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Vesoljska tehnika - Priročnik o toplotni zasnovi - 2. del: Luknje, utori in votline

Space Engineering - Thermal design handbook - Part 2: Holes, Grooves and Cavities

Raumfahrttechnik - Handbuch für thermisches Design - Teil 2: Löcher, Nuten und Hohlräume

Manuel de conception thermique - Partie 2: Trous, rainures et cavités

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Space Engineering - Thermal design handbook - Part 2: Holes, Grooves and Cavities

Ingénierie spatiale - Manuel de conception thermique - Partie 2 : Trous, rainures et cavités

Raumfahrttechnik - Handbuch für thermisches Design - Teil 2: Löcher, Nuten und Hohlräume

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

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European Foreword

This document (CEN/CLC/TR 17603-31-02:2021) 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 16603-31.

This Technical report (TR 17603-31-02:2021) originates from ECSS-E-HB-31-01 Part 2A .

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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).

1
Scope

In this Part 2 of the spacecraft thermal control and design data handbooks, the radiant heat transfer properties of cavities that do not contain an absorbing-emitting medium are analyzed. The effect of radiant energy entering a cavity with one or more openings is discussed taking into consideration the characteristics and properties of the constituents. Examples support the solutions discussed.

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 16601-00-01	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 Symbols

A_c	surface area of the cavity, [m^2]
A_h	area of the surface tightly stretched over the cavity opening, [m^2]
T_W	cavity wall temperature, [K]
T_i	surrounding temperature facing the ith opening, [K]
α	hemispherical total absorptance of a surface
ε	hemispherical total emittance of a surface, the surface is assumed to be diffuse-gray, unless otherwise stated

Subscript

a	apparent radiation property of the cavity

Other Symbols, mainly used to define the geometry of the configuration, are introduced when required.

4
Gray diffuse surfaces

4.1 General

The radiant heat transfer properties of cavities which do not contain an absorbing-emitting medium are analyzed in this item.

When radiant energy arrives to a cavity, having one or more openings, it suffers several reflections and the corresponding absorptions at the walls of the cavity. Hence, the following effects can be observed:

1. The absorption within a single-opening cavity will exceed that of a surface, of the same absorptance, tightly stretched over the cavity opening.
2. the emission from a heated single-opening cavity will exceed that of the surface, of identical emittance and temperature, tightly stretched over the cavity opening.
3. The net radiant heat transfer rate through a passage, open at both ends, and connecting two isothermal media at different temperatures, is smaller than the net radiant heat transfer rate between the same media when separated by a non absorbing-non emitting intermediate layer.

In most cases the cavity surfaces are regarded as gray and diffuse emitters and reflectors. Nondiffuse and/or non gray conditions have been considered in several instances; particularly relevant is the case of specular reflection (Siegel & Howell (1972) [15]).

Concerning the characteristics of the incoming radiation, either of the following two extreme alternatives are normally considered: diffuse distribution of radiation across the cavity openings, or parallel radiation.

The analysis of the radiant interchange between cavities and their environment can be achieved in a unified fashion when attention is paid to the following characteristics of the problem:

1. Openings can be treated as walls of the whole enclosure which have the property of absorbing all of the radiant energy incident upon them, and of emitting al the radiant energy streaming into the enclosure through them.
2. The cavity is normally isothermal over all its material surfaces. The enclosure representing a cavity with n openings exhibits the following distribution of temperature: $T = T_W$ for the material surfaces; $T = T_i$ ($i = 1,2,...n$) for the opening facing the surrounding at temperature T_i.
3. When it is assumed that the optical characteristics of the surfaces are temperature invariant, the equation expressing the radiant interchange at any elemental surface are linear in T_W^4 and T_i^4 ($i = 1,2,...n$), thence a linear superposition of elemental solutions is justified.

The solution of the whole problem is expressed as the superposition of n+1 different solutions; all of them concern the same geometrical enclosure, having n temperatures equal to zero and the remaining one equal to that of the whole problem at the corresponding surface.

Simple examples, which will illustrate the usefulness of this superposition, are given in the following.

To introduce the concept of apparent absorptance of a cavity, which to simplify the presentation is assumed to have only one opening, this opening is assimilated to a black-body surface at the temperature T_1, while the cavity walls are at absolute zero.

The apparent absorptance, α_a, of the cavity is defined as the ratio of the energy absorbed by the cavity to the incoming radiant energy. Obviously, the radiant energy emitted by the cavity wall is zero and in no case should be taken into account for computing the apparent absorptance, α_a, of the cavity.

Conversely, for computing the apparent emittance of the cavity it is assumed that the walls are at temperature T_W, while the surroundings are at absolute zero. The radiant energy which could reach the cavity opening from an external source is not taken into account in the computation of the emittance of the cavity.

The apparent emittance, ε_a, of a cavity is the ratio of the radiative flux from the cavity to the radiative flux from an identically shaped, black-walled cavity at the same temperature.

For gray-walled cavities irradiated by a diffusely distributed incoming radiation, the apparent emittance, ε_a, equals the apparent absorptance, α_a, provided that any of the following conditions applies (Sparrow (1965) [17]):

1. The cavity walls are diffuse emitters and diffuse reflectors.
2. The cavity walls are diffuse emitters and specular reflectors.
3. The radiant flux leaving a surface element is black and diffusely distributed when the incident radiation upon the element has the same characteristics, whichever the directional characteristics of surface emittance and reflectance.

The first two cases are particularly useful since they allow to deduce absorptance data from emittance data or conversely.

The details of the proof of the above statements, which have been given by Sparrow (1965) , [17], can be outlined as follows:

1. An isothermal enclosure is defined by roofing the cavity opening with a black surface at the temperature, T_W, of the cavity.
2. The net heat transfer at any elemental wall surface of the enclosure will be zero, and the radiation within the enclosure will be back and diffusely distributed.
3. The net heat transfer at an element of wall surface can be considered as the superposition of two contributions: the heat transfer of the undisturbed cavity at temperature, T_W, and the heat transfer of an enclosure whose walls are at absolute zero, except the roof which is at temperature T_W. Since both terms cancel each other it follows that α_a=ε_a.

The transmission of radiation through isothermal passages, which are open at both ends, and which connect two isothermal environments at different temperatures, can be also calculated by means of the superposition method. In this case the three elemental solutions are superposed. The first solution corresponds to the passage, at temperature T_W, radiating through both ends to the outer space at absolute zero. In the second solution a cavity at absolute zero, formed by the passage closed at one end with a black surface, receives the energy coming from the surrounding and entering through the open end. Finally, in the third solution the passage is closed at the last mentioned end, while the radiation enters through the opposite one.