



BSI Standards Publication

Space Engineering — Thermal design handbook

Part 3: Spacecraft Surface Temperature

National foreword

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Ingénierie spatiale - Manuel de conception thermique -
Partie 3 : Température de surface des véhicules
spatiaux

Raumfahrttechnik - Handbuch für thermisches Design -
Teil 3: von Oberflächen auf Raumfahrzeugen

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European Foreword

This document (CEN/CLC/TR 17603-31-03:2021) 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 17603-31-03:2021) originates from ECSS-E-HB-31-01 Part 3A.

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

Factors affecting the equilibrium temperature of a spacecraft surface are described in this Part 3 using simple geometrical configurations and basic assumptions.

Methods for conducting calculations on the affect of Solar, planetary and albedo radiation are given taking into consideration the internal and immediate environmental factors and incorporating the various configurations and dimensions of the constituent parts.

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**.

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_E	emitting area of the spacecraft, [m ²]
A_I	area of the spacecraft projected from the sun, [m ²]
B_i	parameters of the truncated power series development of F_{SP} , see clause 6.1
F	Albedo view factor from spacecraft to planet
F_{SP}	view factor from spacecraft to planet
R_P	mean radius of the planet, [m]
S	solar flux, [W.m ⁻²] $S = S_0.d^{-2}$
S_0	solar constant, $S_0 = 1353 \text{ W.m}^{-2}$
T	temperature, [K]
T_A	Albedo temperature, [K] $T_A = [aS_0/\sigma d^2]^{1/4}$
T_R	radiation equilibrium temperature of the infinitely conductive spacecraft, [K]
T_{RA}	radiation equilibrium temperature of the infinitely conductive spacecraft under Albedo radiation, [K]
T_{RP}	radiation equilibrium temperature of the infinitely conductive spacecraft under planetary radiation, [K]
T_P	equivalent planet temperature, [K] $T_P = (e/\sigma)^{1/4}$
T_s	equivalent surrounding temperature, [K]
a	mean Albedo of the planet

b	wall thickness, [m]
c	specific heat, [J.kg ⁻¹ .K ⁻¹]
d	Clause 5: distance from the sun center to the spacecraft, [AU]
e	mean emissive power of the planet per unit area, [W.m ⁻²]
h	distance from the spacecraft to the planet surface, [m]
k	thermal conductivity, [W.m ⁻¹ .K ⁻¹]
γ	dimensionless specific heat in the spinning thin-walled spacecraft, $\gamma = (\rho b c \omega) / (\varepsilon \sigma T_R^3)$
α	hemispherical absorptance
α_s	solar absorptance
ε	hemispherical total emittance
μ	dimensionless thermal conductance in the thin-walled spacecraft, $\mu = (kb) / (\varepsilon \sigma T_R^3 R^2)$, where <i>R</i> is the characteristic length of the spacecraft surface
ρ	density, [kg.m ⁻³]
σ	Stefan-Boltzmann constant, $\sigma = 5,6697 \times 10^{-8} \text{ W.m}^{-2}.\text{K}^{-4}$
τ	dimensionless temperature, $\tau = T/T_R$
ω	angular velocity of the spinning spacecraft

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

4

Solar radiation

4.1 General

Data on the equilibrium temperature of a satellite, heated by the Sun, and cooled by radiation to the outer space, are presented in this Clause. Fairly simple geometrical configurations are considered. The temperature field within the satellite corresponds to either of the following two simplifying assumptions.

1. Infinitely conductive satellite. The satellite is constituted by a homogeneous solid body, exhibiting large thermal conductivity. The temperature of the satellite is uniform. This temperature is usually named Spacecraft Radiation Equilibrium Temperature, and is represented by T_R . The following additional assumptions have been used for the calculations:
 - (a) The heat addition is by parallel radiation from the Sun.
 - (b) The Equivalent Surrounding temperature, T_s , is assumed to be zero.
 - (c) Emittance and solar absorptance of the satellite surface are independent of both temperature and wavelength.
 - (d) Absorptance is independent of the angle between the surface normal and the direction of the incoming radiation.

The Spacecraft Radiation Equilibrium Temperatures, T_R , is given by

$$T_R = \left(\frac{\alpha_s}{s} \frac{A_I}{A_E} \frac{S_o}{\sigma d^2} + T_s^4 \right)^{1/4} \quad [4-1]$$

where T_s is assumed to be zero as it has been indicated > above.

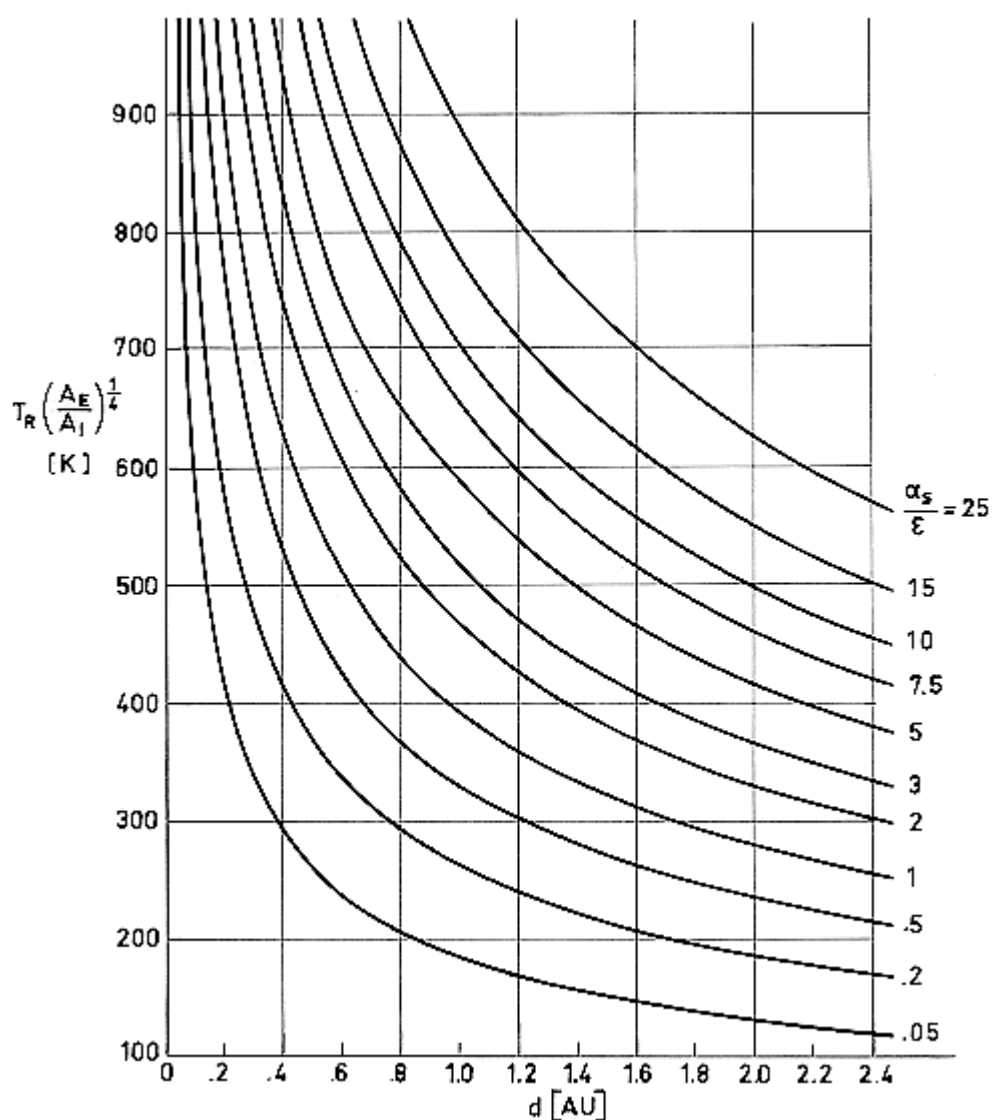
1. Satellites of finite thermal conductivity. A limited amount of the data presented in this Clause concerns bodies of finite thermal conductivity. Some knowledge of the internal structure of the satellite is required to evaluate the temperature field. Here it is assumed that the satellite is a thin-walled body with no internal conductive structure, furthermore, in most cases the gas contained within the body is assumed to be opaque and non conducting.

The data presented are based on the following assumptions:

- (a) The heat addition is by parallel radiation from the Sun.
- (b) The Equivalent Surrounding Temperature, T_s , is assumed to be zero.

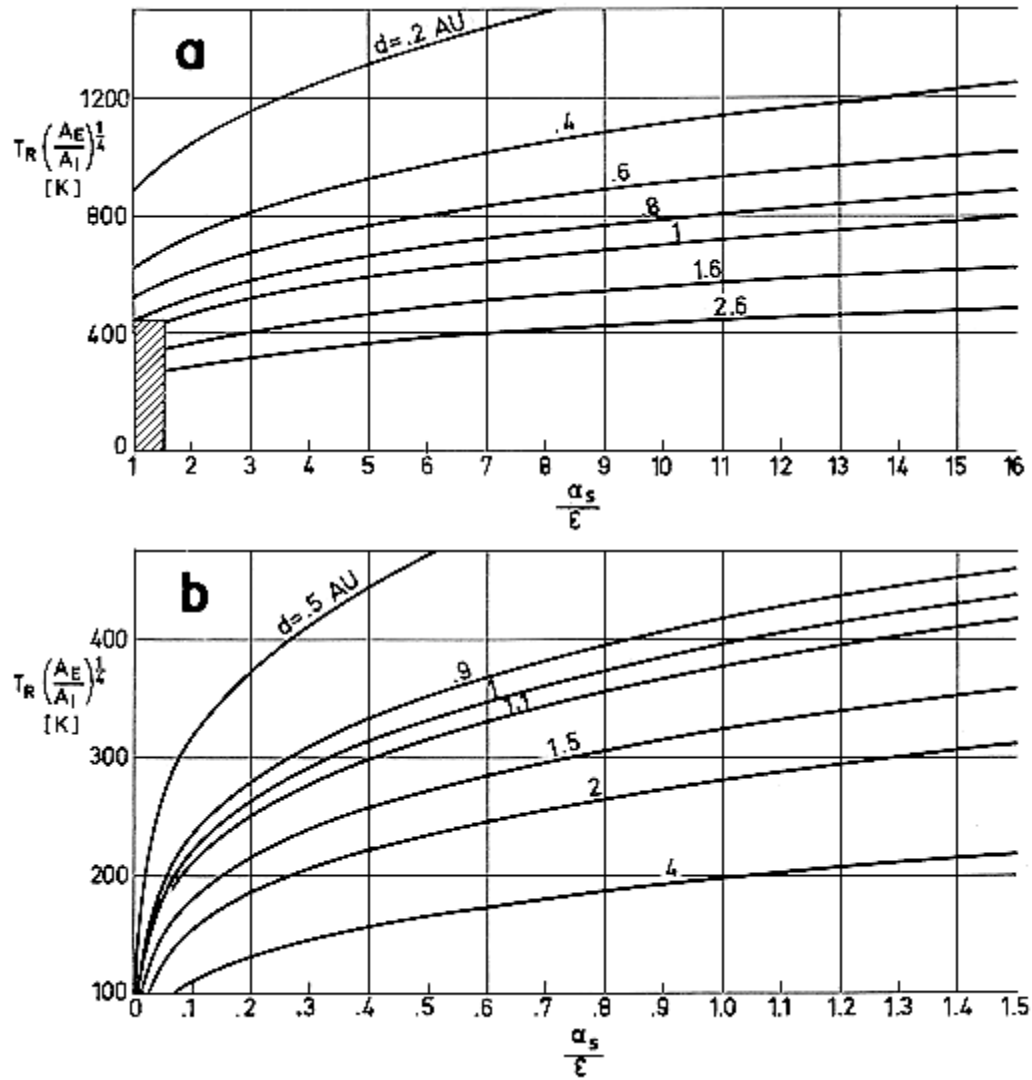
- (c) The configuration has an axis of symmetry, solar radiation being parallel to this axis.
- (d) Emittance and solar absorptance of the satellite surface are independent of both temperature and wavelength.
- (e) Thermal conductivity is temperature independent.
- (f) Lambert's law is assumed to govern reflection and emission.
- (g) The body is filled with an opaque non-conducting gas.

The results are presented in terms of the local temperature, T , made dimensionless with the Spacecraft Radiation Equilibrium Temperature, T_R .



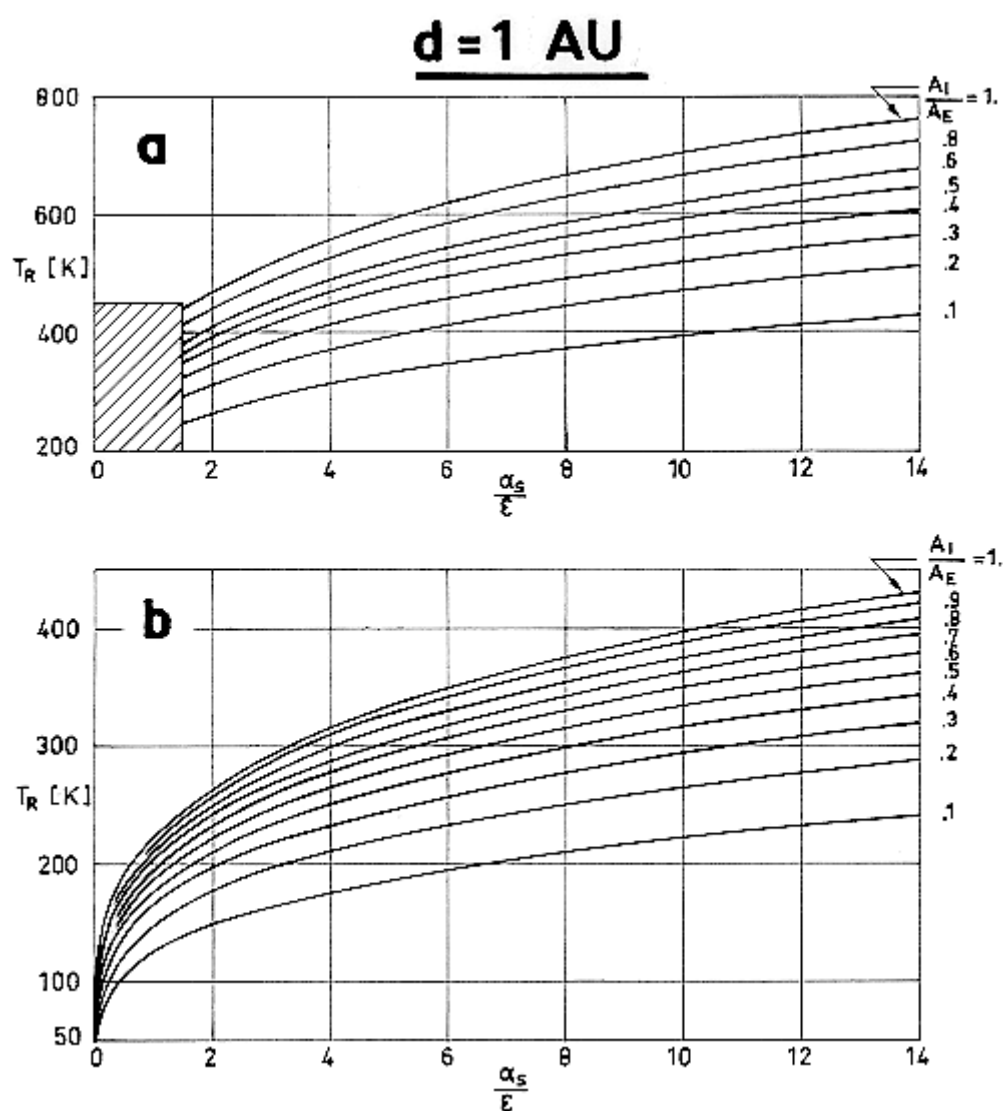
Note: non-si units are used in this figure

Figure 4-1: The function $T_R(A_E/A_I)^{1/4}$ vs. the distance to the Sun. Calculated by the compiler.



Note: non-si units are used in this figure

Figure 4-2: The function $T_R(A_E/A_I)^{1/4}$ vs. the optical characteristics of the surface. Shaded zone of a is enlarged in b . Calculated by the compiler.



Note: non-si units are used in this figure

Figure 4-3: Temperature T_R as a function of α_s / ϵ and A_I / A_E for $d = 1$ AU. Shaded zone of *a* is enlarged in *b*. Calculated by the compiler.

4.2 Infinitely conductive planar surfaces

4.2.1 Flat plate emitting on one or both sides

I.- FLAT PLATE EMITTING ON ONE SIDE.

Sketch:



Formula:

$$(A_i/A_E) = \cos \gamma$$

II.- FLAT PLATE EMITTING ON BOTH SIDES.

Sketch:



Formula:

$$(A_i/A_E) = (\cos \gamma)/2$$

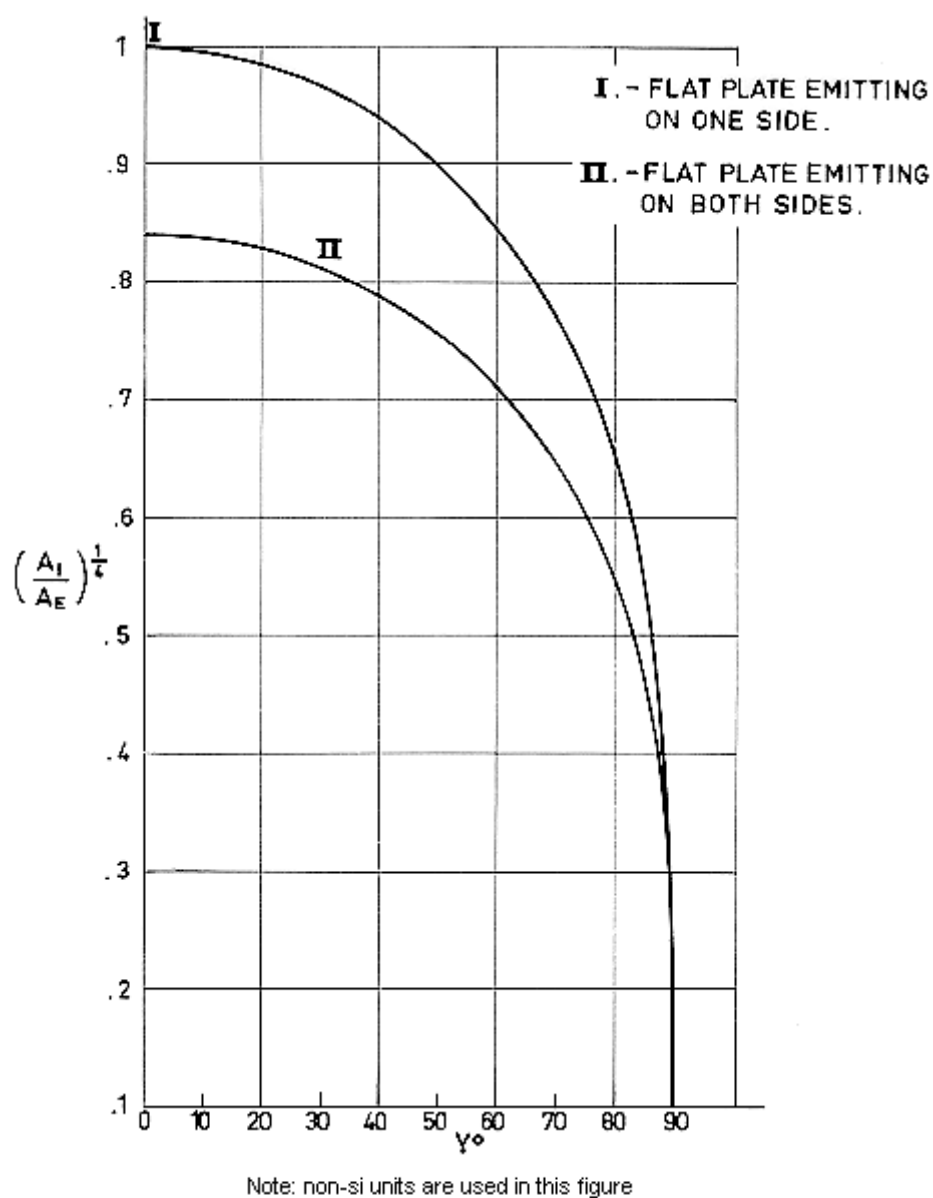
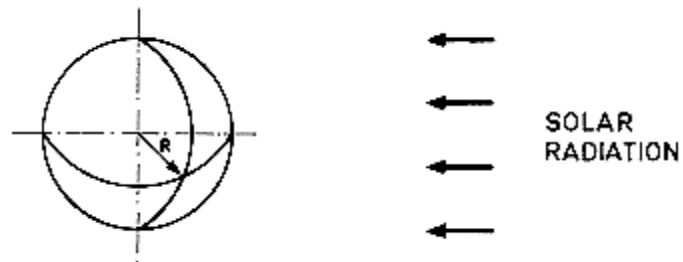


Figure 4-4: Ratio $(A_I/A_E)^{1/4}$ as a function of γ , in the case of a flat plate. Calculated by the compiler.

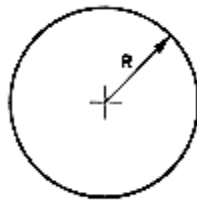
4.3 Infinitely conductive spherical surfaces

4.3.1 Sphere

Sketch:



Area Projected from the Sun, A_i :



Formula:

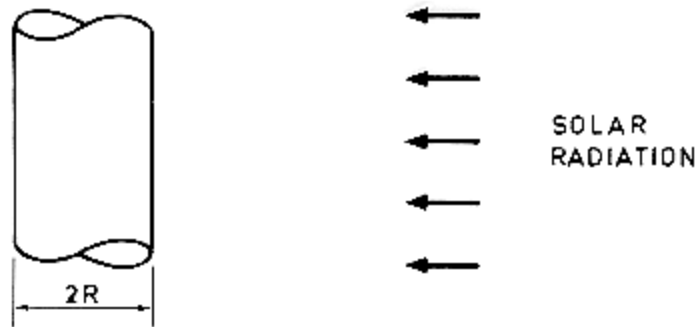
$$(A_i/A_E) = 1/4$$

$$(A_i/A_E)^{1/4} = 0,707$$

4.4 Infinitely conductive cylindrical surfaces

4.4.1 Two-dimensional circular cylinder

Sketch:



Area Projected from the Sun, A_I :



Formula:

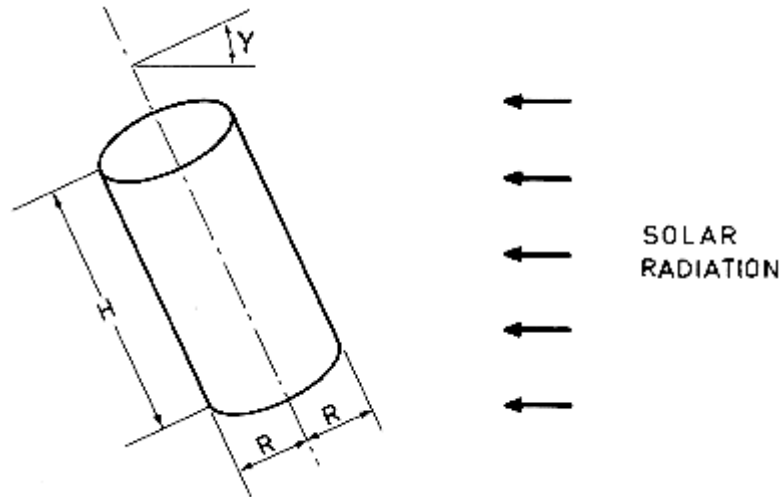
$$(A_I/A_E) = 1/\pi$$

$$(A_I/A_E)^{1/4} = 0,751$$

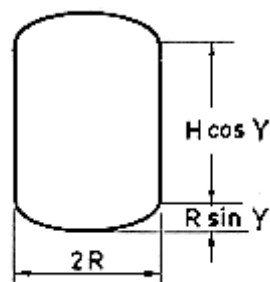
Comments: This expression can be also applied to the finite circular cylinder with isolated bases.

4.4.2 Three-dimensional circular cylinder

Sketch:

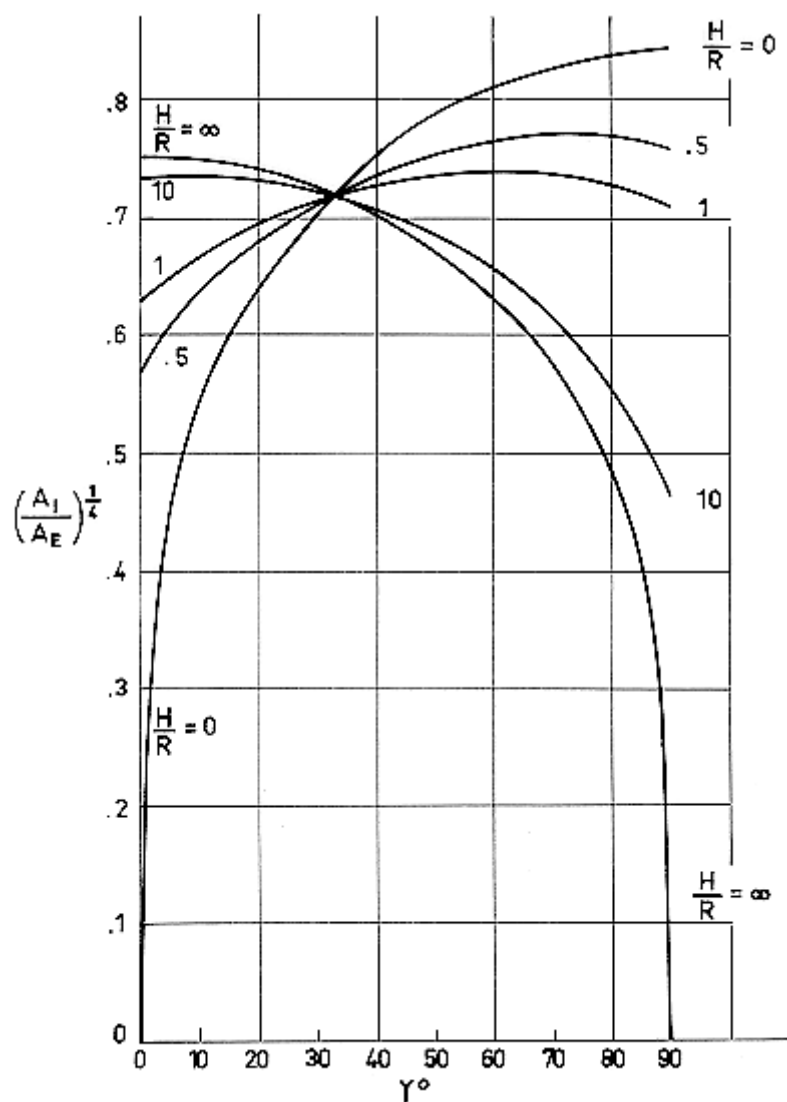


Area Projected from the Sun, A_I :



Formula:

$$\frac{A_I}{A_E} = \frac{\pi \sin \gamma + 2 \frac{H}{R} \cos \gamma}{2\pi \left(1 + \frac{H}{R}\right)} \quad [4-2]$$



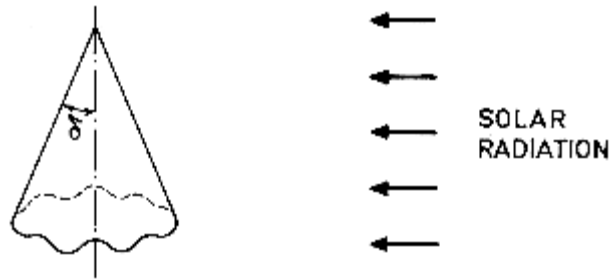
Note: non-si units are used in this figure

Figure 4-5: Ratio $(A_I/A_E)^{1/4}$ as a function of γ and H/R , in the case of a finite height circular cylinder. Calculated by the compiler.

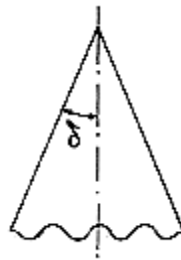
4.5 Infinitely conductive conical surfaces

4.5.1 Semi-infinite circular cone

Sketch:



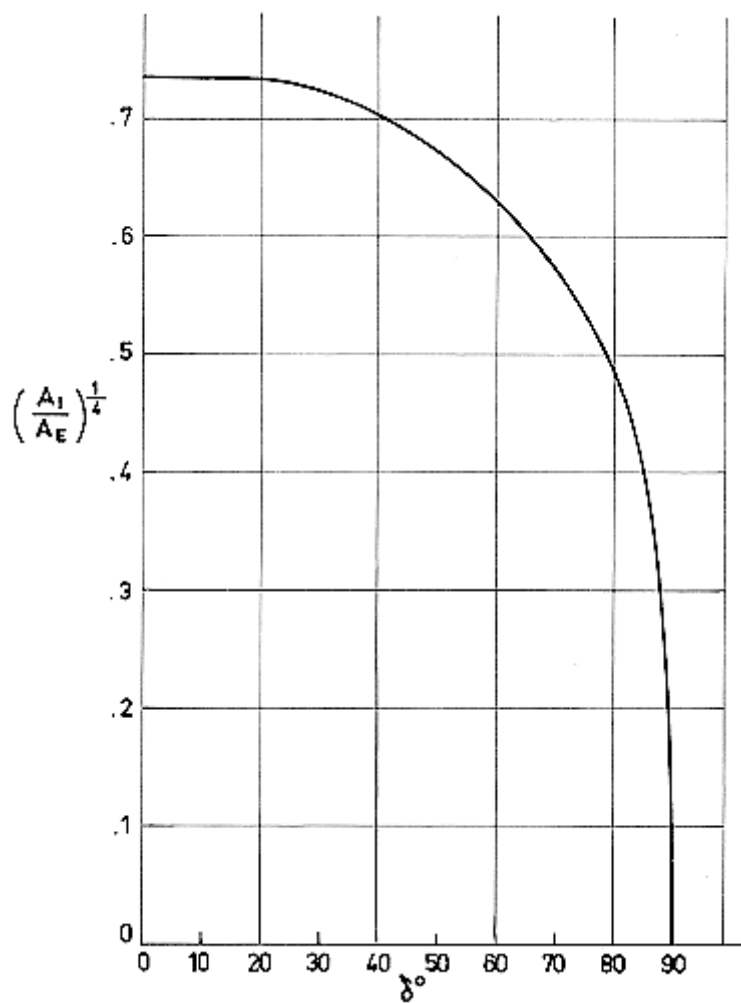
Area Projected from the Sun, A_I :



Formula:

$$A_I/A_E = (\cos \delta)/\pi$$

Comments: This expression can be also applied to the finite circular cone with isolated base provided that the incoming radiation is normal to the cone axis.

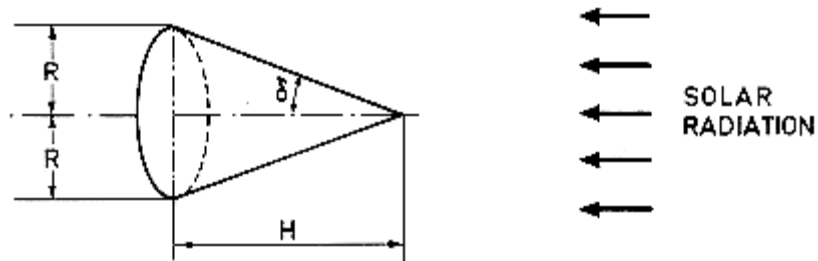


Note: non-si units are used in this figure

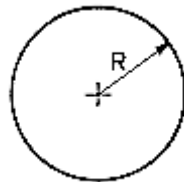
Figure 4-6: Ratio $(A_I/A_E)^{1/4}$ as a function of δ , in the case of a semi-infinite circular cone. Calculated by the compiler.

4.5.2 Finite circular cone with insulated base. (axial configuration)

Sketch:

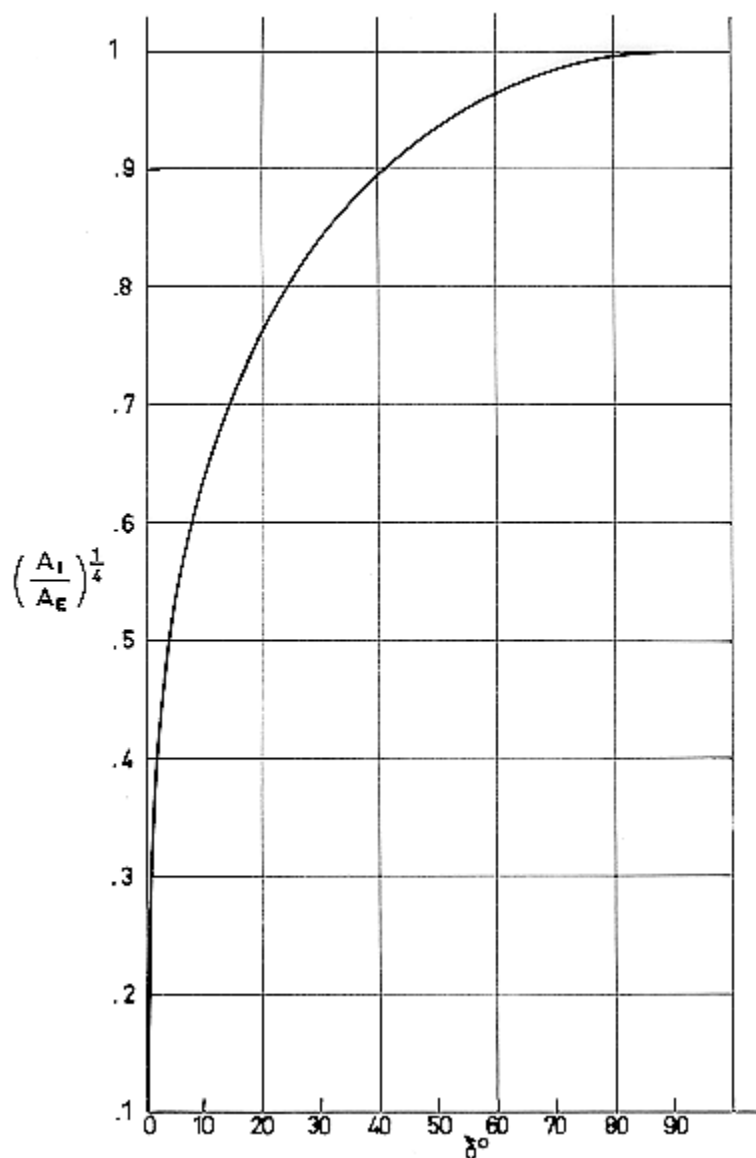


Area Projected from the Sun, A_I :



Formula:

$$A_I/A_E = \sin \delta$$

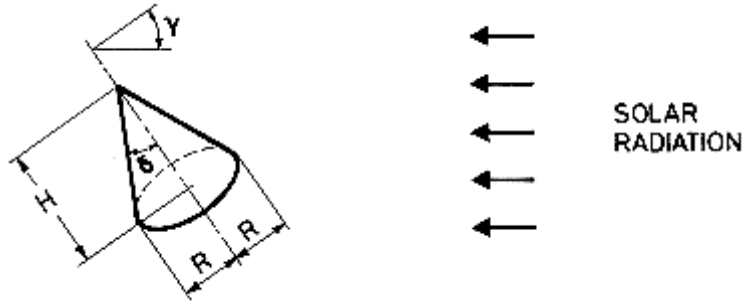


Note: non-si units are used in this figure

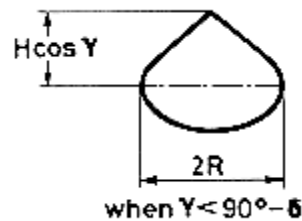
Figure 4-7: Ratio $(A_I/A_E)^{1/4}$ as a function of δ , in the case of a finite circular cone with insulated base (axial configuration). Calculated by the compiler.

4.5.3 Finite height circular cone

Sketch:



Area Projected from the Sun, A_I :



Formula:

a. when $0 \leq \gamma \leq 90^\circ - \delta$,

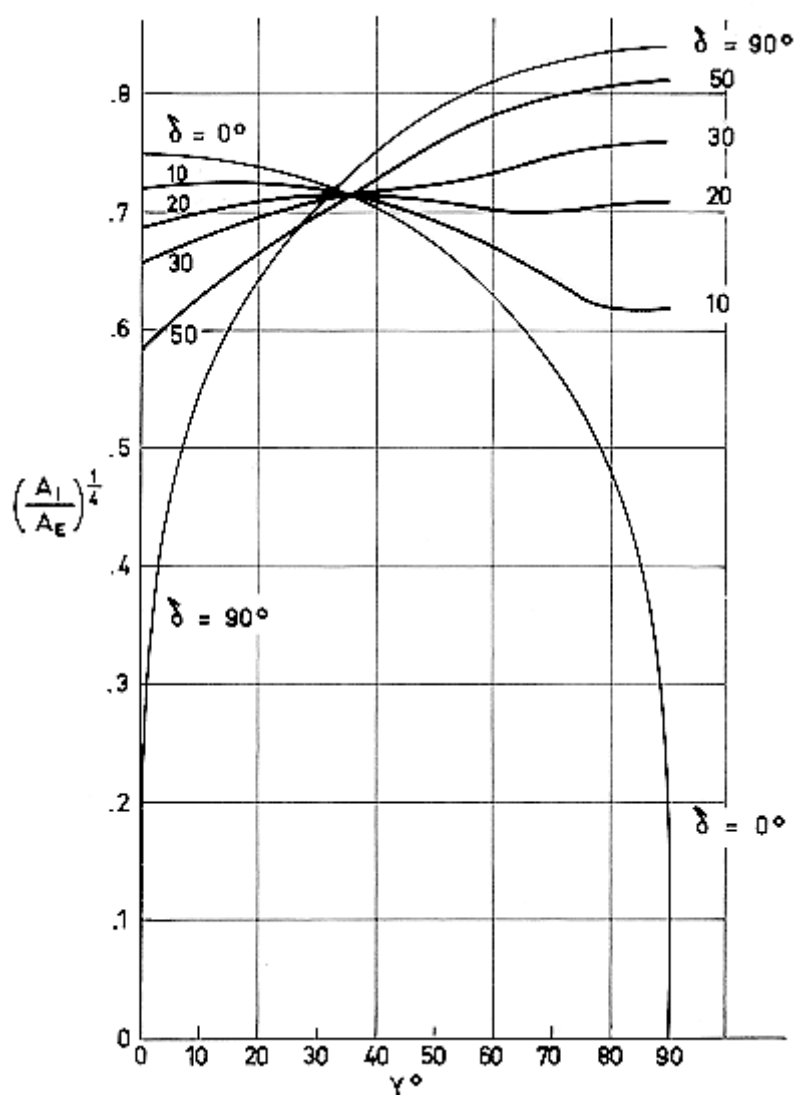
$$\frac{A_I}{A_E} = \frac{\sin \gamma \sin \delta}{\pi(1 + \sin \delta)} \left(\pi + \frac{\sqrt{1 - \tan^2 \gamma \tan^2 \delta}}{\tan \gamma \tan \delta} - \sin^{-1} \sqrt{1 - \tan^2 \gamma \tan^2 \delta} \right) \quad [4-3]$$

when $\gamma = 0$ the above expression becomes

$$\frac{A_I}{A_E} = \frac{\cos \delta}{\pi(1 + \sin \delta)} \quad [4-4]$$

b. when $\gamma \geq 90^\circ - \delta$,

$$\frac{A_I}{A_E} = \frac{\sin \delta \sin \gamma}{1 + \sin \delta} \quad [4-5]$$



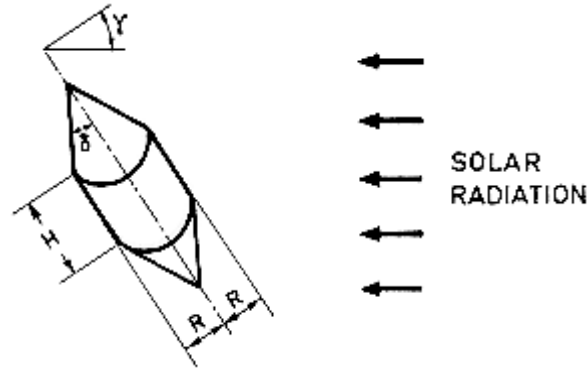
Note: non-si units are used in this figure

Figure 4-8: Ratio $(A_I/A_E)^{1/4}$ as a function of γ and δ , in the case of a finite height cone. Calculated by the compiler.

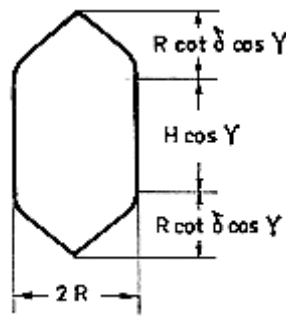
4.6 Infinitely conductive cylindrical-conical surfaces

4.6.1 Cone-cylinder-cone

Sketch:



Area Projected from the Sun, A_I :



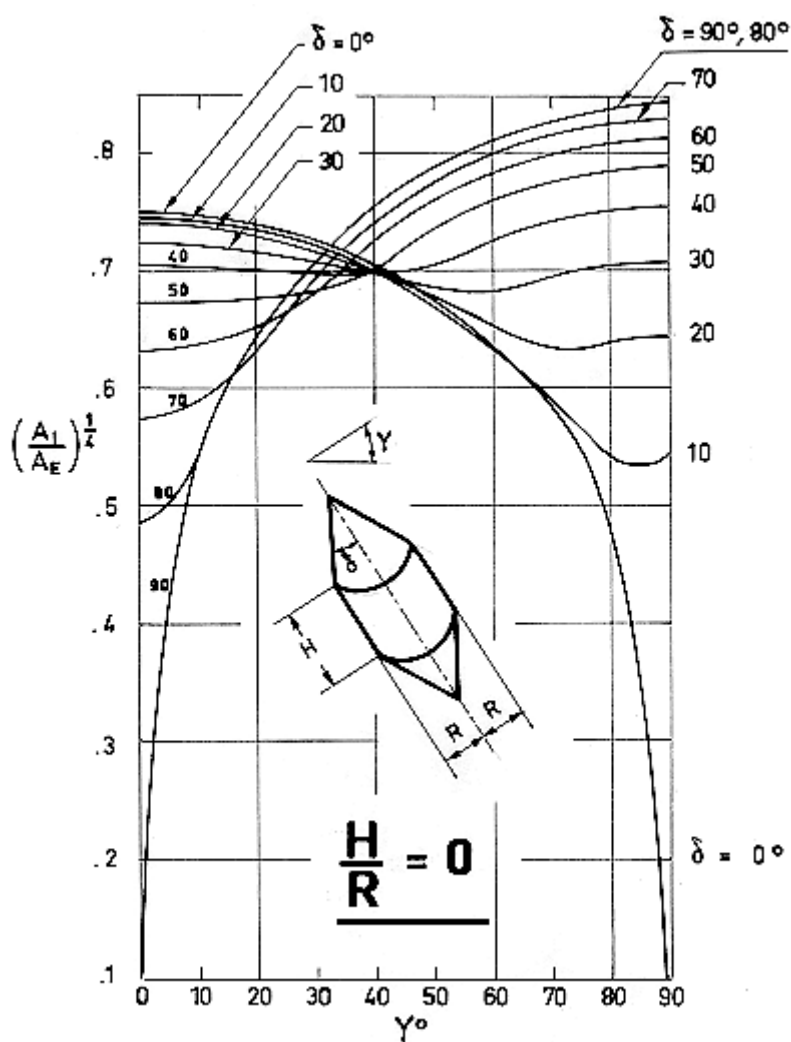
Formula:

a. When $\gamma \leq 90^\circ - \delta$

$$\frac{A_I}{A_E} = \frac{\sin \gamma \sin \delta \left(\frac{\pi}{2} - \sin^{-1} \sqrt{1 - \tan^2 \gamma \tan^2 \delta} \right) + \cos \gamma \left(\frac{H}{R} \sin \delta + \cos \delta \sqrt{1 - \tan^2 \gamma \tan^2 \delta} \right)}{\pi \left(1 + \frac{H}{R} \sin \delta \right)} \quad [4-6]$$

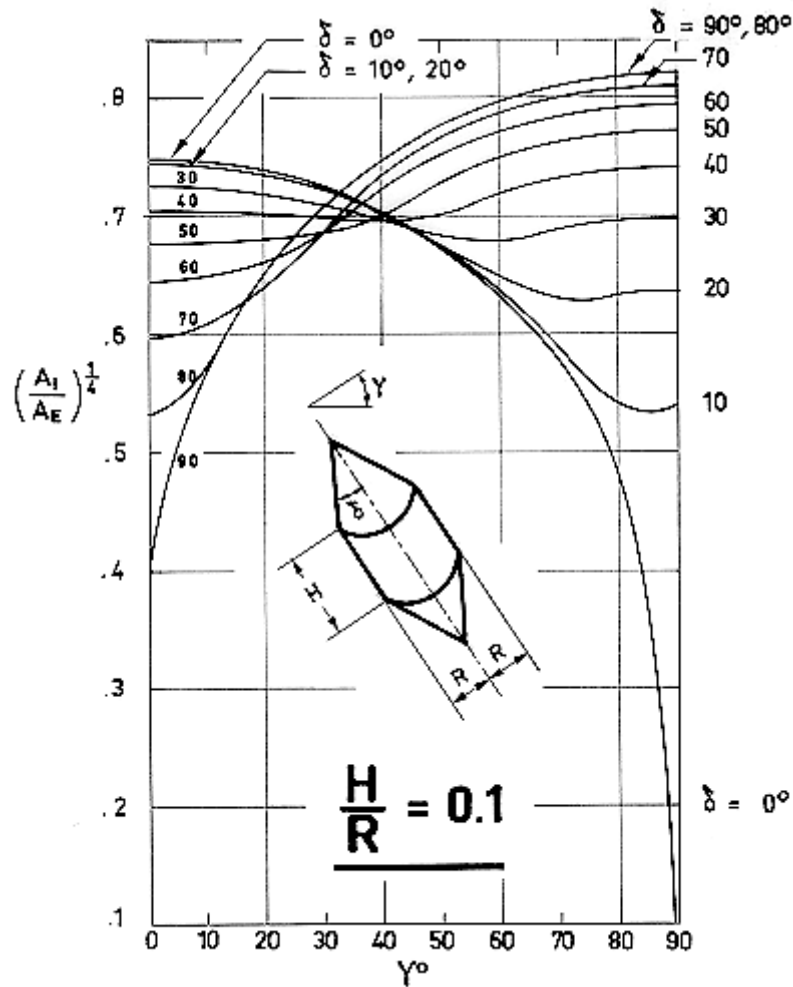
b. when $\gamma \geq 90^\circ - \delta$,

$$\frac{A_I}{A_E} = \frac{\sin \delta \left(\sin \gamma + \frac{2H}{\pi R} \cos \gamma \right)}{\pi \left(1 + \frac{H}{R} \sin \delta \right)} \quad [4-7]$$



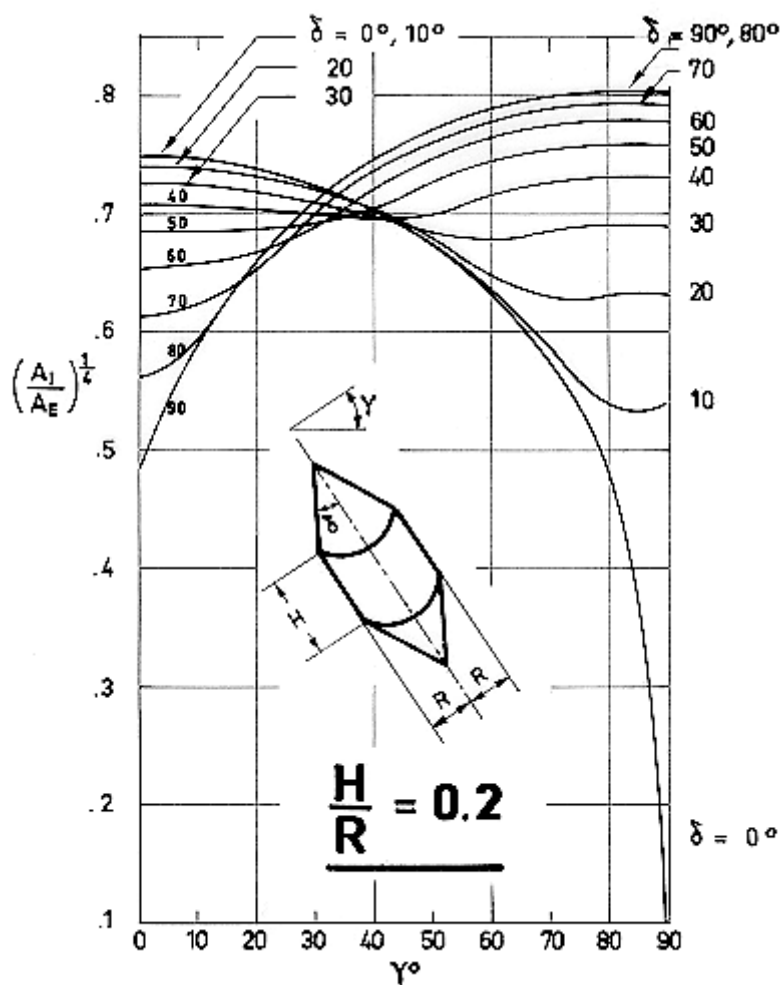
Note: non-si units are used in this figure

Figure 4-9: Ratio $(A_I/A_E)^{1/4}$ as a function of γ and δ , in the case of a cone-cylinder-cone. Calculated by the compiler.



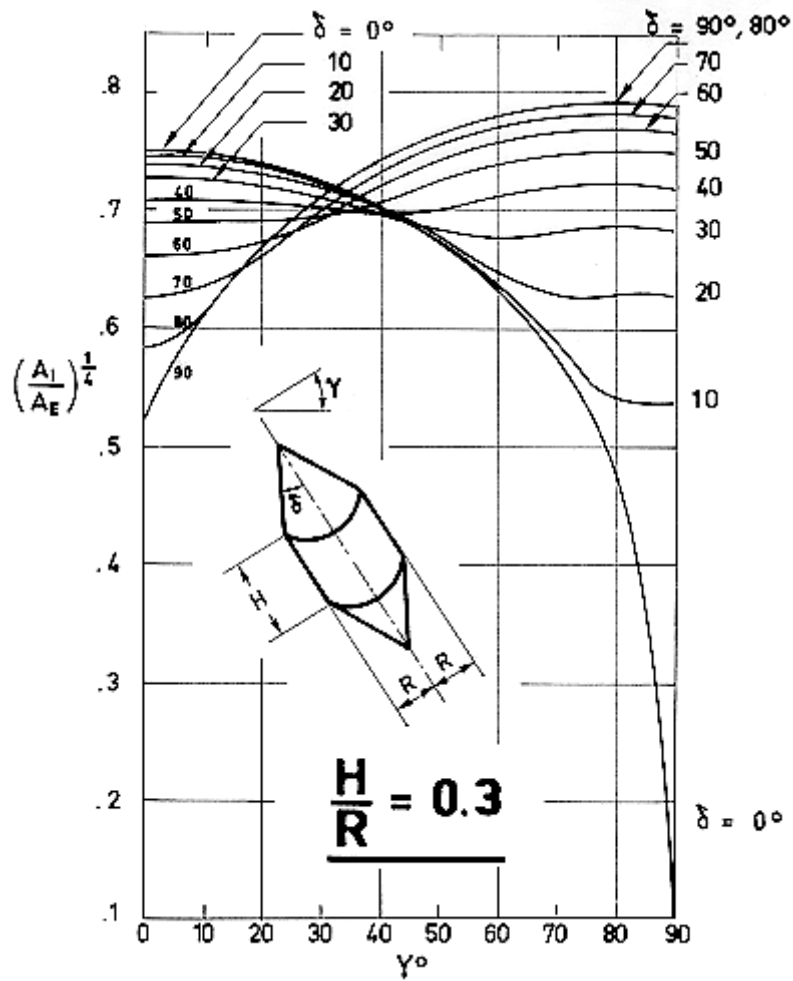
Note: non-si units are used in this figure

Figure 4-10: Ratio $(A_I/A_E)^{1/4}$ as a function of γ and δ , in the case of a cone-cylinder-cone. Calculated by the compiler.



Note: non-si units are used in this figure

Figure 4-11: Ratio $(A_I/A_E)^{1/4}$ as a function of γ and δ , in the case of a cone-cylinder-cone. Calculated by the compiler.



Note: non-si units are used in this figure

Figure 4-12: Ratio $(A_I/A_E)^{1/4}$ as a function of γ and δ , in the case of a cone-cylinder-cone. Calculated by the compiler.

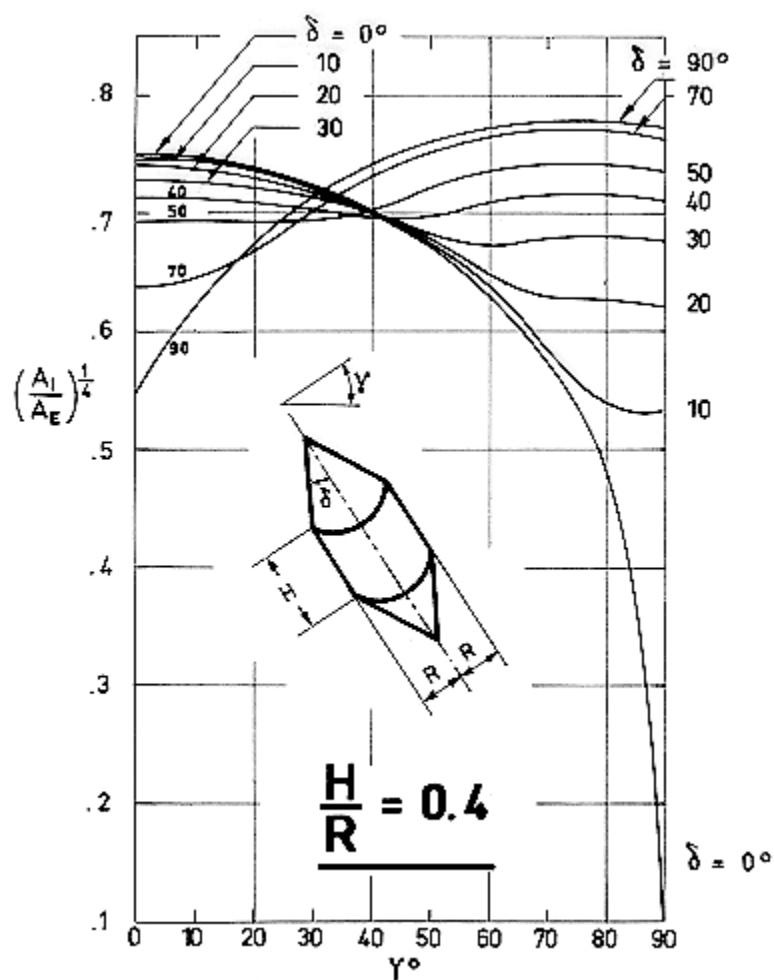
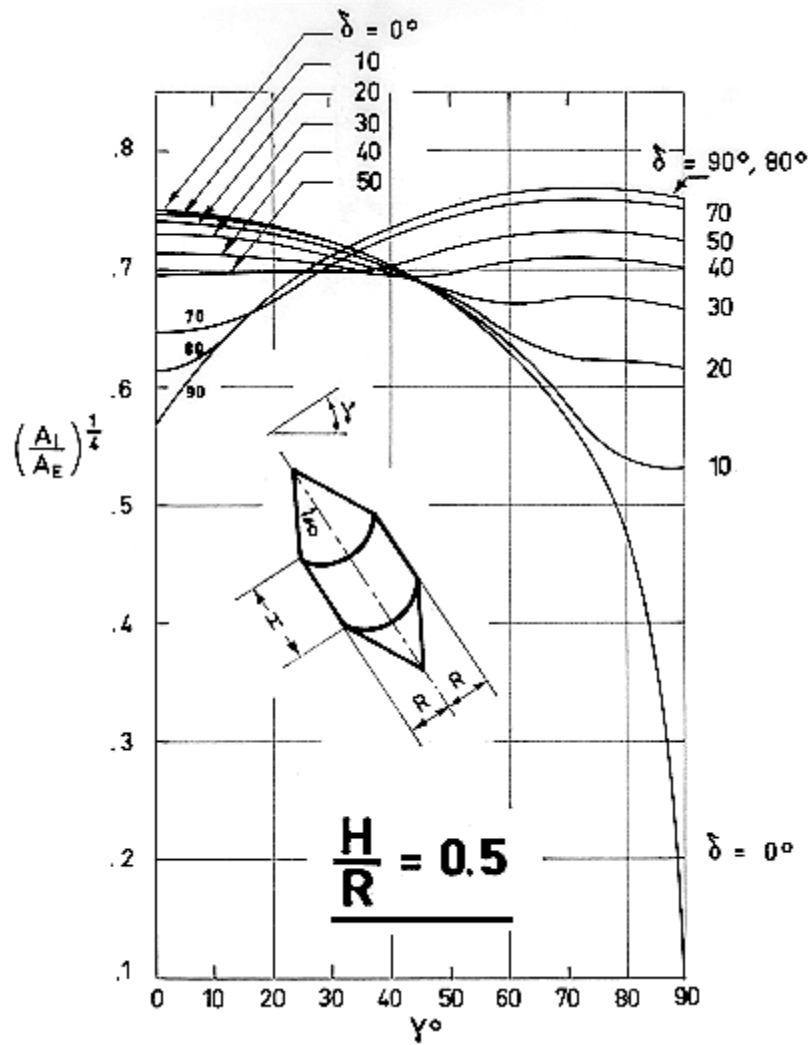
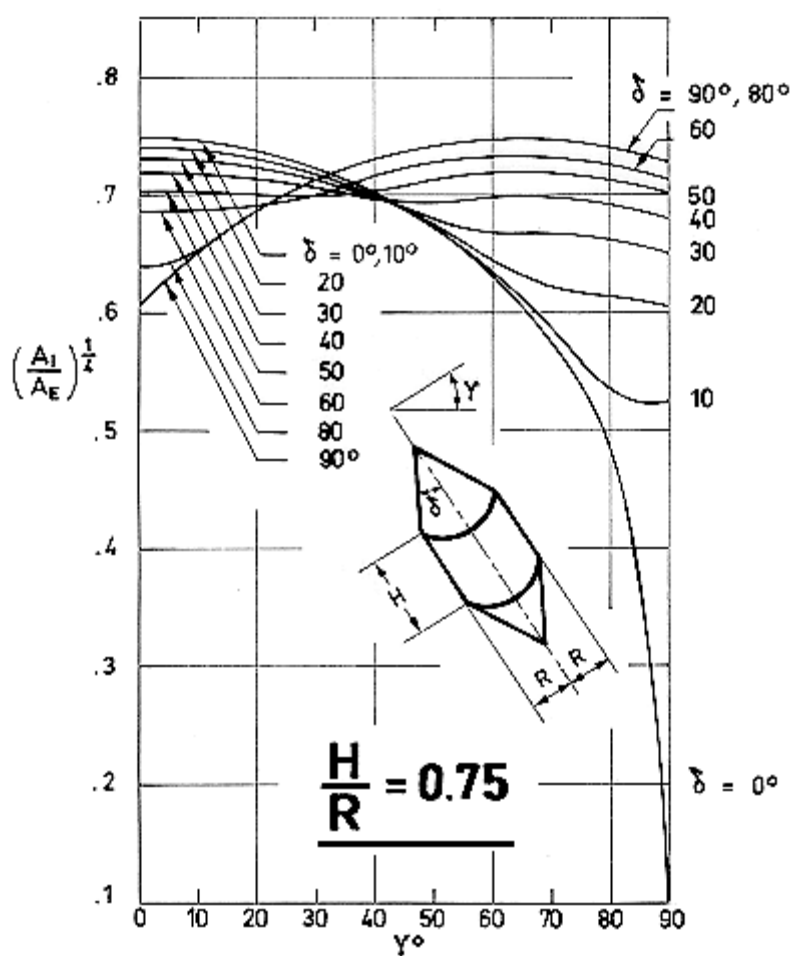


Figure 4-13: Ratio $(A_I/A_E)^{1/4}$ as a function of γ and δ , in the case of a cone-cylinder-cone. Calculated by the compiler.



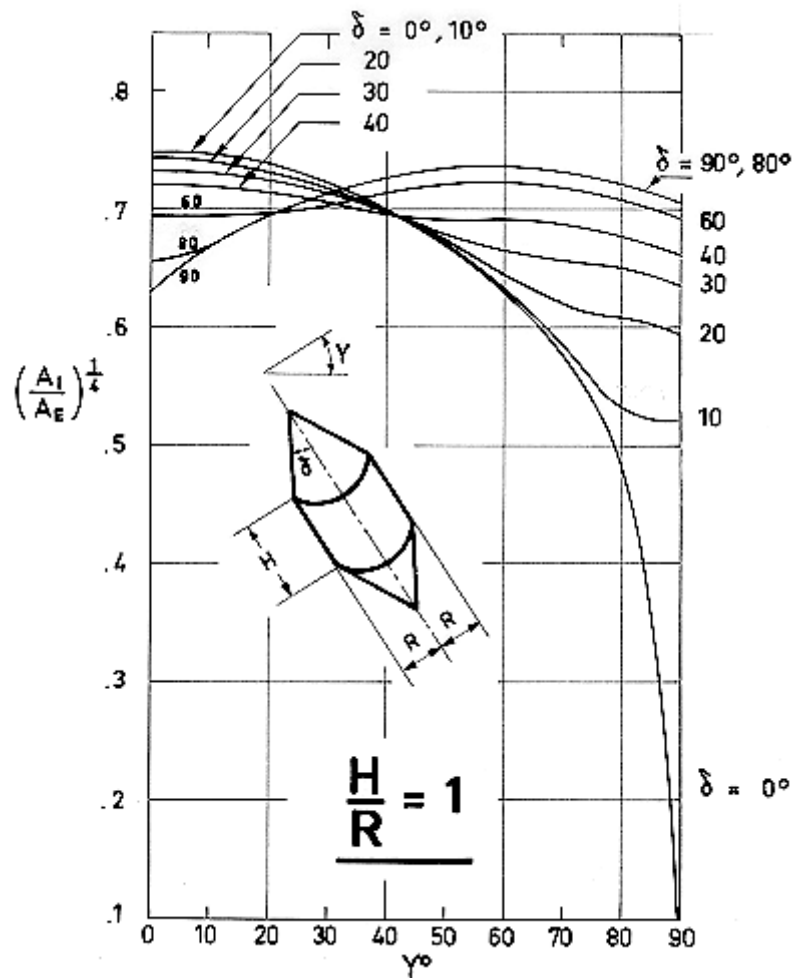
Note: non-si units are used in this figure

Figure 4-14: Ratio $(A_I/A_E)^{1/4}$ as a function of γ and δ , in the case of a cone-cylinder-cone. Calculated by the compiler.



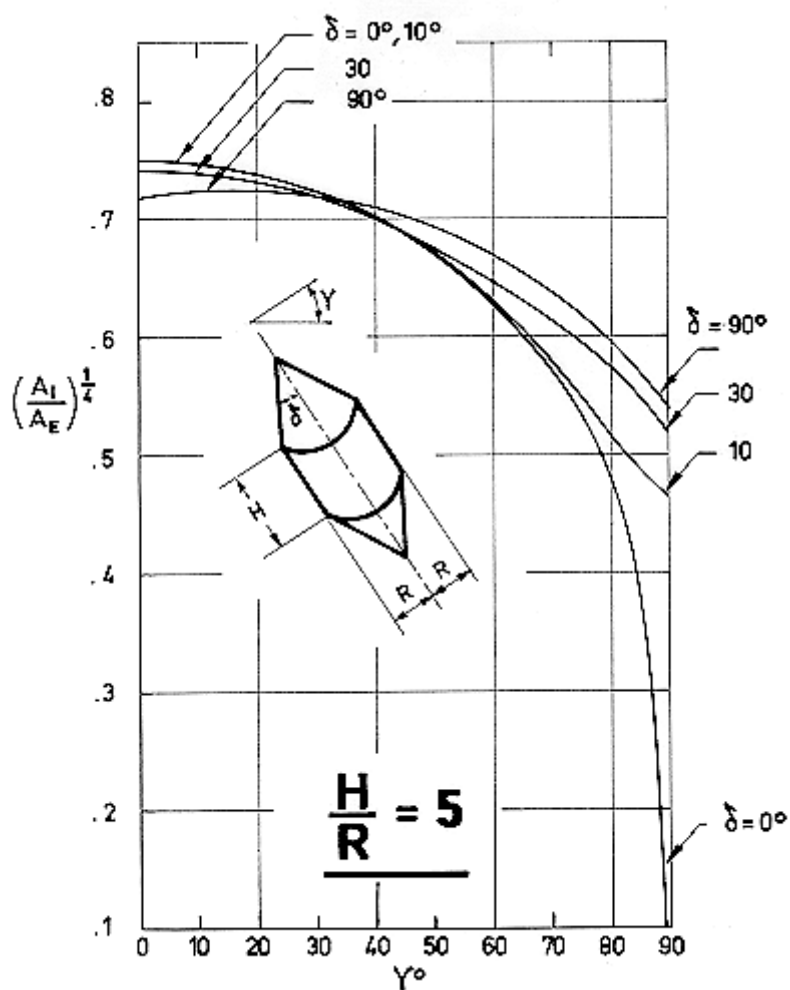
Note: non-si units are used in this figure

Figure 4-15: Ratio $(A_I/A_E)^{1/4}$ as a function of γ and δ , in the case of a cone-cylinder-cone. Calculated by the compiler.



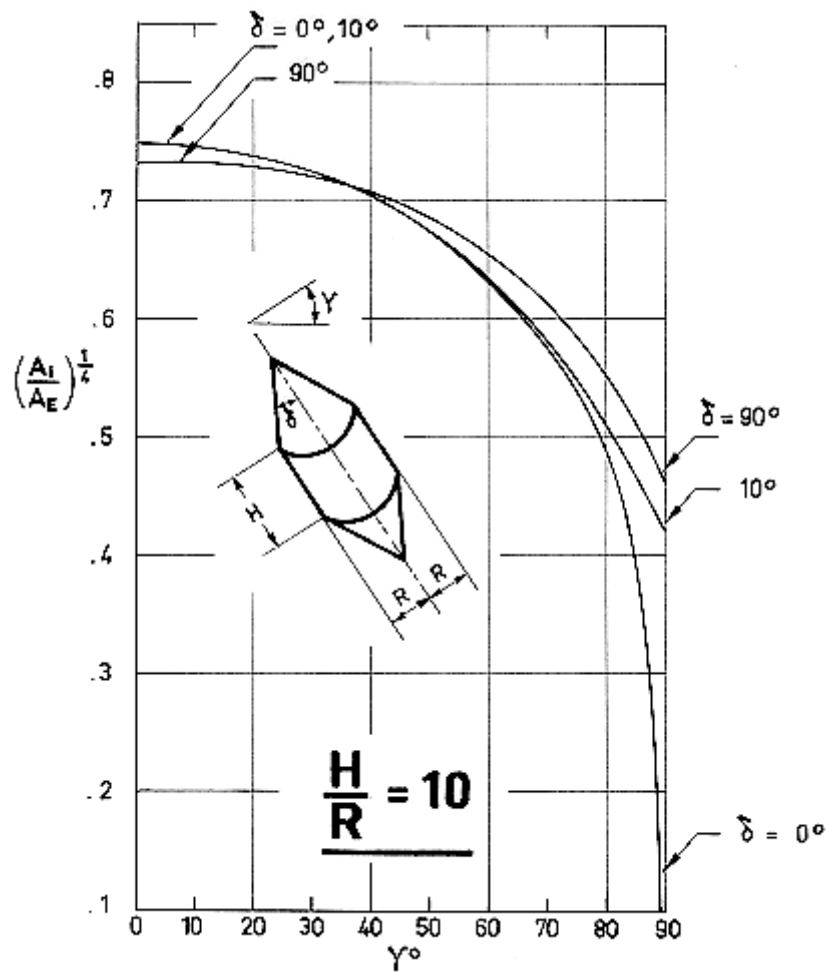
Note: non-si units are used in this figure

Figure 4-16: Ratio $(A_I/A_E)^{1/4}$ as a function of γ and δ , in the case of a cone-cylinder-cone. Calculated by the compiler.



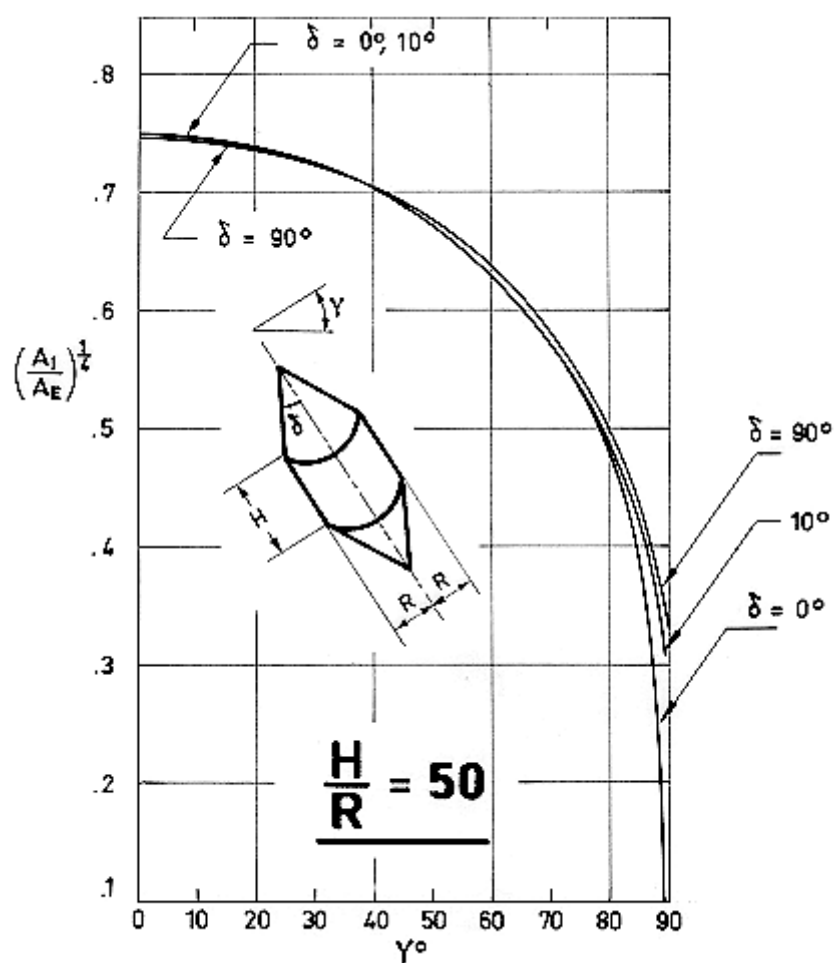
Note: non-si units are used in this figure

Figure 4-17: Ratio $(A_I/A_E)^{1/4}$ as a function of γ and δ , in the case of a cone-cylinder-cone. Calculated by the compiler.



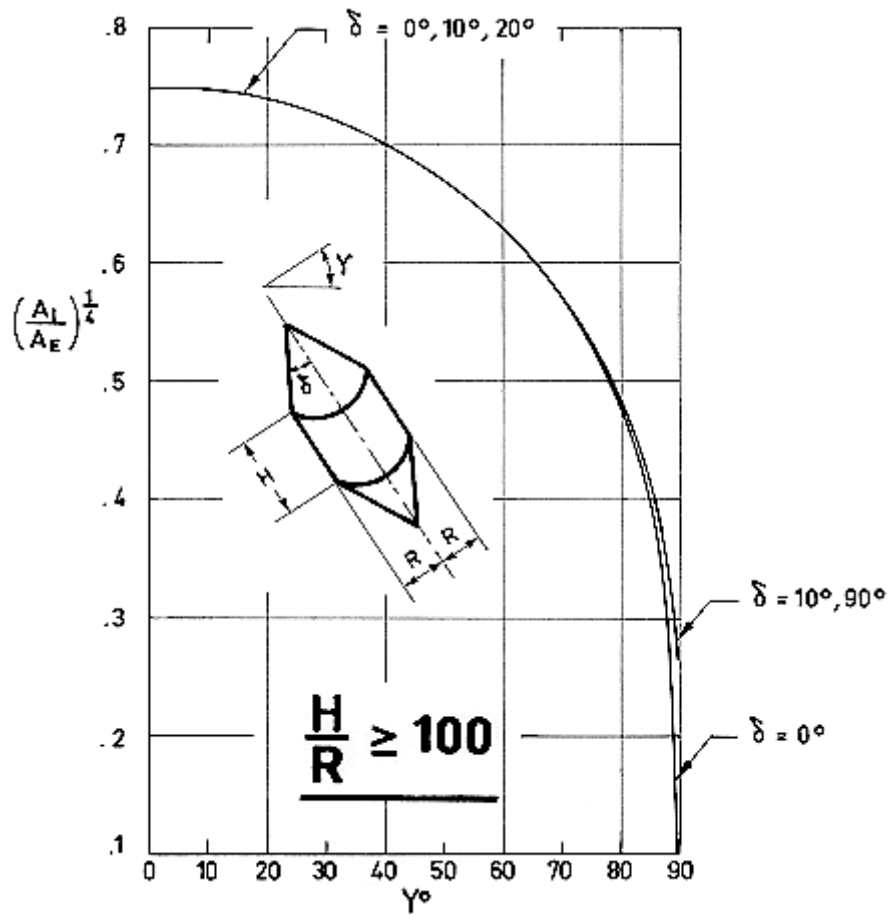
Note: non-si units are used in this figure

Figure 4-18: Ratio $(A_I/A_E)^{1/4}$ as a function of γ and δ , in the case of a cone-cylinder-cone. Calculated by the compiler.



Note: non-si units are used in this figure

Figure 4-19: Ratio $(A_I/A_E)^{1/4}$ as a function of γ and δ , in the case of a cone-cylinder-cone. Calculated by the compiler.



Note: non-si units are used in this figure

Figure 4-20: Ratio $(A_L/A_E)^{1/4}$ as a function of γ and δ , in the case of a cone-cylinder-cone. Calculated by the compiler.