University of Southern Queensland

Faculty of Engineering & Surveying

Temperature Variations in a Free Piston Compression Wind Tunnel

A thesis submitted by

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Abstract

This dissertation presents an investigation of the free stream stagnation temperature variations in the University of Southern Queensland (USQ) hypersonic wind tunnel (designated TUSQ), a short duration wind tunnel operated as a Ludwieg Tube with free piston compression heating. Because the facility is relatively new and because strong disturbances have previously been observed in similar facilities, a study to investigate the thermal characteristics of the hypersonic flow generated by TUSQ was needed.

This study investigates the temporal and spatial thermal characteristics of the hypersonic flow produced in the TUSQ facility and relates these characteristics to the compression and flow discharge processes within the barrel. Quantification of the flow conditions produced in wind tunnels is important. Without such information, it is difficult to relate wind tunnel results to flight conditions or to perform meaningful computational simulations on the tested configuration.

Three different versions of an aspirating thermocouple probe were developed for this work and a thin film heat flux gauge was also tested. Results with the Mach 6 nozzle show that the flow stagnation temperature decreases with time and thermodynamic simulations accurately reflect the majority of the observed temporal variations when flat plate boundary layer cooling is used to model the heat transfer in the barrel of the facility. Because the flat plate boundary layer cooling model provides a good match to the measured temperature on the nozzle centre line for the majority of the flow duration, it is concluded that significant mixing must have occurred across the diameter of barrel prior to flow discharge through the nozzle. Measurements in other facilities have indicated the existence of discrete, large scale thermal disturbance which propagated ahead of the piston and potentially compromised the test flow quality, but no such disturbance were detected at the centre line of the nozzle exit in the present work.

The stagnation temperature measurements indicated a core flow region with a radius of almost 80 mm near the start of the test flow. The maximum average spatial gradient of stagnation temperature was registered at about 150 ms after the start of the test flow and had a value of approximately −0.45 K/mm within the core flow region, indicating an average drop in stagnation temperature of about 20 K over the core flow region at this time. Complementary pitot pressure measurements indicate core flow uniformity to within 2 % and a core flow radius of at least 80 mm for the majority of the test flow duration of around 200 ms. Mach number profiles deduced from the pitot pressure measurements are likewise uniform with a Mach number of 5.81 ± 0.05 for the majority of the test flow duration.

A fully-developed turbulent pipe flow model was developed and stagnation temperature fluctuations in the TUSQ facility were estimated to be around 20 K. Although this value is large compared to results from previous experiments in a gun tunnel facility, the value obtained is consistent with the magnitude of the spatial variation in stagnation temperature within the core region of the nozzle exit flow at about 150 ms from the start of the flow. Relatively low frequency fluctuations in the stagnation point heat flux were observed and these appeared to correlate with the stagnation pressure fluctuations, but further effort in this area is required in order to resolve stagnation temperature fluctuations due to the turbulent mixing in the barrel.

Keywords : temperature fluctuations, hypersonic flow, stagnation temperature, free piston compression

Associated Publications

The following publications were produced during the period of candidature:

Widodo, A. and Buttsworth, D., "Deduction of Temperature Fluctuation in Transient Compression Wind Tunnels Using Incompressible Turbulent Flow Data", *Proceeding of ICEE 2009, 3 rd International Conference on Energy and Environment*, 7-8 December 2009. Malacca, Malaysia: pp 6-10.

Widodo, A. and Buttsworth, D., "Stagnation Temperature Measurements in the USQ Hypersonic Wind Tunnel", *17 th Australasian Fluid Mechanics Conference*, Auckland, New Zealand, 5-9 December 2009.

Widodo, A. and Buttsworth, D., "Stagnation Temperature in a Cold Hypersonic a Flow Produced in a Light Piston Compression Facility", *submitted for publication.*

Widodo, A. and Buttsworth, D., "Radial Stagnation Temperature Distribution at the Nozzle Exit of the USQ Hypersonic Wind Tunnel", *submitted for publication.*

Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Signature of Candidate

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Signature of Supervisor/s

Date

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Agung Sugeng Widodo

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List of Notation

Symbols

c_p	constant pressure specific heat
c_v	constant volume specific heat
d	wire diameter
D	diameter
T	temperature
f	friction factor
h	heat transfer coefficient
I	element i
k	thermal conductivity
Nu	Nusselt number
Pr	Prandtl number
Q_w	heat flux at the wall
q	heat flux
R	resistance
Re	Reynolds number
Re_τ	friction velocity Reynolds number
S	scaling factor
T_{aw}	adiabatic wall temperature
T_τ	friction temperature
T_f	flow temperature
T_0	stagnation temperature
T_w	wall temperature

t	time
t_0	time constant
u	velocity
u_τ	friction velocity
V	voltage; velocity
x	rectangular coordinate
y	rectangular coordinate

Greek Symbols

α	thermal diffusivity; film temperature coefficient
δ	boundary layer thickness
ε	eddy diffusivity
γ	specific heat ratio (c_p/c_v)
ν	convection parameter
ρ	density
σ	standard deviation
τ_i	ignition time
τ_r	reaction time
ϕ	diameter; $T_i - T_0$

Subscript

ad	adiabatic
c	centreline
$exit$	exit conditions
i	ignition; initial; element i
$isen$	isentropic
L	half-length of the wire
M	momentum
pit	pitot
r	reaction; reservoir
rms	root mean square

s	surface
p	piston
w	wall
0	stagnation; initial

Superscript

$+$	directed outward from a surface
$'$	fluctuating
$*$	at throat

Overscore

$-$	average
.	per unit time
$*$	at throat

List of Acronyms

BW	Butt-welded
CHAL	Chromega-Alumega
EMF	Electro Motive Force
LICH	Ludwieg tubes with Isentropic Compression Heating
OUGT	The Oxford University Gun Tunnel
RMS	Root Mean Square
RTD	Resistance Temperature Detector
TUSQ	The University of Southern Queensland Wind Tunnel
USQ	University of Southern Queensland