



ESDU 69010

Issued June 1969
With Amendments A and B
July 1973
Supersedes ESDU
Aero S.00.03.19

Heat transfer by forced convection between a two-dimensional laminar boundary layer and a smooth flat plate, with application to wedges, cylinders and cones

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THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item which supersedes Item No. Aero. S.00.03.19, was monitored and guided by the Aerodynamics Committee. This Committee first met in 1942 and now has the following membership:

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HEAT TRANSFER BY FORCED CONVECTION BETWEEN A TWO-DIMENSIONAL LAMINAR BOUNDARY LAYER AND A SMOOTH FLAT PLATE, WITH APPLICATION TO WEDGES, CYLINDERS AND CONES

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1. NOTATION AND UNITS

Any set of consistent units may be used. Two such sets are indicated below.

		SI	British
a	Reynolds analogy factor, $St/C_f = St_m/C_{fm}$		
C_f	local skin friction coefficient		
C_{fm}	mean skin friction coefficient		
c_p	specific heat capacity at constant pressure	J/kg K	Chu/slug K
k	thermal conductivity	W/m K	Chu/ft s K
M	Mach number		
Pr	Prandtl number, $\mu c_p/k$		
p	static pressure	N/m ²	lbf/ft ²
q	local heat flux intensity	W/m ²	Chu/ft ² s
q_m	mean heat flux intensity	W/m ²	Chu/ft ² s
R_x	Reynolds number based on distance measured from leading edge, $u_1 x/\nu_1$		
r	temperature recovery factor		
St	local Stanton number, $q/\rho_1 u_1 c_p (T_{wr} - T_w)$		
St_m	mean Stanton number, $q_m/\rho_1 u_1 c_p (T_{wr} - T_w)$, $(\equiv \frac{1}{x} \int_0^x St(x') dx')$ *		
St_i	local Stanton number in incompressible flow, <i>i.e.</i> $M_1 = 0, T_w = T_{wr} = T_1$		
St_{mi}	mean Stanton number in incompressible flow, <i>i.e.</i> $M_1 = 0, T_w = T_{wr} = T_1$		
T	temperature	K	K

For footnote refer to end of Notation.

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T_{wr}	recovery temperature (<i>i.e.</i> temperature of the wall for zero heat transfer), $T_1 \left[1 + r \frac{(\gamma-1)}{2} M_1^2 \right]$	K	K
u	velocity	m/s	ft/s
x	distance measured along surface from leading edge	m	ft
x'	dummy variable of integration	m	ft
γ	ratio of specific heat capacities		
μ	viscosity	kg/m s	slug/ft s
ν	kinematic viscosity	m ² /s	ft ² /s
ρ	density	kg/m ³	slug/ft ³

Suffixes

c	relating to cone flow
w	relating to conditions at the wall
1	relating to conditions at edge of boundary layer
∞	relating to conditions in uniform flow upstream.

* For cone flow $(St_m)_c = \frac{2}{x_c^2} \int_0^x [St(x')]_c x'_c dx'_c$.

2. FLAT PLATE FLOW

Figure 1 presents local and mean Stanton numbers (St_i and St_{mi}) respectively for the two-dimensional laminar boundary layer on a smooth flat plate with a uniform wall temperature and zero pressure gradient in incompressible flow (*i.e.* $M_1 = 0$ and $T_w = T_{wr} = T_1$). The data are given for a range of Reynolds numbers, R_x , up to 10^8 .

The effects of Mach number, M_1 , temperature ratio, T_w/T_{wr} , and ambient temperature, T_1 , on Stanton number are given in Figure 2. Data are presented for Mach numbers in the range $0 \leq M_1 \leq 5$, temperature ratios in the range $0.20 \leq T_w/T_{wr} \leq 2.0$ and ambient temperatures of 100, 200, 216.5[†], 300 and 400 Kelvin. The heat transfer data are normalised by dividing by the relevant Stanton number for incompressible flow at the same Reynolds number.

[†] It will be noted that the case of flight in the stratosphere ($T_1 = 216.5$ K for the flat plate case) is treated as a particular case in this Item.