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FACULTÉ DES SCIENCES APPLIQUÉES

VON KARMAN INSTITUTE FOR FLUID DYNAMICS
TURBOMACHINERY & PROPULSION DEPARTMENT



High Frequency Gas Temperature and Surface Heat Flux Measurements

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Thesis presented by V. Iliopoulou, Engineer, in order to obtain the degree of Docteur en Sciences Appliquées, Université Catholique de Louvain, September 2005.

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High Frequency Gas Temperature and Surface Heat Flux Measurements

Keywords: measurement techniques, gas temperature, wall heat transfer, high frequency response, gas turbines, Unsteady interactions, short duration facilities, tip leakage flows.

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Nomenclature

a	Angle of the pressure perturbation on the second stator with the horizontal	α	Thermal diffusivity [m^2/s], $\alpha = k/(\rho c)$
a	Gain, coefficient [dependent on subscript]	γ	ratio of specific heats
A	Surface, area	δ	Clearance [m]
c	Class index	δ	Boundary layer thickness [m]
c	Specific heat [$J/(kgK)$]	Δ	Variable change
C	Blade chord [m]	ΔR	Radial increase/decrease
C	Capacity [F]	ε	emissivity
C	Clearance [m]	ζ	correction factor for non-uniform heating
D	Depth [m]	μ	Absolute viscosity [Ns/m^2]
D	Diameter [m]	ζ, η	Non dimensional axes
f	Frequency [Hz]	π	3.14...
$f(\dots)$	Function of ...	ρ	density [kg/m^3]
h	Heat transfer coefficient [$W/(m^2K)$]	σ	Thermal products ratio
H	Transfer function in Laplace domain	σ :	Contraction coefficient
H^{-1}	Inverse transfer function in Laplace domain	τ	Clearance [m]
I	Current intensity [A]	Φ	Phase locked time on periodic passing events
j	$j^2 = -1$	ϕ	Incidence angle of the flow
k	Thermal conductivity [$W/(mK)$]	ω	Frequency [rad/s]
L	Length [m]	Ω	Rotational speed [RPM]
M	Mach number	Subscripts / Superscripts	
n	Total number of points	*	Total conditions
Nu	Nusselt number	∞	Free stream
p	Laplace variable	0	Reference, Zero
P	Pressure [bar]	0	Total flow conditions
Pr	Prandtl	1	Cascade inlet
Q	Heat flux [W/m^2]	1	First hemispherical head
r	Radial coordinate [m]	1	First layer of the substrates
r_c	Recovery factor	1	First linear system
R	Gas constant [$287\text{ J}/(kg\text{ K})$]	1	Nozzle inlet
R	Radius [m]	1	Stage inlet
R	Resistance [Ω]	2	Cascade exit
Re	Reynolds number	2	Nozzle exit
S	Curvilinear abscissa	2	Second hemispherical head
St	Strouhal number	2	Second layer of the substrates
t	Time [s]	2	Second linear system
T	Temperature [$K, ^\circ C$]	3	Second stator inlet
Tu	Turbulence intensity	4	Second stator exit
u	Auxiliary variable Eq. (50)	AIR	Properties of air
U	Peripheral velocity [m/s]	AMB	Ambient conditions
V	Voltage [V]	AV	Average value
W	Velocity [m/s]	AW	Adiabatic wall
W	Width [m]	AX	Axial direction
x	Distance, depth, coordinate [m]	C	Conduction
y	Distance, coordinate [m]	CYL	Cylindrical geometry
Y	Distance [m]	E, e	Jet exit
		FP	Geometry of flat plate

<i>GAS</i>	Gas temperature dependent
<i>inf</i>	Property of the free stream flow
<i>INIT</i>	Initial value concerning the time
<i>INP</i>	Input
<i>IS</i>	Isentropic conditions
<i>j</i>	Space step
<i>L</i>	Properties of liquid
<i>m</i>	time step
<i>M</i>	Medium
<i>M</i>	Model
<i>M</i>	Space step
<i>OS</i>	Periodic oscillations
<i>P</i>	Time step
<i>R, ΔR</i>	Resistance dependent
<i>RAD</i>	Dependent on Radiation
<i>REL</i>	Flow conditions expressed to the relative frame
<i>S</i>	Dependent on sampling
<i>S</i>	Static conditions
<i>T</i>	Test
<i>T, ΔT</i>	Temperature dependent
<i>V</i>	Dependent on the vortex shedding
<i>V, ΔV</i>	Dependent on the Wheatstone bridge
<i>W</i>	Wall, surface

Abbreviations

<i>1D</i>	One dimensional
<i>2D</i>	Two dimensional
<i>3D</i>	Three dimensional

<i>B.C.</i>	Boundary condition
<i>BL</i>	Boundary layer
<i>CL</i>	Blade camber line
<i>ct</i>	constant
<i>CT2</i>	I.L.P. facility-test section: a cascade
<i>CT3</i>	I.L.P. facility-test section: a 1.5 stage turbine
<i>D.T.F.</i>	Dual thin film
<i>D.T.F.P.</i>	Dual thin film probe
<i>DEM</i>	Demodulated
<i>FFT</i>	Fast Fourier Transform
<i>G</i>	Galvanometer
<i>HP</i>	High Pressure
<i>I.L.P.</i>	Isentropic Light Piston
<i>L.E.</i>	Leading edge
<i>L.P.</i>	Low pass filtered
<i>Ma</i>	Exit Mach number
<i>MAX</i>	Maximum value
<i>MID</i>	Midspan
<i>MOD</i>	Modulated
<i>P.S.</i>	Pressure Side
<i>PLA</i>	Phase Locked Average
<i>R</i>	Reattachment (point, line)
<i>REF</i>	Reference
<i>RMS</i>	Root Mean Square
<i>RPM</i>	rotor speed
<i>S</i>	Separation line
<i>S.S.</i>	Suction side
<i>T.F.</i>	Thin film
<i>W/B</i>	Wheatstone bridge