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A.R.C. Heat and Mass Transfer Sub-Committee Proposed Nomenclature for Film Cooling Investigations

By J. Odgers and B. R. Smith
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The following Tables are the recommended terminology for film-cooling investigations. Wherever possible the proposed symbol has been taken from the British Standard 1991, Part 1; 'General Letter Symbols, Signs and Abbreviations', incorporating amendments issued July 1955, February 1957 and October 1960. In addition it has been the aim of the authors, wherever possible, to avoid duplication of symbols and also to suggest symbols of a suitable form for printing and report purposes. For this reason the use of dots and 's, ″s and ‴s to signify rate and dimensions, has been avoided. Wherever possible the use of Greek letters has been restricted to those which are easily identifiable from the corresponding Roman letters.

No attempt is made here to specify the units to be used with the definitions since it is hoped that with the adoption of the decimal system only a single set of units will be used.

From time to time there has been some confusion in the interpretation of the phrases 'cooling efficiency' and 'cooling effectiveness'. It is suggested that the former term be dropped and replaced by the latter and that a new term 'overall cooling effectiveness' be used. Therefore the following terms are proposed.

(a) *cooling effectiveness*, (η). A dimensionless parameter to describe the temperature of an *adiabatic* wall at any point downstream of the coolant injection.

(b) *overall cooling effectiveness*, (ε). A dimensionless parameter to describe the temperature of a non-adiabatic wall at any point downstream of a given reference position.

Another definition thought worthy of inclusion is the Hydrodynamic Transition Length. This is the distance in the direction of flow from the end of the potential core to the point where it may be considered that a universal velocity profile exists in the film.

The nomenclature is arranged in two forms:

(a) the alphabetical list of the terminology (Table I).

(b) according to the order of symbols used (Table II).

The proposed nomenclature does not contain all the symbols and their definitions which have been used from time to time, in papers and reports on film cooling. Infrequently used symbols have been omitted although a few of the more important ones are listed in Appendix 1.

*Replaces A.R.C. 28 935.

TABLE 1

Arrangement by Definition

Absolute static pressure	p
Absolute total pressure	P
Absorption factor for radiation	α
Adiabatic wall temperature	T_{ad}
Angle of plane	ϕ
Area, cross-sectional	A
Coefficient of convective heat transfer	h_c
diffusion	D
discharge	C_d
equivalent heat transfer, due to radiation	h_r
gas stream heat transfer	h_g
gas stream mass transfer	C_m
heat transfer	h
local drag	C_D
local heat transfer due to combined convective and radiative heat fluxes	h_{TOT}
local skin friction	c_f
overall heat transfer	U
pressure	C_p
total skin friction	C_f
Conductivity, thermal	k
Constant pressure, specific heat at	c_p
Constant volume, specific heat at	c_v
Convection, heat transfer due to	C
Convective heat-transfer coefficient	h_c
Coolant injection angle, effective	θ_{eff}
Coolant injection angle relative to adiabatic wall	θ
Cooling air mass flow	m_a
Cooling effectiveness	η
Cooling effectiveness, overall	ε
Correlation parameter	X
Cross-sectional area	A
Density	ρ

TABLE 1—*continued*

Depth of slot	s
Diameter	d
Diameter, equivalent or hydraulic	d_e
Difference in temperature	ΔT
Diffusion coefficient	D
Diffusivity, eddy	ε_D
Diffusivity, thermal	α
Dimensionless distance in downstream direction	x^*
Dimensionless distance normal to wall	y^*
Discharge coefficient	C_d
Distance downstream	x
Distance normal to wall	y
Drop in pressure	ΔP
Eddy diffusivity	ε_D
Effective coolant injection angle	θ_{eff}
Effectiveness of cooling	η
Enthalpy	H
Enthalpy, specific	h
Entrainment rate	w
Equivalent heat-transfer coefficient due to radiation	h_r
Equivalent of heat, mechanical	J
Equivalent or hydraulic diameter	d_e
Gap width	s
Gas constant	R
Gas stream heat-transfer coefficient	h_g
Gas stream mass-transfer coefficient	C_m
Heat content, total	Q
Heat flow, rate of	q
Heat flux, radiative	q_r
Heat, mechanical equivalent of	J
Heat transfer coefficient	h
Heat-transfer coefficient, convective	h_c
equivalent, due to radiation	h_r

TABLE 1—*continued*

local, due to combined convective and radiative heat fluxes	h_{TOT}
of gas stream	h_g
overall	U
Heat transfer due to convection	C
Hydraulic or equivalent diameter	d_e
Hydrodynamic starting length	L
Hydrodynamic transition length	x_T
Kinematic viscosity	ν
Length	l
Length of potential core	x_p
Length of slot	l_s
Length, hydrodynamic transition	x_T
Local drag coefficient	C_D
Local heat transfer coefficient due to combined convective and radiative heat fluxes	h_{TOT}
Local skin-friction coefficient	c_f
Mach number	Ma
Mass flow	m
Mass-transfer driving force	B
Mass velocity	G
Mechanical equivalent of heat	J
Molecular weight	M
Nusselt number	Nu
Overall cooling effectiveness	ε
Overall heat-transfer coefficient	U
Plane angle	ϕ
Potential core length	x_p
Prandtl number	Pr
Pressure coefficient	C_p
Pressure drop	ΔP
Radiation, absorption factor for	α
Radiative heat flux	q_r

TABLE 1—*continued*

Rate of entrainment	w
Rate of heat flow	q
Ratio of specific heats	γ
Reynolds number	Re
Schmidt number	Sc
Shear stress	τ
Shear stress at the wall	τ_w
Slot depth	s
Sound, velocity of	a
Specific enthalpy	h
Specific heat at constant pressure	c_p
Specific heat at constant volume	c_v
Specific heats, ratio of	γ
Specific volume	C_v
Stanton number	St
Starting length, hydrodynamic	L
Static pressure, absolute	p
Static temperature	t
Stephan-Boltzmann constant	σ
Temperature difference	ΔT
Temperature, static	t
Thermal conductivity	k
Thermal diffusivity	α
Thickness of any layer	δ
Time	t
Total heat content	Q
Total pressure, absolute	P
Total skin-friction coefficient	C_f
Total temperature	T
Universal constant in mixing length relationship	κ
Velocity of sound	a
Velocity in x direction	u

TABLE 1—*continued*

Velocity in y direction	v
Viscosity	μ
Viscosity, kinematic	ν
Volume, specific	C_v
Wall temperature, adiabatic	T_{ad}
Width of gap	s

TABLE 2

Arrangement by Symbol

A	Cross-sectional area
a	Velocity of sound
B	Mass-transfer driving force
C	Heat transfer due to convection
C_D	Local drag coefficient
C_d	Discharge coefficient
C_f	Total skin-friction coefficient
C_m	Gas stream mass-transfer coefficient
C_p	Pressure coefficient
C_v	Specific volume
c_f	Local skin-friction coefficient
c_p	Specific heat at constant pressure
c_v	Specific heat at constant volume
D	Diffusion coefficient
d	Diameter
d_e	Equivalent or hydraulic diameter
G	Mass velocity
H	Enthalpy
h	Specific enthalpy
h	Heat-transfer coefficient
h_c	Convective heat-transfer coefficient
h_g	Gas stream heat-transfer coefficient
h_r	Equivalent heat-transfer coefficient due to radiation
h_{TOT}	Local heat-transfer coefficient due to combined convective and radiative heat fluxes
J	Mechanical equivalent of heat
k	Thermal conductivity
L	Hydrodynamic starting length
l	Length
l_s	Length of slot
M	Molecular weight
Ma	Mach number
m	Mass flow

TABLE 2—*continued*

m_a	Cooling air mass flow
Nu	Nusselt number
P	Absolute total pressure
Pr	Prandtl number
p	Absolute static pressure
Q	Total heat content
q	Rate of heat flow
q_r	Radiative heat flux
R	Gas constant
Re	Reynolds number
Sc	Schmidt number
St	Stanton number
s	Slot depth (Gap width)
T	Total temperature
T_{ad}	Adiabatic wall temperature
t	Time
t	Static temperature
U	Overall heat-transfer coefficient
u	Velocity in the x direction
v	Velocity in the y direction
w	Entrainment rate
X	Correlation parameter
x	Distance downstream
x^*	Dimensionless distance in downstream direction
x_p	Potential core length
x_T	Hydrodynamic transition length
y	Distance normal to wall
y^*	Dimensionless distance normal to wall
α	Thermal diffusivity
α	Absorption factor for radiation
γ	Ratio of specific heats
ΔP	Pressure drop
ΔT	Temperature difference

TABLE 2—*continued*

δ	Thickness of any layer
ε	Overall cooling effectiveness
εD	Eddy diffusivity
η	Cooling effectiveness
θ	Coolant injection angle relative to adiabatic wall
θ_{eff}	Effective coolant injection angle
κ	Universal constant in mixing length relationship
μ	Viscosity
ν	Kinematic viscosity
ρ	Density
σ	Stephan-Boltzmann constant
τ	Shear stress
τ_w	Shear stress at the wall
ϕ	Plane angle

APPENDIX 1

Miscellaneous Terms also Noted in Film Cooling Literature.

Ratio of local interior mass-flow rates	B_1
Gas Constant for molecular weight	b
Area available for heat conduction in metal of the wall	C_m
Coolant at the slot	c
Temperature effectiveness ratio $\frac{T_w - T_g}{T_{RO} - T_g}$	E
Injection mass normal to surface	F
Heat transfer area unit length	f
Evaporation coefficient	f
Mass-transfer conductance	g
Altitude	H
Specific stagnation enthalpy	h°
Total enthalpy	I
Enthalpy of air at temperature T	i
Flux of mass relative to a plane moving with the fluid	J
Acceleration parameter	K
Thermal conductivity at $T = 0°C$	$K_\circ$
Length of sweat cooling section	L
Width of adiabatic wall	L
Unheated starting length	l
Mixing length	l
Momentum deficit	M^1
Velocity ratio	m
Dimensionless entrainment rate from main stream	m_G
Mass flow/unit slot width	$\dot{m}^1$
Dimensionless mean entrainment ratio into the potential core region	$\overline{m}_G$
Total number of sweat cooling holes	N
Number of holes/inch length of sweat cooled surface	n
Resistance of laminar sublayer	P
Pressure	p
Total pressure of coolant upstream of device	p_c
Cooling air mass flow/unit cooled surface area	Q

Conventional flow function	Q
Heat flux at surface	q
Heat flux in boundary layer	q''
Heat-transfer rate/unit of surface	$q''s$
Boundary-layer Reynolds number	R_θ
Temperature-recovery factor $(T_r - T_c)/(T_e - T_c)$	r
Dimensionless shear stress	s
Ambient temperature	T_{amb}
Cold-gas temperature	T_c
Hot-gas temperature	T_h
Wall-metal temperature	T_w
Temperature of gas in contact with wall	T_{wg}
Transverse fluctuation velocity	v'
Oxygen transfer/unit area/unit time	w
Equivalent flat-plate distance from start of boundary layer	X
Distance coolant flows along wall before temperature decreases	x'
Pressure gradient parameter	β
Liquid flow/unit time/unit length of tube circumference	Γ
Coolant heat of vaporisation	ΔH
Thermal thickness	δT
Effectiveness $(T_g - T_m)/(T_c - T_m)$	ε
Corrected effectiveness	ε
Total hemispherical emissivity	ε
Gas emissivity factor	ε_G
Eddy diffusivity for heat	ε_h
Cooling film effectiveness $(T_{ad} - t_w)/(T_{ad} - t_c)$	η
Cone semi-vertex angle	θ
Oxidizer specific concentration	θ
Non-dimensionless temperature	θ
Dimensionless temperature $(T - T_G)/(T_S - T_a)$	θ
Momentum thickness	θ
Coefficient of conductivity	λ
Ratio of eddy diffusivities	λ

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