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BSI Standards Publication

Space Engineering — Thermal design handbook

Part 9: Radiators

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European Foreword

This document (CEN/CLC/TR 17603-31-09:2021) 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 17603-31-09:2021) originates from ECSS-E-HB-31-01 Part 1A .

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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).

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1 Scope

In this Part 9 of the spacecraft thermal control and design data handbooks, view factors of diffuse and specular thermal surfaces are discussed.

For diffuse surfaces, calculations are given for radiation emission and absorption between different configurations of planar, cylindrical, conical, spherical and ellipsoidal surfaces for finite and infinite surfaces.

For specular surfaces the affect of reflectance on calculations for view factors is included in the calculations. View factors for specular and diffuse surfaces are also included.

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

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2 References

EN Reference	Reference in text	Title
EN 16601-00-01	ECSS-S-ST-00-01	ECSS System - Glossary of terms
TR 17603-31-03	ECSS-E-HB-31-01 Part 3	Thermal design handbook – Part 3: Spacecraft Surface Temperature

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

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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

$\mathbf{A_i}$	surface area of the i-th surface, [m^2]
$\mathbf{B_i}$	energy flux leaving surface, *i*. often called radiosity, [$W.m^{-2}$]
$\mathbf{F_{ij}}$	view factor from diffuse surface, A_i to diffuse surface, A_j
$\mathbf{F_{(i1,i2,...in)(j1,j2,...jn)}}$	view factor from the ensemble of diffuse surfaces, A_{i1}, A_{i2},...A_{in} to the ensemble of diffuse surfaces, A_{j1}, A_{j2},...A_{jn}
$\mathbf{F_{ij}^s}$	view factor from specular surface A_i to specular surface A_j
$\mathbf{H_i}$	energy flux incident on surface *i*, [$W.m^{-2}$]
$\mathbf{K_{i2}}$	term which appears in the expression for the view factor between elements of parallel plates, $K_{i2} = A_i F_{ii'}$
$\mathbf{K_{mn}(i,j,k,p,q,...)}$	fraction of the radiative energy leaving A_m which reaches A_n after *i* perfectly specular reflections from surface A_i, *j* from surface A_j, *k* from surface A_k,...
$\mathbf{S}$	distance between two differential elements, [m]
$\mathbf{T}$	temperature, [K]
$\boldsymbol{\beta_i}$	angle from normal to surface *i*, [angular degrees]
$\boldsymbol{\varepsilon}$	hemispherical emittance of a (diffuse-gray) surface
$\boldsymbol{\rho^d}$	hemispherical diffuse reflectance of a (diffuse-gray) surface

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ρ^s	specular reflectance of a (gray) surface, it is assumed to be independent of incident angle
σ	Stefan-Boltzmann constant, S = 5,6697x10^{-8} W.m^{-2}.K^{-4}

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

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4 Diffuse surfaces

4.1 General

The view factor, F_{12}, between the diffuse surface A_1 and A_2, is the fraction of the energy leaving the isothermal surface A_1 that arrives at A_2.

If the receiver surface is infinitesimal, the view factor is infinitesimal for both infinitesimal and finite emitting surfaces, and is given by the expression

$$dF_{12} = \frac{\cos\beta_1 \cos\beta_2}{\pi S^2} dA_2 \qquad [4\text{-}1]$$

when both surfaces are infinitesimal, and by

$$dF_{12} = \frac{dA_2}{A_1} \int_{A_1} \frac{\cos\beta_1 \cos\beta_2}{\pi S^2} dA_1 \qquad [4\text{-}2]$$

when A_1 is finite.

If the receiver surface is finite, the view factor is finite for both infinitesimal and finite emitting surfaces, and is given by the expression

$$F_{12} = \int_{A_2} \frac{\cos\beta_1 \cos\beta_2}{\pi S^2} dA_2 \qquad [4\text{-}3]$$

when A_1 is infinitesimal, and by

$$F_{12} = \frac{1}{A_1} \int_{A_1} \int_{A_2} \frac{\cos\beta_1 \cos\beta_2}{\pi S^2} dA_2 dA_1 \qquad [4\text{-}4]$$

when A_1 is finite.

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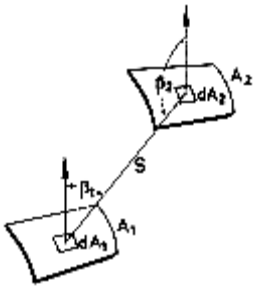

Figure 4-1: Geometric notation for view factors between diffuse surface.

Regardless of which surfaces are considered, their view factors satisfy the following reciprocity relation:

$A_1F_{12} = A_2F_{21}$

If we consider the diffuse surfaces A_1, A_2 and A_3, the view factor between the surfaces A_1 and $A_2 + A_3$ is

$F_{1(2,3)} = F_{12} + F_{13}$,

when the receiver surface is formed by two surfaces, and

$$F_{(2,3)1} = \frac{A_2F_{21} + A_3F_{31}}{A_2 + A_3} \qquad [4\text{-}5]$$

when the emitting surface is formed by two surfaces. notice that the notation $F_{1(2,3)}$ and $F_{(2,3)1}$ will be used in the following data sheets.

When an enclosure of N surfaces $A_1, A_2, \ldots, A_n$ is considered, their view factors satisfy the relation

$$\sum_{j=1}^{N} F_{ij} = 1 \qquad [4\text{-}6]$$

for any surface A_i. This relationship results from the fact that the overall heat transfer in the enclosure should be zero.

4.2 Infinitesimal to finite surfaces

4.2.1 Planar to planar

4.2.1.1 Two-dimensional configurations

A plane point source dA_1 and any surface A_2 generated by an infinitely long line moving parallel to itself and to the plane dA_1.

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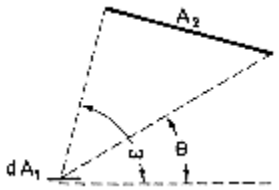


Formula:

$$F_{12} = \frac{1}{2}(\cos\theta - \cos\omega) \qquad [4\text{-}7]$$

References: Hamilton & Morgan (1952) [15], Moon (1961) [26], Kreith (1962) [22]

Comments:

Notice that F_{12} is independent of the shape of A_2 for given values of θ and ω.

View factors for several configurations may be obtained as a particular case of this one. An example is shown in the next page.

A plane point source dA_1 and any infinite plane A_2 with the planes of dA_1 and A_2 intersecting at an angle θ.

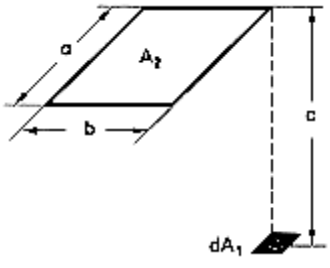
Formula:

$$F_{12} = \frac{1}{2}(1 + \cos\theta) \qquad [4\text{-}8]$$

References: Hamilton & Morgan (1952) [15], Moon (1961) [26], Kreith (1962) [22]

4.2.1.2 Point source to rectangle

A plane source dA_1 and a plane rectangle A_2 parallel to the plane of dA_1 (see sketch). The normal to dA_1 passes through one corner of A_2.



$x = a/c$
$y = b/c$

Formula:

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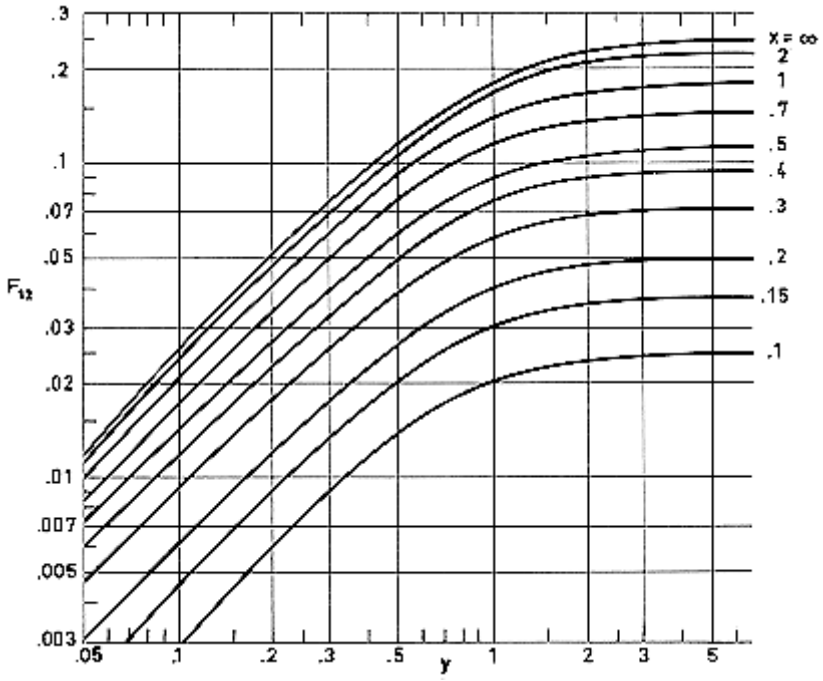
$$F_{12} = \frac{1}{2\pi}\left(\frac{x}{\sqrt{1+x^2}} \tan^{-1} \frac{y}{\sqrt{1+x^2}} + \frac{y}{\sqrt{1+y^2}} \tan^{-1} \frac{x}{\sqrt{1+y^2}} \right) \quad [4\text{-}9]$$

$$\lim_{y\to\infty} F_{12} = \frac{x}{4\sqrt{1+x^2}} \quad [4\text{-}10]$$

$$\lim_{x\to\infty} F_{12} = \frac{y}{4\sqrt{1+y^2}} \quad [4\text{-}11]$$

References: Hamilton & Morgan (1952) [15], Hottel (1954) [17], Jakob (1957) [19], Moon (1961) [26], Kreith (1962) [22]



Note: non-si units are used in this figure

Figure 4-2: Values of F_{12} as a function of x and y. From Hamilton & Morgan (1952) [15].

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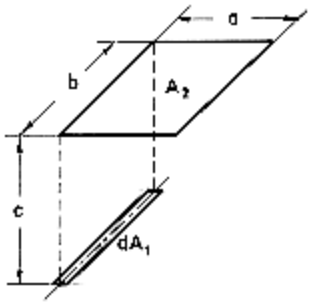
4.2.1.3 Line source to rectangle

A line source dA_1 and a plane rectangle A_2 parallel to the plane of dA_1 with dA_1 opposite one edge of A_2.



$x = b/c$
$y = a/c$

Formula:

$$F_{12} = \frac{1}{\pi x}\left(\begin{array}{l}\sqrt{1+x^2}\,\tan^{-1}\dfrac{y}{\sqrt{1+x^2}} - \tan^{-1} y + \\ + \dfrac{xy}{\sqrt{1+y^2}}\tan^{-1}\dfrac{x}{\sqrt{1+y^2}}\end{array}\right) \qquad [4\text{-}12]$$

$$\lim_{x\to\infty} F_{12} = \frac{y}{2\sqrt{1+y^2}} \qquad [4\text{-}13]$$

$$\lim_{y\to\infty} F_{12} = \frac{1}{2}\left(\sqrt{1+\frac{1}{x^2}} - \frac{1}{x}\right) \qquad [4\text{-}14]$$

References: Hamilton & Morgan (1952) [15], Kreith (1962) [22]

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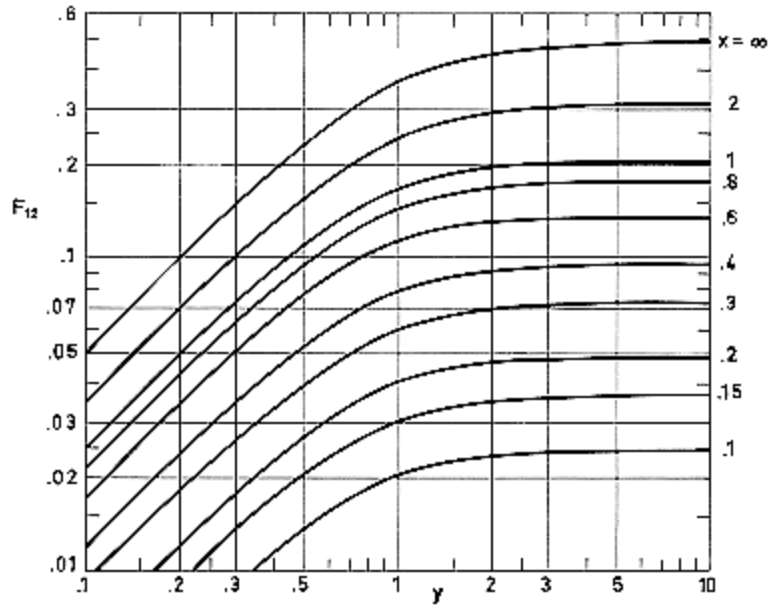
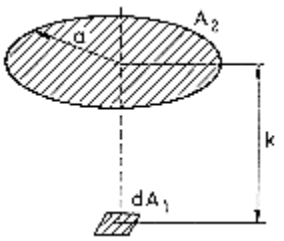


Note: non-si units are used in this figure

Figure 4-3: Values of F_{12} as a function of x and y. From Hamilton & Morgan (1952) [15]

4.2.1.4 Point source to coaxial disc or annulus

Infinitesimal surface to finite coaxial disc.



$H = a/k$

Formula

$$F_{12} = \frac{H^2}{1+H^2} \qquad [4\text{-}15]$$

The following case can be obtained by differentiating the above expression.

Infinitesimal surface to very thin coaxial annulus with finite radius.

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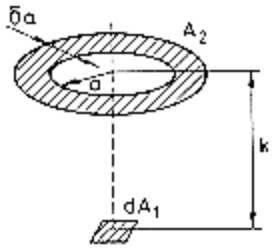

$H = a/k$
$\delta H = \delta a/k$

Formula

$$F_{12} = \frac{2H \cdot \delta H}{\left(1 + H^2\right)^2} \qquad [4\text{-}16]$$

This expression has been represented in the Figure 4-4.

Reference: Chung & Sumitra (1972) [6].

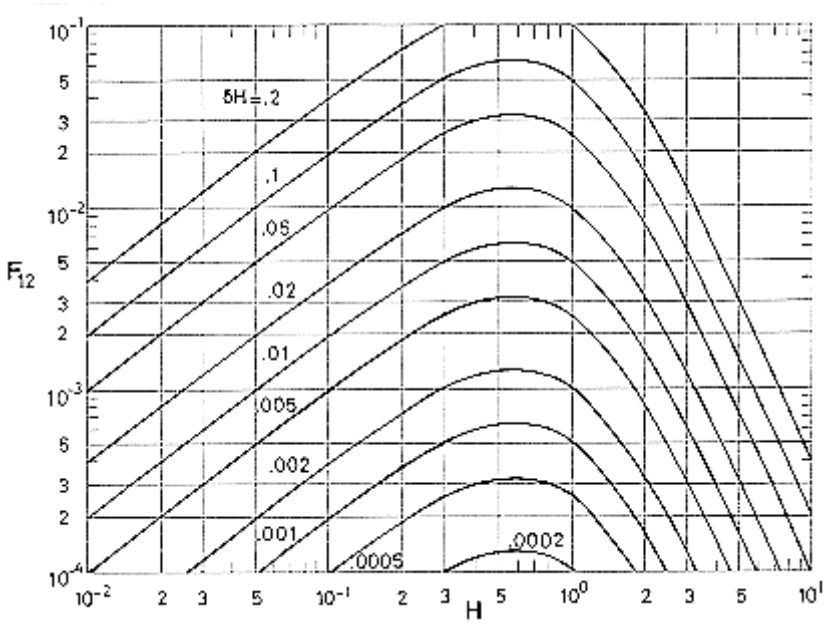

Figure 4-4: F_{12} vs. H for different values of dH. Infinitesimal surface to very thin coaxial annulus with finite radius. Calculated by the compiler.

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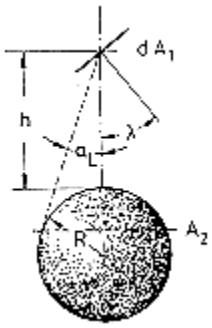
4.2.2 Planar to spherical

One face of an elemental plate to sphere.



$H = h/R$
$\text{cosec}\alpha_L = 1 + H$

Two cases can be distinguished:

I. The upper cap is fully visible from the plate ($\lambda + \alpha_L \leq \pi/2$).

The analytical expression for the view factor is:

$$F_{12} = \frac{\cos\lambda}{(1+H)^2} \qquad [4\text{-}17]$$

II. The upper cap is partially visible from the plate ($\lambda + \alpha_L > \pi/2$).

The self-shielding of the plate destroys the ease of integration of case I. the calculations are carried out numerically, by means of the following finite polynomial:

$F_{12} = B_0 + B_1\cos\lambda + B_2\cos^2\lambda + B_3\cos^3\lambda + B_4\cos^6\lambda$.

The parameters B_i (i = 0,...,4) are given in ECSS-E-HB-31-01 Part 3 Clause 5.1

This expression can be used in both cases although the values in the shadowed area in Figure 4-5 below have been calculated by the use of the analytical expression.

References: Cunningham (1961) [8], Kreith (1962) [22], Bannister (1965) [1], Clark & Anderson (1965) [7].

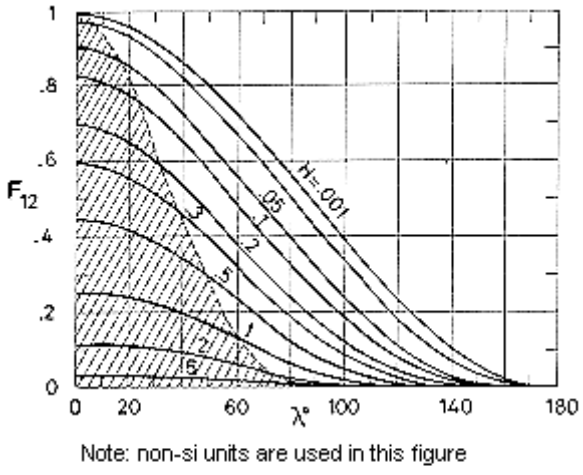


Figure 4-5: Values of F_{12} vs. λ for different values of H. The analytical expression (case I) is only valid in the shadowed region. Calculated by the compiler.

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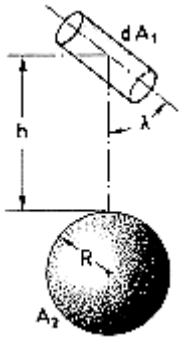
4.2.3 Cylindrical to spherical

Outer area of an infinitesimal cylindrical surface to sphere.

$H = h/R$



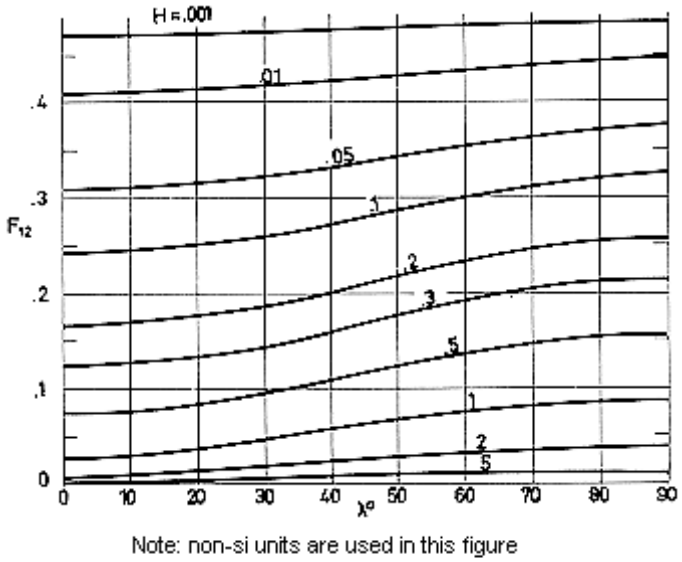
Formula:

$$F_{12} = \frac{1}{\pi^2}\int_0^{2\pi} d\phi \int_0^{\theta_o} \sqrt{1-\left(\cos\theta\cos\lambda + \sin\theta\sin\lambda\cos\phi\right)^2}\,\sin\theta d\theta \qquad [4\text{-}18]$$

where

$$\sin\theta_o = \frac{1}{1+H} \qquad [4\text{-}19]$$

References: Watts (1965) [50], Clark & Anderson (1965) [7].



Note: non-si units are used in this figure

Figure 4-6: Values of F_{12} as a function of H and λ. Calculated by the compiler.

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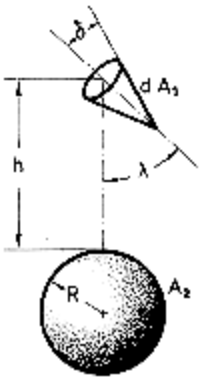
4.2.4 Conical to spherical

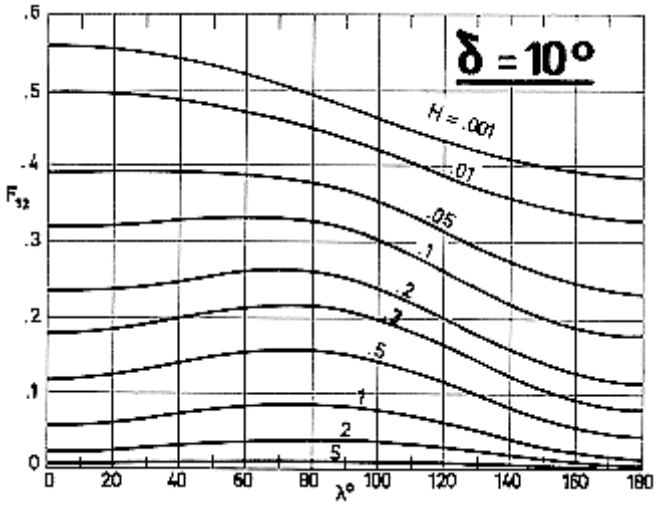
Outer area of an infinitesimal conical surface to sphere.

$H = h/R$



All results presented in the literature are obtained numerically.

References: Clark & Anderson (1965) [7].



Note: non-si units are used in this figure

Figure 4-7: Values of F_{12} as a function of H and λ, for $\delta = 10°$. Calculated by the compiler.

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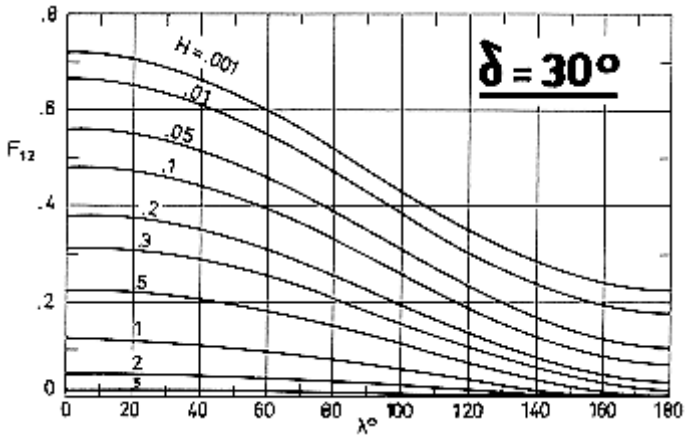
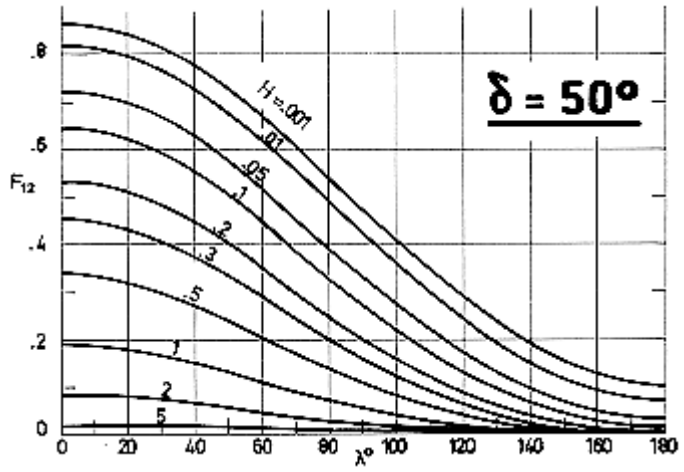


Note: non-si units are used in this figure

Figure 4-8: Values of F_{12} as a function of H and λ, for $\delta = 30°$. Calculated by the compiler.



Note: non-si units are used in this figure

Figure 4-9: Values of F_{12} as a function of H and λ, for $\delta = 50°$. Calculated by the compiler.

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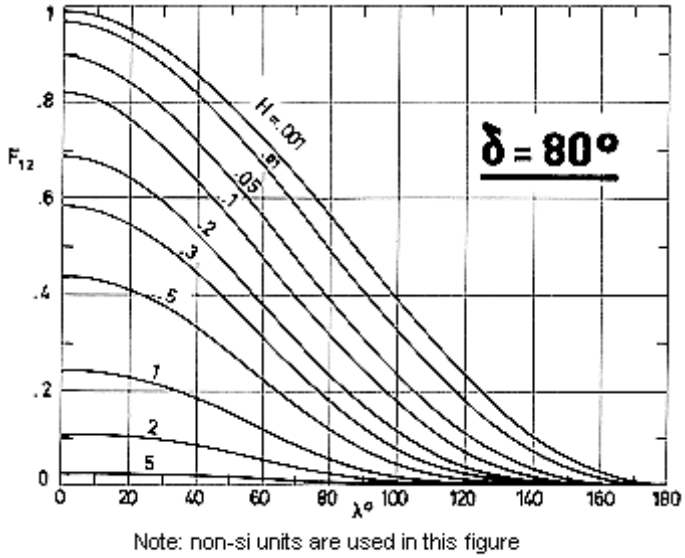


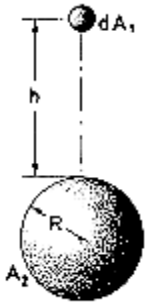
Figure 4-10: Values of F_{12} as a function of H and λ, for $\delta = 80°$. Calculated by the compiler.

4.2.5 Spherical to spherical

4.2.5.1 Sphere to outer sphere

Infinitesimal sphere to finite sphere.

$H = h/R$



Formula:

$$F_{12} = \frac{1}{2}\left(1 - \frac{\sqrt{H^2 + 2H}}{1 + H}\right) \qquad [4\text{-}20]$$

Reference: Watts (1965) [50].

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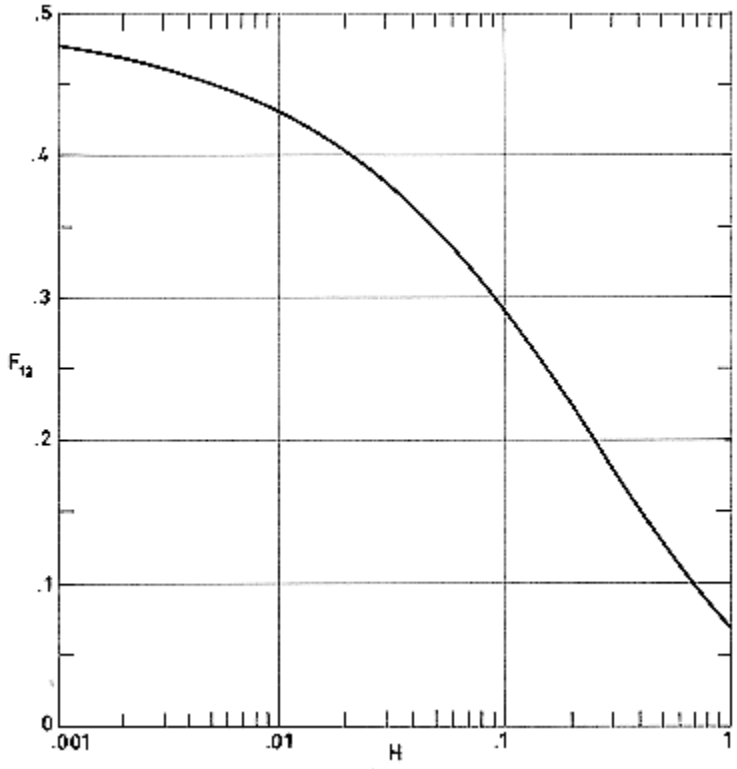


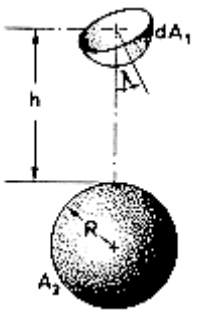
Note: non-si units are used in this figure

Figure 4-11: F_{12} as a function of H in the case of an infinitesimal sphere viewing a finite sphere. Calculated by the compiler.

4.2.5.2 Convex hemispherical surface to outer sphere

Convex surface of an infinitesimal hemisphere to sphere.

$H = h/R$



Formula:

$$F_{12} = \frac{1}{2}\left[1 - \frac{\sqrt{H^2 + 2H}}{1+H} + \frac{\cos\lambda}{2}\left(\frac{1}{1+H}\right)^2\right] \qquad [4\text{-}21]$$

Reference: Watts (1965) [50].

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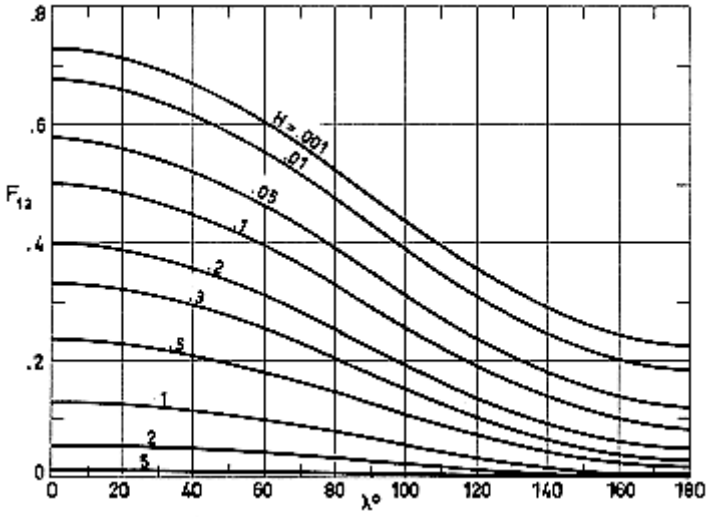


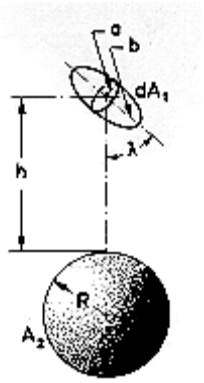
Note: non-si units are used in this figure

Figure 4-12: F_{12} as a function of angle λ for different values of the dimensionless distance H. Calculated by the compiler.

4.2.6 Ellipsoidal to spherical

Infinitesimal ellipsoid of revolution to sphere.

$H = h/R$
$A = a/b$



Formula:

$$F_{12} = \frac{1}{S}\int_0^{2\pi} d\phi \int_0^{\theta_o} \sqrt{\frac{A^4 + \tan^2\Delta}{A^2 + \tan^2\Delta}}\,\sin\left[\Delta + \tan^{-1}\left(A^2\cot\Delta\right)\right]\sin\theta d\theta \qquad [4\text{-}22]$$

where

$$\sin\theta_o = \frac{1}{1+H} \qquad [4\text{-}23]$$

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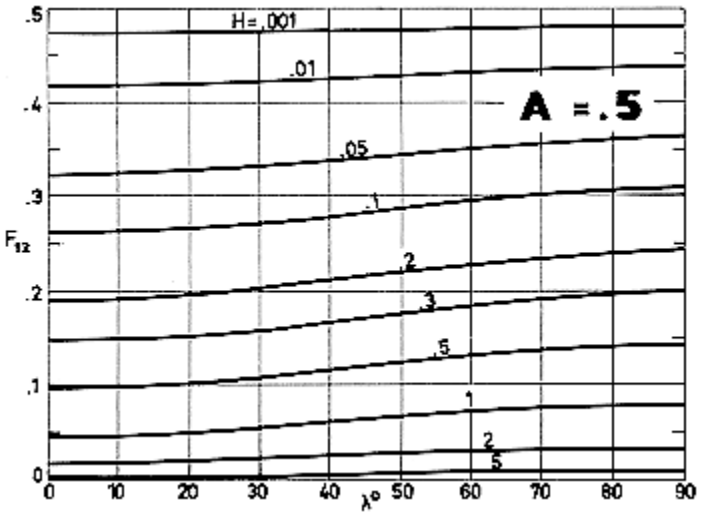
$$\cos\Delta = \cos\theta\cos\lambda + \sin\theta\sin\lambda\cos\phi \qquad [4\text{-}24]$$

$$S = 2\pi\left(A + \frac{\sin^{-1}\sqrt{1-A^2}}{\sqrt{1-A^2}}\right) \quad if\ A<1(prolate\ ellipsoid) \qquad [4\text{-}25]$$

$$S = 2\pi\left[A + \frac{\ln\left(A+\sqrt{A^2-1}\right)}{\sqrt{A^2-1}}\right] \quad if\ A>1(oblate\ ellipsoid) \qquad [4\text{-}26]$$

Reference: Watts (1965) [50].



Note: non-si units are used in this figure

Figure 4-13: F_{12} as a function of λ and H, for A = 0,5. Calculated by the compiler.

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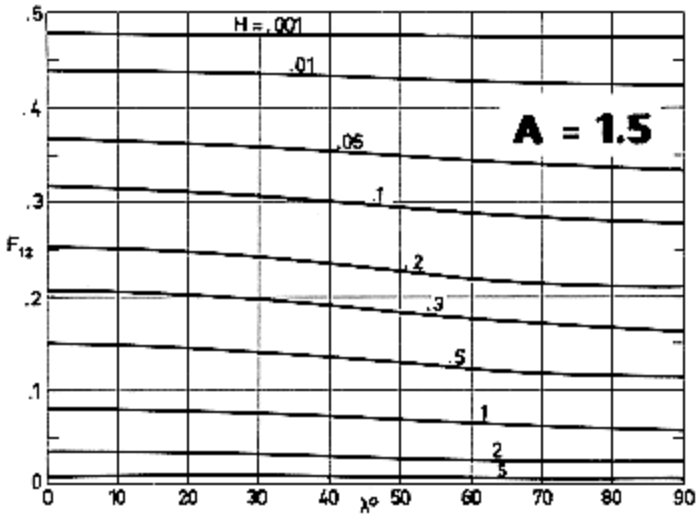
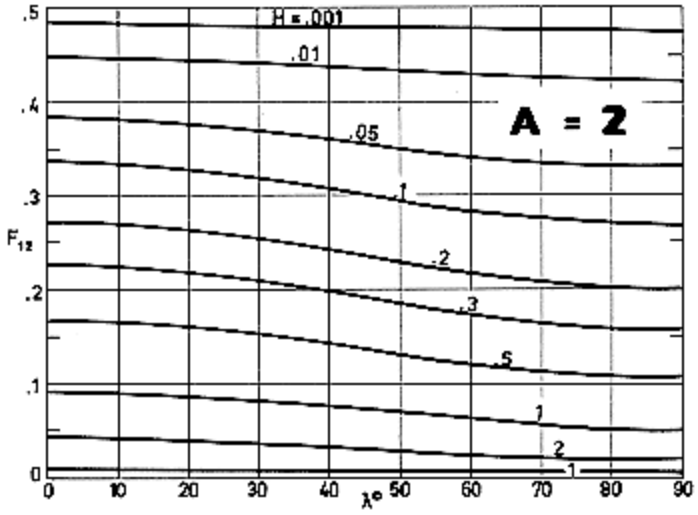


Note: non-si units are used in this figure

Figure 4-14: F_{12} as a function of λ and H, for A = 1,5. Calculated by the compiler.



Note: non-si units are used in this figure

Figure 4-15: F_{12} as a function of λ and H, for A = 2. Calculated by the compiler.

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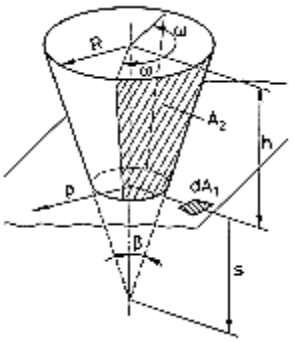
4.2.7 Planar to conical

Infinitesimal surface of a ring to an inverted coaxial cone.

Two different configurations could arise depending on whether the cone intersects or not the planar surface.



$L = s/(h\text{-}s)$
$M = \rho/R$

$$\omega = 2\tan^{-1}\sqrt{\frac{M+L}{M-L}} \qquad [4\text{-}27]$$

Configuration 1. Cone and plane dA_1 intersect. ($s < 0$, $\rho \geq -s\tan\beta$).

Configuration 2. Cone and plane dA_1 do not intersect. ($s > 0$).

Formula:

Configuration 1:

$$F_{12} = \frac{\sin\beta}{\pi}\tan^{-1}\left(\frac{L+1}{\sin\beta\sqrt{M^2-L^2}}\right) + \frac{1}{\pi}\tan^{-1}\sqrt{\frac{M-L}{M+L}} + f(M,L,\beta) \qquad [4\text{-}28]$$

$$f(M,L,\beta) = \frac{(1-M^2)\tan^2\beta-(L+1)^2}{\pi\sqrt{\left[(1+M^2)\tan^2\beta+(L+1)^2\right]^2-4M^2\tan^4\beta}}\tan^{-1}\sqrt{\frac{M+L}{M-L}\frac{(1+M^2)\tan^2\beta+(L+1)^2}{(1-M^2)\tan^2\beta+(L+1)^2}} \qquad [4\text{-}29]$$

Configuration 2:

Case 2a: $M > L$

$$F_{12} = \frac{\omega}{2\pi} + \frac{\sin\beta}{\pi}\left[\tan^{-1}\left(\frac{L+1}{\sin\beta\sqrt{M^2-L^2}}\right) - \tan^{-1}\left(\frac{L}{\sin\beta\sqrt{M^2-L^2}}\right)\right] + f(M,L,\beta) \qquad [4\text{-}30]$$

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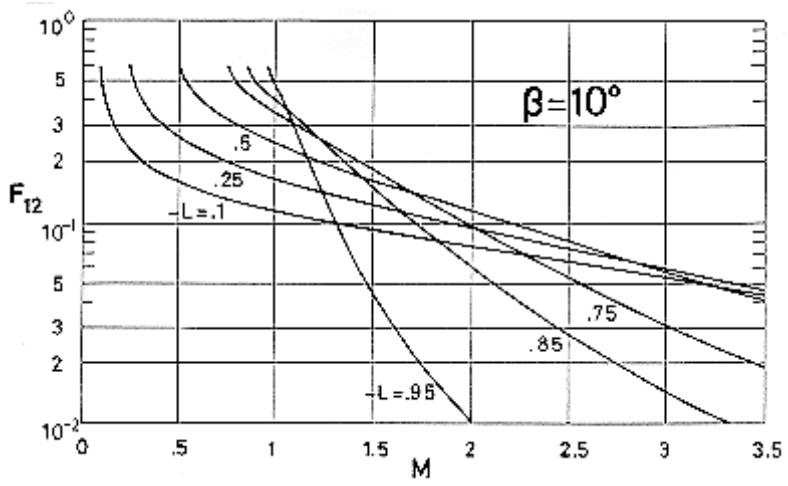
Case 2b: $M \leq L$ (Cone is seen as a disc of radius R. See the sketch).

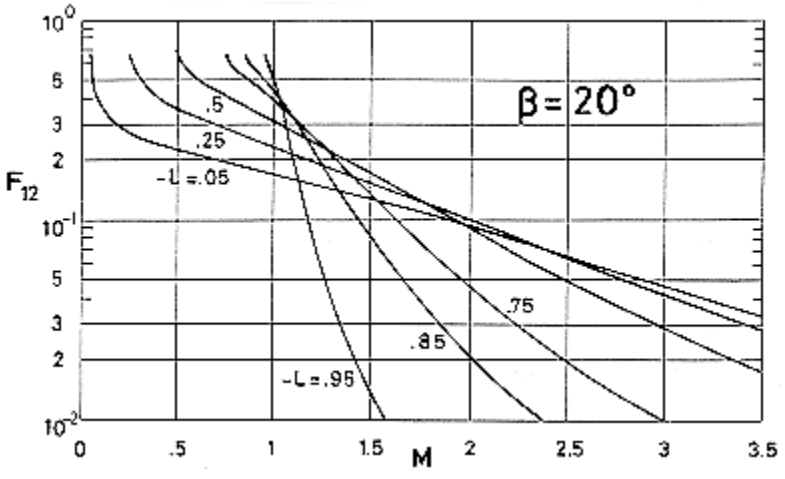
$$F_{12} = \frac{1}{2}\left[1 + \frac{(1-M^2)\tan^2\beta - (L+1)^2}{\pi\sqrt{\left[(1+M^2)\tan^2\beta + (L+1)^2\right]^2 - 4M^2\tan^4\beta}}\right] \qquad [4\text{-}31]$$

Reference: Minning (1977) [25].



Note: non-si units are used in this figure

Figure 4-16: Values of F_{12} vs. M for different values of L. Configuration 1, $\beta = 10°$. Calculated by the compiler.



Note: non-si units are used in this figure

Figure 4-17: Values of F_{12} vs. M for different values of L. Configuration 1, $\beta = 20°$. Calculated by the compiler.

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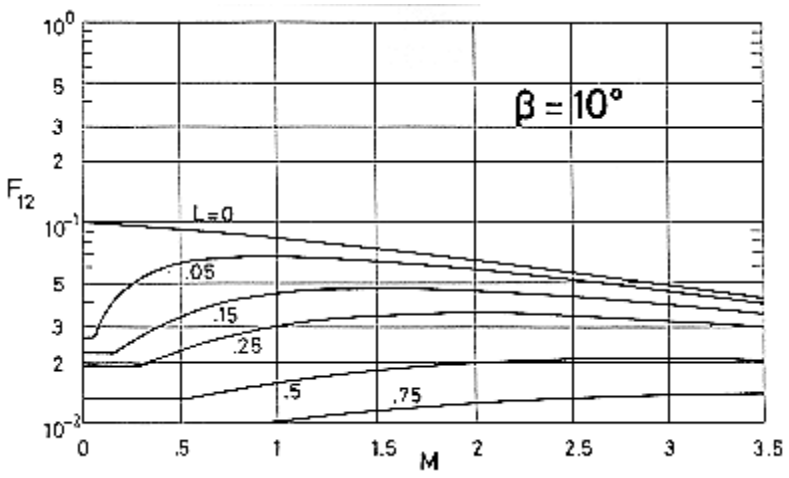
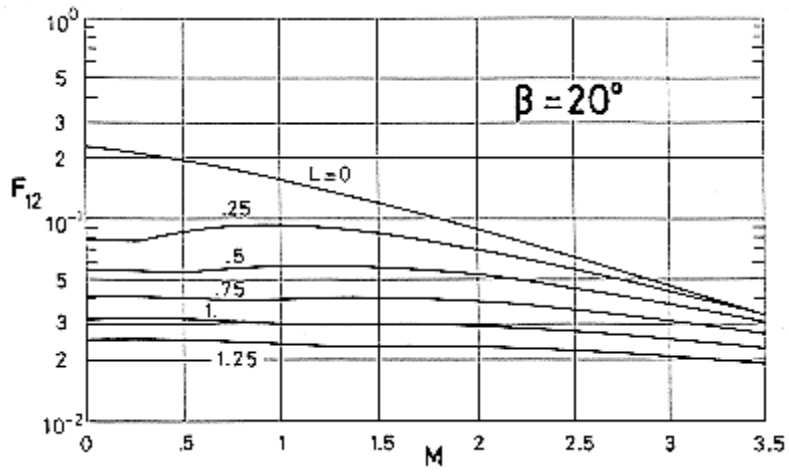


Note: non-si units are used in this figure

Figure 4-18: Values of F_{12} vs. M for different values of L. Configuration 2, $\beta = 10°$. Calculated by the compiler.



Note: non-si units are used in this figure

Figure 4-19: Values of F_{12} vs. M for different values of L. Configuration 2, $\beta = 20°$. Calculated by the compiler.

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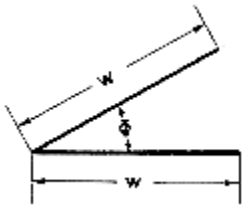
4.3 Finite to finite surface

4.3.1 Planar to planar. Two-dimensional configurations

4.3.1.1 Two strips of equal width at any angle

Two infinitely long plates of equal finite width w, having one common edge, and at an included angle ϕ to each other.



Formula:

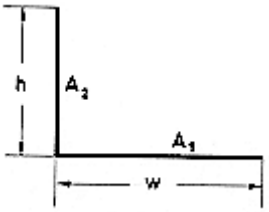
$$F_{12} = F_{21} = 1 - \sin\frac{\phi}{2} \qquad [4\text{-}32]$$

Reference: Siegel & Howell (1972) [37].

4.3.1.2 Two strips of unequal width normal to each other

Two infinitely long plates of unequal finite with, having one common edge, and at an included angle $\phi = 90°$ to each other.

$H = h/w$



Formula:

$$F_{12} = HF_{21} = \frac{1}{2}\left[1 + H - \sqrt{1 + H^2}\right] \qquad [4\text{-}33]$$

References: Kreith (1962) [22], Siegel & Howell (1972) [37].

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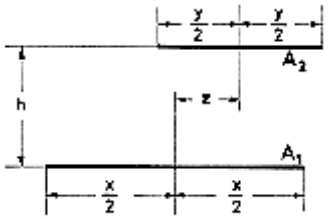
4.3.1.3 Two parallel strips

Two infinitely long parallel strips of unequal width



$X = x/h$
$Y = y/h$
$Z = z/h$

Formula:

$$F_{12} = \frac{Y}{X} F_{21} = \frac{1}{2X}\left[\sqrt{1+\left(\frac{Y+X-2Z}{2}\right)^2} + \sqrt{1+\left(\frac{Y+X+2Z}{2}\right)^2} - \sqrt{1+\left(\frac{X-Y-2Z}{2}\right)^2} - \sqrt{1+\left(\frac{X-Y+2Z}{2}\right)^2}\right] \quad [4\text{-}34]$$

Reference: Kutateladze & Borishanskii (1966) [23].

When $X = Y$ and $Z = 0$, one obtains:

$$F_{12} = F_{21} = \frac{1}{X}\left[\sqrt{1+X^2} - 1\right] \quad [4\text{-}35]$$

References: Kreith (1962) [22], Siegel & Howell (1972) [37].

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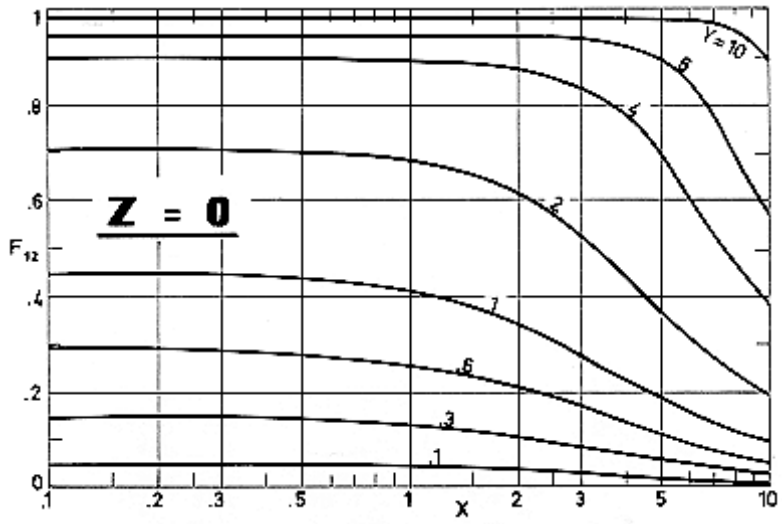
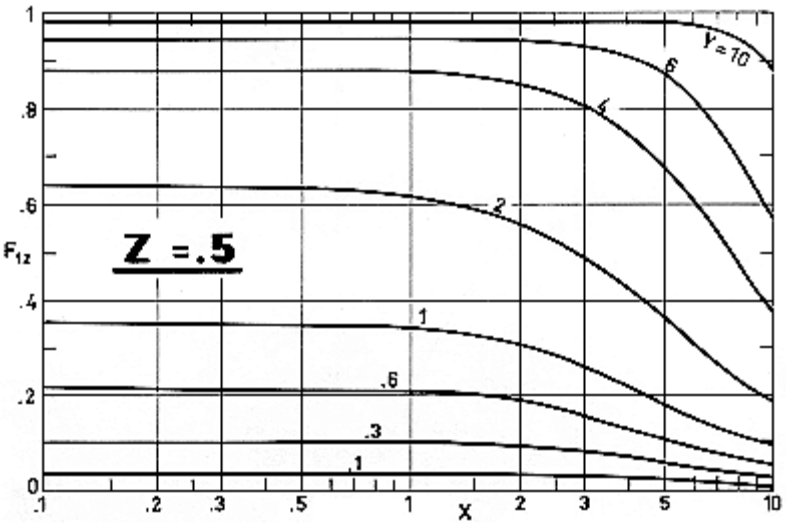


Note: non-si units are used in this figure

Figure 4-20: Values of F_{12} as a function of X and Y, for $Z = 0$. Calculated by the compiler.



Note: non-si units are used in this figure

Figure 4-21: Values of F_{12} as a function of X and Y, for $Z = 0{,}5$. Calculated by the compiler.

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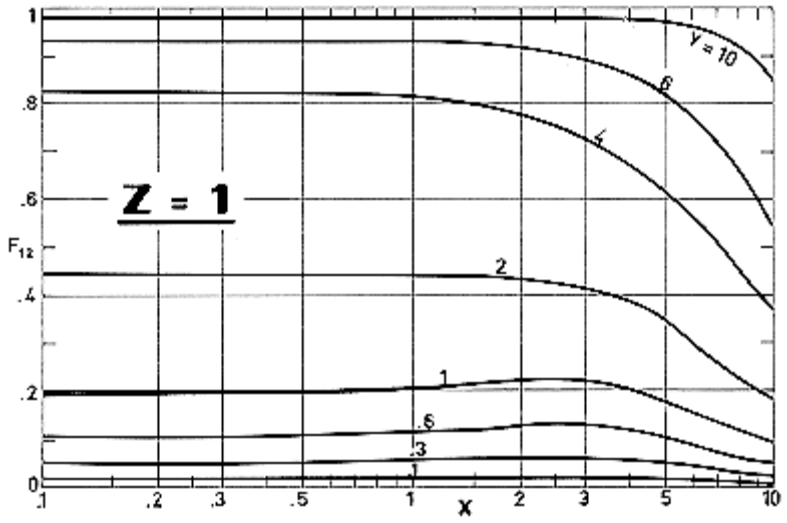
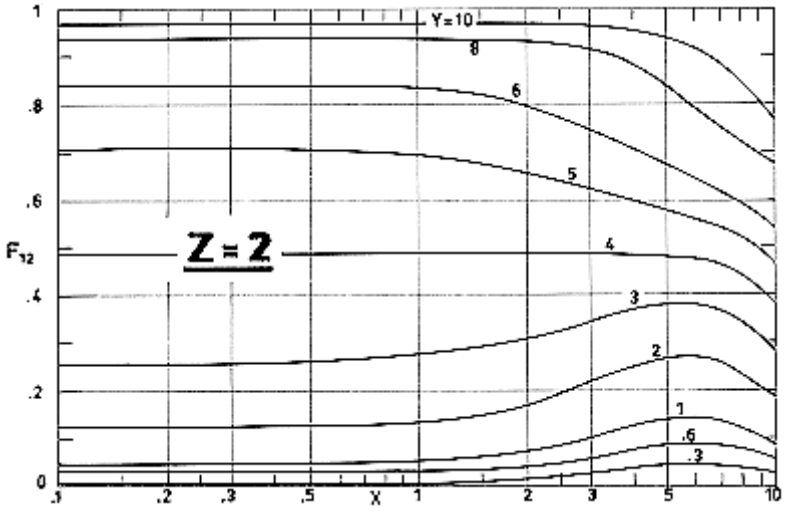


Note: non-si units are used in this figure

Figure 4-22: Values of F_{12} as a function of X and Y, for $Z = 1$. Calculated by the compiler.



Note: non-si units are used in this figure

Figure 4-23: Values of F_{12} as a function of X and Y, for $Z = 2$. Calculated by the compiler.

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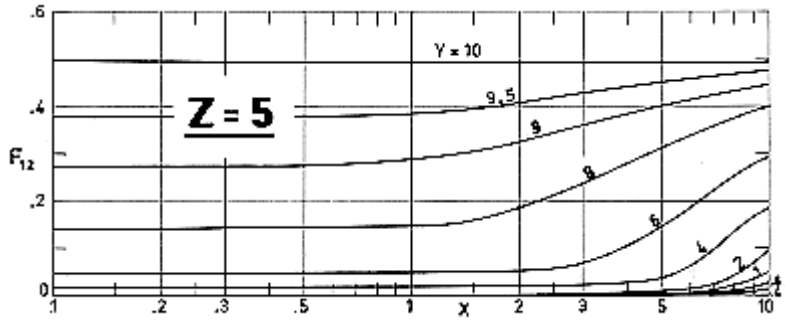


Note: non-si units are used in this figure

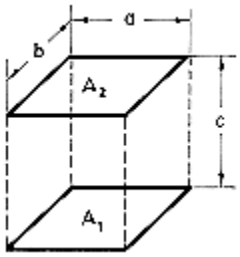
Figure 4-24: Values of F_{12} as a function of X and Y, for $Z = 5$. Calculated by the compiler.

4.3.2 Planar to planar. Three-dimensional configurations

4.3.2.1 Parallel rectangles of the same dimensions

Parallel, directly opposed rectangles of same width and length

$X = a/c$
$Y = b/c$



Formulae:

$$F_{12} = \frac{2}{\pi XY}\left\{\ln\left[\frac{(1+X^2)(1+Y^2)}{1+X^2+Y^2}\right]^{1/2} + X\sqrt{1+Y^2}\tan^{-1}\frac{X}{\sqrt{1+Y^2}} + Y\sqrt{1+X^2}\tan^{-1}\frac{Y}{\sqrt{1+X^2}} - X\tan^{-1}X - Y\tan^{-1}Y\right\} \quad [4\text{-}36]$$

When $X \approx Y << 1$, $F_{12} = XY/\pi$.

References: Hamilton & Morgan (1952) [15], Jakob (1957) [19], Kreith (1962) [22], Hsu (1967) [18], Siegel & Howell (1972) [37].

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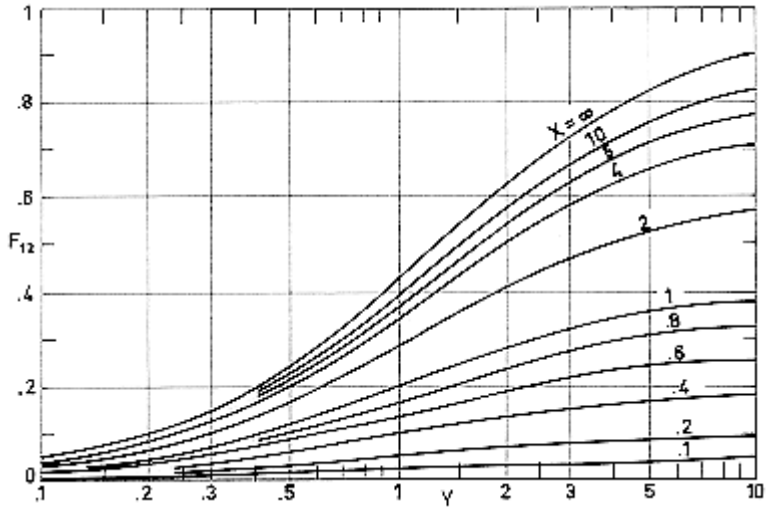


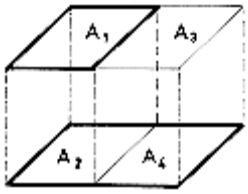
Note: non-si units are used in this figure

Figure 4-25: Values of F_{12} as a function of X and Y. Calculated by the compiler.

4.3.2.2 Parallel rectangle of unequal dimensions

The following view factors can be deduced by using the results for two parallel directly opposed rectangles.

Two rectangles in parallel planes with one rectangle directly opposite to portion of the other.

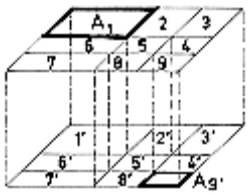


View factor is:

$$F_{1(2,4)} = \frac{1}{2A_1}\left[A_{(1,3)}F_{(1,3)(2,4)} + A_1F_{12} - A_3F_{34}\right] \qquad [4\text{-}37]$$

References: Moon (1961) [26], Kreith (1962) [22], Hsu (1967) [18].

Two rectangles of arbitrary size in parallel planes with one edge of a rectangle parallel to one of the other.



View factor is:

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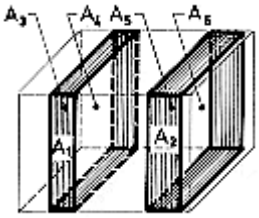
$$A_1F_{19'} = \frac{1}{4}\left[\begin{array}{l} K_{(1,2,3,4,5,6,7,8,9)^2} - K_{(1,2,5,6,7,8)^2} - K_{(2,3,4,5,8,9)^2} - K_{(1,2,3,4,5,6,7,8,9)^2} - \\ - K_{(1,2,3,4,5,6)^2} - K_{(1,2,5,6)^2} - K_{(2,3,4,5)^2} - K_{(4,5,8,9)^2} - K_{(4,5)^2} - K_{(5,8)^2} - \\ - K_{(5,6)^2} - K_{(4,5,6,7,8,9)^2} - K_{(5,6,7,8)^2} - K_{(4,5,6)^2} - K_{(2,5,8)^2} - K_{(2,5)^2} - K_{5^2} \end{array}\right] \quad [4\text{-}38]$$

where $K_{m2} = A_m F_{mm'}$.

Reference: Hsu (1967) [18].

Finite area on interior of a rectangular channel.



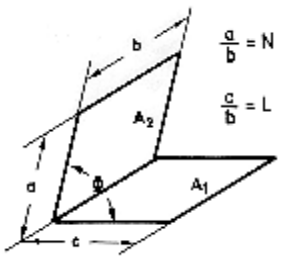
View factor is:

$$F_{12} = \frac{A_4}{A_1}\left(F_{45} + F_{36} + F_{46} - F_{35}\right) \quad [4\text{-}39]$$

Reference: Siegel & Howell (1972) [37].

4.3.2.3 Rectangles with one common edge

Two rectangles A_1 and A_2 with one common edge and included angle ϕ between the two planes.



Formulae:

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