



ESDU 69012

Issued October 1969
With Amendments A and B
July 1973
Supersedes ESDU
Aero S.00.03.20

Effects of kinetic heating on equilibrium temperature of flight vehicles

Endorsed by
The Royal Aeronautical Society



Documents
Document Sharing Hub

ESDU DATA ITEMS

Data Items provide validated information in engineering design and analysis for use by, or under the supervision of, professionally qualified engineers. The data are founded on an evaluation of all the relevant information, both published and unpublished, and are invariably supported by original work of ESDU staff engineers or consultants. The whole process is subject to independent review for which crucial support is provided by industrial companies, government research laboratories, universities and others from around the world through the participation of some of their leading experts on ESDU Technical Committees. This process ensures that the results of much valuable work (theoretical, experimental and operational), which may not be widely available or in a readily usable form, can be communicated concisely and accurately to the engineering community.

We are constantly striving to develop new work and review data already issued. Any comments arising out of your use of our data, or any suggestions for new topics or information that might lead to improvements, will help us to provide a better service.

THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item which supersedes ESDU Aero S.00.03.20, was monitored and guided by the Areodynamics Committee. This Committee first met in 1942 and now has the following membership:

Chairman

Prof. G.M. Lilley — University of Southampton

Vice-Chairmen

Prof. D.W. Holder — University of Oxford

Mr W.F. Wiles — Rolls-Royce Ltd

Members

Mr E.C. Carter — Aircraft Research Association

Dr L.F. Crabtree — Royal Aircraft Establishment

Mr R.L. Dommert — Royal Aircraft Establishment

Mr H.C. Garner — National Physical Laboratory

Mr J.R.C. Pedersen — British Aircraft Corporation (Guided Weapons) Ltd

Mr M.W. Salisbury — British Aircraft Corporation (Weybridge) Ltd

Mr J. Taylor — Hawker Siddeley Aviation Ltd, Woodford

Mr J.W.H. Thomas — Hawker Siddeley Aviation Ltd, Hatfield

Mr J. Weir — University of Salford.

The construction and subsequent development of the Data Item was undertaken by

Dr A.J. Ward Smith — Head of Fluid Mechanics and Thermodynamics Group

Mr P.D. Chappell — Senior Engineer, Fluid Mechanics and Thermodynamics Group.

EFFECTS OF KINETIC HEATING ON EQUILIBRIUM TEMPERATURE OF FLIGHT VEHICLES

CONTENTS

	Page
1. NOTATION AND UNITS	1
2. NOTES	2
3. DERIVATION	4
4. REFERENCES	4
5. EXAMPLE	4
6. TABLES	7
FIGURES 1 to 3	9 to 11

ESDU Copyright material. For current status contact ESDU.

EFFECTS OF KINETIC HEATING ON EQUILIBRIUM TEMPERATURE OF FLIGHT VEHICLES

1. NOTATION AND UNITS

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

		<i>SI</i>	<i>British</i>
B	Stefan-Boltzmann radiation constant, taken as $5.67 \times 10^{-8} \text{ W/m}^2 \text{ K}^4$ ($2.78 \times 10^{-12} \text{ Chu/ft}^2 \text{ s K}^4$)	$\text{W/m}^2 \text{ K}^4$	$\text{Chu/ft}^2 \text{ s K}^4$
C_1	factor in Equations (2.3), taken as $2.83 \times 10^{-12} \text{ kg/m}^3 \text{ K}^{2.5}$ ($5.47 \times 10^{-15} \text{ slug/ft}^3 \text{ K}^{2.5}$)	$\text{kg/m}^3 \text{ K}^{2.5}$	$\text{slug/ft}^3 \text{ K}^{2.5}$
C_2	factor in Equations (2.3), taken as $1.76 \times 10^7 \text{ m}^2 \text{ K}^4 / \text{W}$ ($3.60 \times 10^{11} \text{ ft}^2 \text{ s K}^4 / \text{Chu}$)	$\text{m}^2 \text{ K}^4 / \text{W}$	$\text{ft}^2 \text{ s K}^4 / \text{Chu}$
c_p	specific heat capacity at constant pressure, taken as 10^3 J/kg K (7.72 Chu/slug K) for air	J/kg K	Chu/slug K
K_1	non-dimensional parameter, $\varepsilon B T_1^{2.5} / St \rho_1 c_p \sqrt{\gamma R}$		
K_2	non-dimensional parameter, $(\alpha_s q_s / \varepsilon B T_1^4) + (T_\infty / T_1)^4 - 1$		
M_1	Mach number at edge of boundary layer		
q	local forced convection heat flux intensity	W/m^2	$\text{Chu/ft}^2 \text{ s}$
q_s	solar radiation heat flux intensity	W/m^2	$\text{Chu/ft}^2 \text{ s}$
R	gas constant, taken as 287 J/kg K ($3090 \text{ ft lbf/slug K}$) for air	J/kg K	ft lbf/slug K
r	temperature recovery factor		
St	local Stanton number, $q / \rho_1 u_1 c_p (T_{wr} - T_w)$		
T_w	wall temperature	K	K
T_{we}	equilibrium wall temperature	K	K
T_{wr}	recovery temperature, $T_1 \left[1 + r \frac{(\gamma - 1)}{2} M_1^2 \right]$	K	K
T_1	temperature at edge of boundary layer	K	K

Issued October 1969

With Amendments A and B, July 1973 - 11 pages

T_{∞}	temperature of uniform flow upstream	K	K
u_1	velocity at edge of boundary layer	m/s	ft/s
α	normal total surface absorptivity		
α_s	normal total solar absorptivity		
γ	ratio of specific heat capacities, taken as 1.4 for air		
ε	normal total surface emissivity		
ε_G	gas emissivity, taken as unity for air		
ρ_1	density at edge of boundary layer	kg/m ³	slugs/ft ³

2. NOTES

Figures 1 to 3 present data for estimating the equilibrium temperature distribution on flat plates, wedges, cylinders and cones in constant velocity flight in air. The equilibrium temperature is attained (see Item No. 69009 for a full discussion) when the effects of forced convection heat transfer and solar radiation to the surface are balanced by the difference between radiation from the surface and atmospheric radiation to the surface. The heat balance equation under these conditions is

$$St \rho_1 u_1 c_p (T_{wr} - T_{we}) + \alpha_s q_s = \varepsilon B T_{we}^4 - \alpha \varepsilon_G B T_{\infty}^4.$$

For the purposes of this Item it will be assumed that the emissivity of air, ε_G , is unity and that the absorptivity of the surface, α , is equal to the emissivity, ε . The above equation therefore reduces to

$$St \rho_1 u_1 c_p (T_{wr} - T_{we}) + \alpha_s q_s = \varepsilon B (T_{we}^4 - T_{\infty}^4). \quad (2.1)$$

Substitution for u_1 and T_{wr} in Equation (2.1) yields, with some rearrangement

$$\left(\frac{T_{we}}{T_1} \right)^4 + \frac{M_1 T_{we}}{K_1 T_1} - \frac{M_1}{K_1} \left[1 + r \frac{(\gamma-1)}{2} M_1^2 \right] - (K_2 + 1) = 0 \quad (2.2)$$