



**UNIVERSITI PUTRA MALAYSIA**

**DEVELOPMENT OF AN EXPERIMENTAL FACILITY FOR  
MEASUREMENT OF TANGENTIAL JET FLOW IN A SUDDEN  
EXPANSION CHANNEL**

**IRFAN BIN ABD RAHIM.**

**FK 2006 2**



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EXPANSION CHANNEL**

**By**

**IRFAN BIN ABD RAHIM**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,  
in Fulfilment of the Requirements for the Degree of Master of Science**

**February 2006**



In the name of Allah, Most Gracious, Most Merciful

Lillahi Taala ....



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science

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**February 2006**

**Chairman: Abdul Aziz bin Jaafar, PhD**

**Faculty: Engineering**

This thesis describes the development of an experimental facility of a tangential jet flow in a sudden expansion channel. The present study is intended to clarify experimentally the relation between flow and geometrical variables on the thermal development using a point wise temperature measurements technique. The temperature measurements have been conducted on a flat plate inside a low speed open circuit wind tunnel. The mainstream flow has a maximum of temperature  $50^{\circ}\text{C}$ . The temperature was controlled by a 10 kVA/40 Ampere voltage regulator. A maximum velocity, ( $U_{\infty}$ ) at the mainstream intake is 10 m/s. The velocity on the coolant jet flow ( $U_j$ ) is between 2 m/s to 8 m/s, the expansion ratio (ER) is 1.2 and the Reynolds numbers, ( $Re_{\infty}$ ) is,  $1.3 \times 10^5$  on the mainstream location. The coolant distribution system is fabricated into three type of geometry: a slot shape  $20 \text{ mm}^2 / \text{mm}$ , a square shape 10 mm x 10 mm and a circular shape 10 mm of diameter. The surface temperature in the direction of the jet flow media is evaluated based on



the measured temperatures, obtained through the thermocouples over the flat surfaces. The jet flow is tangentially injecting a jet of cooling air at an exit angle of  $0^\circ$  from the coolant distribution system to the plate surface. The test plate is made of plastic material (acrylonitrile butadiene styrene) plate of 10 mm thick flat plate which is installed on the channel wall and instrumented with a stream wise row of T-type thermocouples. The thermocouples are spaced 25.4 mm apart along the center line of the plate. The temperature ratio between the cooling air temperature ( $T_i$ ) and the mainstream temperature ( $T_\infty$ ) is in the range of  $0.77 \leq \frac{T_i}{T_\infty} \leq 0.87$  while the velocity ratio between the cooling velocity ( $U_i$ ) and mainstream velocity ( $U_\infty$ ) is in range of  $0.2 \leq \frac{U_i}{U_\infty} \leq 0.7$ . From the observation made at the location  $X/h = 0.5$ , the cooling effectiveness ( $\eta$ ) for tangential jet flow emanating from the slot, square and circular holes geometry, is to be at maximum value of 0.8, 0.6, and 0.5 respectively. The data presented here would be off interest to engineers to gain further understanding in the development of heat transfer due to tangential jet flow in a sudden expansion channel.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi sebahagian keperluan untuk ijazah Master Sains

**PEMBANGUNAN SEBUAH KEMUDAHAN UJIKAJI UNTUK  
PENGUKURAN ALIRAN JET TANGEN DALAM ALUR  
PENGEMBANGAN MENDADAK**

Oleh

**IRFAN BIN ABD RAHIM**

**Februari 2006**

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**Fakulti: Kejuruteraan**

Tesis ini menerangkan pembangunan peralatan ujikaji untuk aliran jet tangen dalam alur pengembangan mendadak. Kajian ini lebih tertumpu untuk menjelaskan perhubungan antara aliran dan pelbagai bentuk geometri terhadap pembangunan haba dengan menggunakan teknik pengukuran suhu secara titik. Pengukuran suhu telah dijalankan ke atas plat rata didalam terowong angin litar terbuka berhalaju rendah. Arus aliran tersebut mempunyai bacaan suhu maximum  $50^{\circ}\text{C}$  dengan suhu dikawal oleh pembolehubah voltan 10 kVA/40 Ampere. Halaju maksimum ( $U_{\infty}$ ) arus pada salur masuk adalah 10 m/s. Halaju pada aliran jet ( $U_j$ ) adalah diantara 2 m/s hingga 8 m/s. Nisbah pengembangan (ER) ialah 1.2 dan nombor Reynolds ( $Re_{\infty}$ ) bernilai  $1.3 \times 10^5$  pada lokasi arus. Sistem pengagihan pendinginan di fabrikasi kepada tiga jenis bentuk geometri: bentuk lubang alur  $20 \text{ mm}^2/\text{mm}$ , bentuk segiempat sama 10 mm x 10 mm dan bentuk bulat berdiameter 10 mm. Suhu permukaan dalam arah aliran jet adalah dinilai berdasarkan suhu pengukuran yang

diambil menerusi pengganding suhu menerusi permukaan plat rata. Aliran jet disuntik kepada permukaan plat secara tangen pada sudut keluar  $0^\circ$  dari sistem pengagihan pendinginan. Plat ujian dibuat daripada bahan plastik (acrylonitrile butadiene styrene) yang berukuran 10 mm tebal di mana plat ini dipasang pada saluran dinding dan dilengkapi dengan pengganding suhu jenis-T yang ditanam sepanjang plat rata tersebut. Setiap pengganding suhu dijarakan sebanyak 25.4 mm dibahagian tengah sepanjang plat tersebut. Nisbah suhu di antara suhu udara pendinginan ( $T_i$ ) dan suhu aliran utama ( $T_\infty$ ) adalah di dalam julat  $0.77 \leq \frac{T_i}{T_\infty} \leq 0.87$  manakala nisbah halaju di antara halaju pendinginan ( $U_i$ ) dan halaju aliran utama ( $U_\infty$ ) adalah didalam julat  $0.2 \leq \frac{U_i}{U_\infty} \leq 0.7$ . Melalui pemerhatian yang dibuat pada lokasi  $X/h = 0.5$  keberkesanan pendinginan ( $\eta$ ) bagi aliran jet tangen yang mengalir dari lubang yang bergeometri masing-masing: lubang alur, lubang-lubang bergeometri segiempat sama dan lubang-lubang bergeometri bulat adalah pada nilai maksimum 0.8, 0.6 dan 0.5. Data yang dibandingkan di sini akan menarik minat para jurutera untuk lebih memahami dalam pembangunan pemindahan haba berdasarkan aliran jet tangen dalam alur pengembangan mendadak.

## ACKNOWLEDGEMENTS

First and foremost, all praise and thanks giving to Allah the Almighty, for gracing me with strength to complete of my thesis. Alhamdullilah.

I am greatly indebted to my supervisor Dr Abdul Aziz Bin Jaafar for his guidance and friendship throughout my graduate work. He is very helpful and supportive and his continuous encouragement has made me work hard. Dr Abdul Aziz Bin Jaafar has been a continual source of inspiration and helped me to make the thesis a reality.

Much credit must also be given to committee members, Prof Madya Dr Megat Mohammad Hamdan Bin Megat Ahmad and Dr Abd Rahim Bin Abu Talib for their guidance, advice and encouragement throughout the completion of my thesis. To En Ropiee Bin Mat, I would like to extend special word of thanks for his support and guidance to provide valuable information during my thesis completion.

I am forever in debt to my parents for their dedication and continuous prayer throughout my whole life. Over the past years, their guidance, care and love has been undoubtedly indispensable. I would also like to acknowledge my beloved wife, Haryanti for her love, smiles and encouragement. Her warm support and company has helped me through the difficult time. Word is not sufficed to express it. To my little hero, Mohd Izzudin Al-Qasimi you always make me busy at home. All tiredness during work will disappear when I see your smile and laughter. I would also like to express my appreciation towards my family, relatives and member at aerodynamics lab. Special thanks to Prof Ir. Dr. Shahnor bin Basri for his motivation.





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## LIST OF ABBREVIATIONS

<i>a</i>	geometrical shape (mm)
$a_o$	speed of sound (m/s)
$A_{out}$	area of outlet (m <sup>2</sup> )
$A_t$	cross sectional area (m <sup>2</sup> )
$A$	area (m <sup>2</sup> )
$A$	Agilent 34970A Temperature data logger
$A$	area ratio
<i>b</i>	geometrical shape (mm)
$B1, B2$	pressure scanning module
$B$	Blowing ratio $\left( \frac{\rho_t U_t}{\rho_\infty U_\infty} \right)$
<i>c</i>	geometrical shape (mm)
$c_p$	specific heat of constant pressure
$c_v$	specific heat of constant volume
$C_p$	pressure coefficient
$C_f$	skin-friction coefficient
$C$	computer
$C$	contraction ratio
<i>d</i>	hydraulic diameter (m)
<i>d</i>	orifice diameter (mm)
<i>d</i>	geometrical shape (mm)

$dz$	width of the cooled test plate (m)
$D_a$	Damkohler number $\left( \frac{\tau_{flow}}{\tau_{chem}} \right)$
$D_t$	hydraulic diameter (m)
$D$	diameter of downstream and upstream pipe (mm)
DA	primary voltage regulator
DB	secondary voltage regulator
DC	Ammeter
$e$	thickness of the orifice (mm)
$E_{in}$	energy in (W)
$E_{out}$	energy out (W)
$E_{system}$	total energy (W)
$E$	thickness of the orifice plate (mm)
ER	expansion ratio
$f$	function
$F$	thrust produced ( $Ns/kg$ )
$F$	angle of bevel orifice plate
$G$	orifice upstream edge
$h$	step height (mm)
$h$	convection heat transfer coefficient ( $W/m^2K$ )
$h_0$	local convection heat transfer coefficient ( $W/m^2K$ )
$H$	channel high (mm)

$H$	enthalpy (kJ)
$H$	shaft power input
$H$	high (m)
$H$	orifice downstream edge
$H^*$	heat release potential, $\left( \frac{T_{ad} - T_{t,\infty}}{T_{t,\infty}} \right)$
$H$	heat transfer coefficient ( $\text{W.m}^{-2}.\text{K}^{-1}$ )
$I$	current (A)
$I$	specific momentum ratio $\left( \rho_t U_t^2 / \rho_\infty U_\infty^2 \right)$
$I$	orifice downstream edge
$k$	thermal conductivity ( $\text{W.m}^{-1}.\text{K}^{-1}$ )
$K_{screen}$	<i>screen</i> pressure drop coefficients
$K$	<i>screen</i> pressure drop coefficients
$K_{sum}$	overall pressure drop coefficients
KE	kinetic energy
$L_s$	length of working section channel lip respectively (m)
$L$	length of working section (m)
$L$	dimensionless (m)
$\dot{m}$	mass flow rate ( $\text{kg.s}^{-1}$ )
$M$	dimensionless (kg)
$M_0$	inlet mach number
$M_\infty$	mainstream mach number

$M_a$	mach number
$n$	number of holes
Nu	Nusselt number, $Nu = \frac{hL}{k}$
$P_t$	total pressure (Pa)
$P_s$	static pressure (Pa)
P	absolute pressure (Pa or Psi)
P	power (Watt)
Pa1	Pitot-Static tube
Pb1,2,3	static pressure taping (secondary settling chamber)
Pb4,5	static pressure taping (orifice plate)
$Pr_x$	Prandtl number, $Pr = \frac{c\mu}{k}$
PE	potential energy
$q$	dynamic pressure ( $P_t - P_s$ )
$q''$	heat flux ( W/m <sup>2</sup> )
$q_0''$	local heat flux ( W/m <sup>2</sup> )
$Q_{in}$	heat transfer of the energy into the system
$Q_{out}$	heat transfer of the energy out the system
$R$	electrical resistance ( $\Omega$ )
$R_{1,2,3,4,5}$	electrical resistance ( $\Omega$ )
$R_{T1,T2}$	total electrical resistance ( $\Omega$ )

R	gas constant for air (J/kg.K)
Re	Reynolds number, $Re = \frac{\rho u d}{\mu}$
Re <sub>d</sub>	Reynolds number based on hole diameter, $Re = \frac{U_{\infty} d}{\nu_{\infty}}$
Re <sub>s</sub>	Reynolds number based on slot, $Re = \frac{U_{\infty} d}{\nu_{\infty}}$
Re <sub>u</sub>	Reynolds number based on mainstream velocity, $Re = \frac{U_{\infty} (H - h)}{\nu_{\infty}}$
Ri	Bouyancy parameter,
RS	RS Component
s	step
S	duct local parameter
S	separation between the injection hole
St <sub>x</sub>	Stanton number, $\left( \frac{Nu_L}{Re_L Pr} = \frac{h}{\rho V c_p} \right)$
T <sub>∞</sub>	mainstream flow temperature (°C)
T <sub>0</sub>	starting temperature reading (°C)
T <sub>a,b,c,d</sub>	thermocouple probe (T-type)
T <sub>f</sub>	film temperature (°C)
T <sub>s</sub>	surface temperature (°C)
T <sub>i</sub>	cooling flow temperature (°C)
T <sub>w</sub>	wall temperature (°C)
T	absolute temperature (°C or °K)