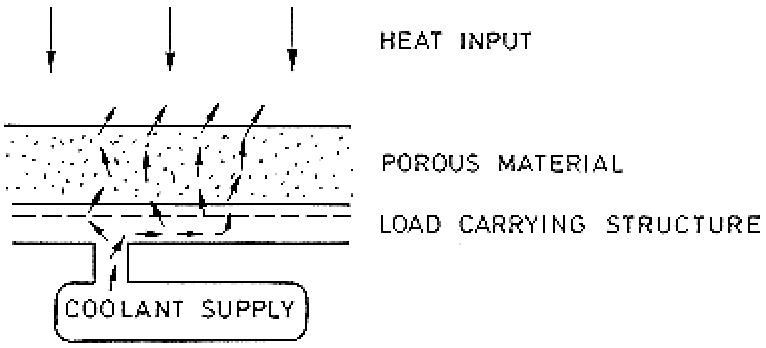

Figure 4-5: Sketch of a transpiration thermal protection system.

In some applications, the shape change caused by the surface recession of an ablating surface is not acceptable for aerodynamic performance reasons. In such cases, if the environment is too severe for radiative or heat sink systems, transpiration cooling may be the only practical solution. This TPS makes possible performance in environments that could not otherwise be withstood. However, its mechanical complexity (see Figure 4-6), with the associated reliability problems, tend to limit its use.

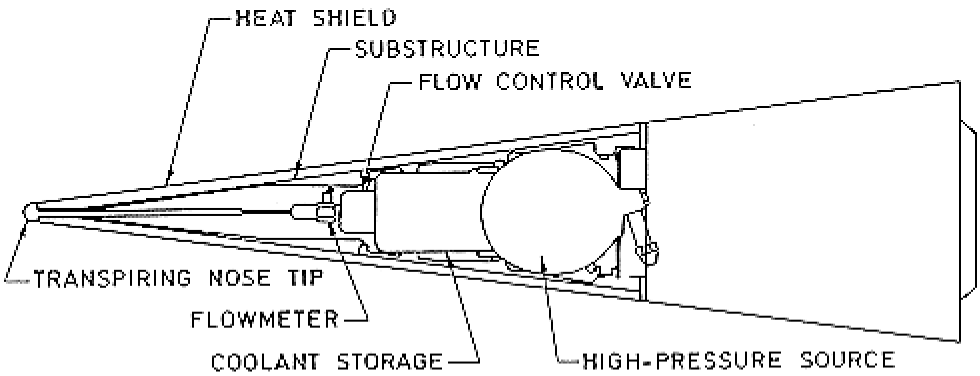

Figure 4-6: Typical transpiration cooling system

For re-entry application, the most acceptable coolants are:

- H_2O
- NH_3
- CF_4
- CO_2