U20ASSJ09 - EXPERIMENTAL METHODS IN PROPULSION

TABLE OF CONTENTS

LIST OF NOMENCLATURES

SL.NO	SYMBOL	DESCRIPTION
1	C_p	*Pressure coefficient*
2	V	*Free stream velocity of the fluid*
3	p_{atm}	*Atmospheric pressure*
4	p_0	*Total pressure*
5	p	*Static pressure*
6	q	*Dynamic pressure*
7	p_{air}	*Free stream fluid density (air at sea level and 15 °c) is 1.225 kg / m^3*
8	p_w	*Water density is 1000 kg / m^3*
9	g	*Acceleration due to gravity is 9.81 m / s^2*
10	α	*Angle of attack*
11	ΔH	*Change in manometer head*
12	μ_∞	*Dynamic Viscosity of air 1.789 x 10^{-5} kg/m s*
13	Re/l	*Reynolds Number per unit length*

EXP NO: 01 DATE:	STUDY OF FREE CONVECTION HEAT TRANSFER IN A FLAT PLATE

Introduction

Convection is a mode of heat transfer where by a moving liquid transfers heat from a surface. When the fluid movement is caused by density differences in the fluid, due to temperature variations, it is called free or natural convection. This provides students with a sound information about the features of free convection heat transfer from a heated vertical rod a vertical rod duct is fitted with a heated vertically placed cylinder air gets heated and dense around this cylinder, causing it to rise. This in turn gives rise to continuous flow of air upward in the duct. The instrumentation provides the heat input and temperature at different point on the heated cylinder.

Aim

To determine the theoretical and actual heat transfer co-efficient using natural convection apparatus.

Apparatus required

Natural convection apparatus

Specifications

Rod length l = 270mm

Rod diameter b = 100mm

Formula used

Actual method

Average temperature of heater $= (T_2+T_3+T_4+T_5) / 4$

Average temperature of air $= (T_1+T_6) / 2$

Power input of heater 'Q' $= VI = hA\Delta T$

Overall heat transfer co-efficient 'h' $= Q / A\Delta T$

Theoretical method

$Nu = hl_c/K = 0.53(G_rP_r)^{1/4}$ *for* $G_rP_r < 10^5$

Where, ΔT – *(Avg. temp of heater rod) – (Avg. temp of air)*

G_r – *Grashoff's number* – $\beta g\Delta T L^3 / \gamma^2$

P_r – *Prandtl number*

γ – *Kinematic viscosity*

β – $1 / (\text{Mean temp of air} + 273)$

K – Thermal conductivity

Nu– Nusette's number = hl/K

$Nu = hl/K = 0.56(G_rP_r)^{1/4}$ for $10^5 < G_rP_r < 10^8$

$Nu = hl/K = 0.13(G_rP_r)^{1/3}$ for $10^8 < G_rP_r < 10^{12}$

Procedure

- Switch on the unit and adjust the regulator to provide suitable power input.
- Allow some time for the unit to reach steady state condition.
- Note the specimen temperature (T_2, T_3, T_4, T_5) and note down the inlet temperature (T_1) and outlet temperature (T_6).
- Note ammeter and voltmeter reading.
- Repeat the procedure and take 3 sets of readings.
- Calculate the theoretical and actual heat transfer co-efficient using the given formula.

Tabulation

Sl. No	Voltmeter Reading In volts	Ammeter Reading In ampere	Q = VI Watts	Thermocouple readings (K)							Actual heat Transfer Co-efficient	Theoretical Heat Transfer coefficient
				T_1	T_2	T_3	T_4	T_5	T_6	ΔT		

Calculation

Result

Thus, the theoretical and actual heat transfer co-efficient using natural convection apparatus are calculated.

EXP NO: 02 DATE:	**DETERMINATION OF FLASH POINT AND FIRE POINT OF A FUEL**

Introduction:

The flash and fire points of a liquid fuel specimen are the indicators of its flammability. In general, flash point is the lowest temperature of the test specimen, corrected to a barometric pressure of 101.3 kPa, at which the application of an ignition source causes the vapor of the test specimen to ignite momentarily and the flame to propagate across the surface of the liquid under the specified conditions of test. It is important to realize that the value of the flash point is not a physical constant but is the result of a flash point test and is dependent on the apparatus and procedure used. Fire point may be considered as the lowest temperature of the liquid at which vapor combustion and burning commences. A fire point happens when an ignition source is applied and the heat produced is self-sustaining, as it supplies enough vapors to combine with air and burn even after the removal of the ignition source.

Aim:

Determination of flash point and fire point for a sample using pensky martin's test

Apparatus:

Oil cups, air bath, electric heater, current regulator, tapeonerassy, thermo meter.

Theory:

Flash point:

The flash point is defined as the lowest temperature at which lubricating oil will "flash" when a lighted match or lighted taper is passed across its surface.

Fire point:

If the oil is heated further after the flash point temperature has been reached. The lower temperature at which the oil will burn continuously is called the fire point. These two temperatures must be enough in oil so that it doesn't flash or burn in service. The flash point is mostly used.

Diagram:

Fig: flash and fire point test apparatus

Procedure:

1. Thoroughly clean up all parts of cup and dry.
2. Fill the cup with given oil is to be tested up to level indicated by a mark.
3. Lid has to be placed on cup and insert thermometer to required range.
4. Electrical supply is switched on and sample is gradually heated.
5. Oil is constantly stirred and the test flame is applied at the interval of 10 c raised is noted.
6. Heating is continued until oil vapors get ignited and burn on application of test flame continuously and temperature is noted.

Table:

Flash point:

Fire point:

Precautions:

1. Cup is cleaned and accessories are also cleaned and dried.
2. Supply of electricity is switched off after attaining flash point.
3. Gas regulators should be carefully handled.

Result:

Flash point of the given oil is ____ and fire point of the given oil ______

EXP NO: 03 DATE:	ESTIMATION OF SPREAD RATE IN INCOMPRESSIBLE CIRCULAR JETS

Aim

To determine the spread rate of circular jet plot the variation of velocity profile.

Apparatus Required

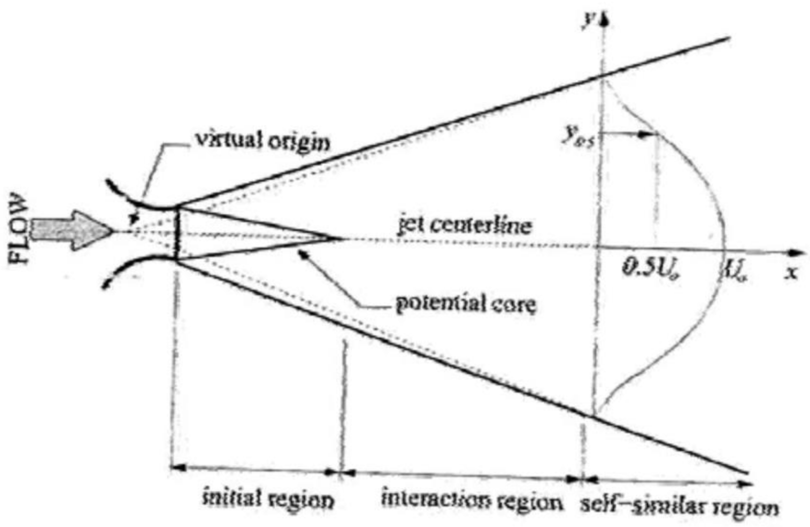
- Centrifugal Blower
- Settling Chamber
- Circular Plate with circular orifice
- Pitot Tube
- Manometer
- 3 D traverse mechanism

Tools Required

- Steel rule or Vernier caliper
- Spanner
- Screw drive
- Alien key

Theory

Jet half width at any axial location is defined as the distance between the centreline and a transverse plane where the mean velocity becomes half of the corresponding centreline velocity. Half width generally increases linearly with x except in regions of axis switching. Slope of the half width line in the axial direction is called as spread rate. Usually, the spread rate of a high Reynolds number turbulent jet is 0.11 while that of a laminar jet is around 0.4. Virtual origin is the point from which the jet appears to be originating as shown in fig.



It may be different from the geometric origin and may be located inside or outside the nozzle, depending upon the nozzle exit boundary layer profiles. Virtual origin is related to the half width through the expression.

$$\frac{b_u}{d} = K_{2u}\left(\frac{x}{d} \pm C_{2u}\right) \quad \text{--}$$

Where C_{2u} is the virtual origin and K_{2u} is the spread rate. Also, b_u is the jet half width.

Formula used

$$Density,\ \rho_\infty = \frac{p_{atm}}{RT}$$

$$Renolds\ number, R_e = \frac{\rho_\infty V_\infty d}{\mu_\infty}$$

$$Velocity, V = \sqrt{\frac{2\Delta p}{\rho_\infty}}$$

$$Mach\ number, M = \frac{V}{a}$$

$$P_0 = P_{atm} + P_{gauge}$$

$$P_{static} = 100928\ pa$$

$$\Delta p = p_0 - p_{static}$$

Where

$\rho_a -$ *Density of air*

$V_e -$ *velocity at the outlet of the orifice*

$R_e -$ *Reynolds number*

$\Delta p -$ *Dynamic presure*

$P_{atm} -$ *atmospheric pressure*

$p_0 -$ *Total pressure*

$R -$ *Gas constant*$(287\ J/kg.K)$

$T -$ *Air temperature*

$x -$ *distance measured along the centerline of the jet from the orifice outlet*

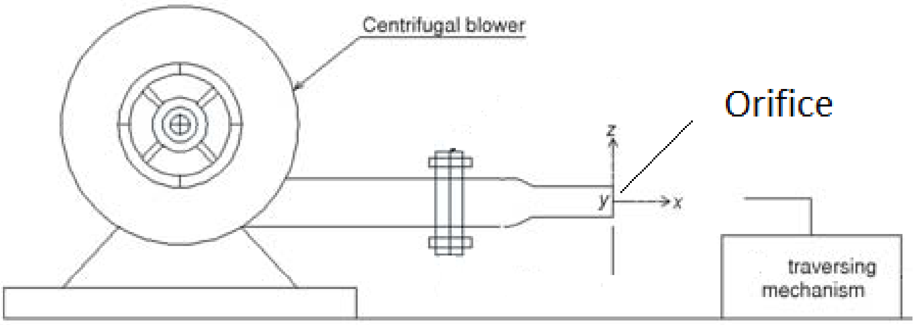
$d -$ *diameter of the orifice*

$a -$ *speed of sound*

$$Non\ dimensionalized\ velocity = \frac{Vy}{V_e}$$

$$Non\ dimensionalized\ pressure = \frac{p_{0y}}{p_{0e}}$$

Experimental Setup



Procedure

This experiment involves the measurement of total pressure along the transverse direction for jet issuing from circular orifice the basic goals of this experiment are:

- To determine velocity profile in transverse direction at different x location.
- Place pitot tube mounted on 3D traverse at exit plane of orifice.
- Connect the pitot tube to manometer.
- Switch on the blower and wait for 1 min for the blower to reach the steady RPM.
- Now note down the reading in manometer at exit plane of orifice.
- Measure the pressure in transverse direction i.e Y direction in interval 0.5 cm unit the pressure reading in manometer is zero.
- Repeat the above step for different x(1cm, 2cm,3cm…etc) location.

Tabulation

<table>
<tr><td colspan="6">Atmospheric pressure, P_{atm}</td><td colspan="5">Gas constant R=287 J/kg. K</td></tr>
<tr><td colspan="11">Gamma =1.4</td></tr>
<tr><td colspan="11">Exit Diameter of the Circular orifice =</td></tr>
<tr><td>S. No.</td><td>Location x</td><td>Location y</td><td>x/d</td><td colspan="2">Digital manometer reading</td><td>Dynamic pressure</td><td>Velocity at location V=$\sqrt{\frac{2\Delta P}{\rho}}$</td><td>Mach number M=$\frac{V}{a}$</td><td>$\frac{Vy}{Ve}$</td><td>$\frac{P0y}{P0e}$</td></tr>
<tr><td></td><td></td><td></td><td></td><td>Pitot pressure</td><td>Static pressure</td><td></td><td></td><td></td><td></td><td></td></tr>
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Calculation

Graph

Plot the graph x/d vs V_y/V_e

Plot the graph x/d vs P_{0y}/P_{0e}

Result

Thus, the spread rate of circular jet plot the variation of velocity profile has been done.

EXP NO: 04 DATE:	**ESTIMATION OF SPREAD RATE IN INCOMPRESSIBLE NON-CIRCULAR JETS**

Aim

To determine the spread rate of Non-Circular jet plot the variation of velocity profile.

Apparatus Required

- Centrifugal Blower
- Settling Chamber
- Non-Circular Plate with non-circular orifice
- Pitot Tube
- Manometer
- 3 D traverse mechanism

Tools Required

- Steel rule or Vernier caliper
- Spanner
- Screw driver
- Alien key

Formula used

$$Density,\ \rho_\infty = \frac{p_{atm}}{RT}$$

$$Renolds\ number, R_e = \frac{\rho_\infty V_\infty d}{\mu_\infty}$$

$$Velocity, V = \sqrt{\frac{2\Delta p}{\rho_\infty}}$$

$$Mach\ number, M = \frac{V}{a}$$

$$P_0 = P_{atm} + P_{gauge}$$

$$P_{static} = 100928\ pa$$

$$\Delta p = p_0 - p_{static}$$

Where,

$\rho_a -$ *Density of air*

$V_e -$ *velocity at the outlet of the orifice*

$R_e -$ *Reynolds number*

$\Delta p -$ *Dynamic presure*

$P_{atm} -$ *atmospheric pressure*

$p_0 -$ *Total pressure*

$R - Gas\ constant(\ 287\ J/kg.K)$

$T - Air\ temperature$

$x - distance\ measured\ along\ the\ centerline\ of\ the\ jet\ from\ the\ orifice\ \ outlet$

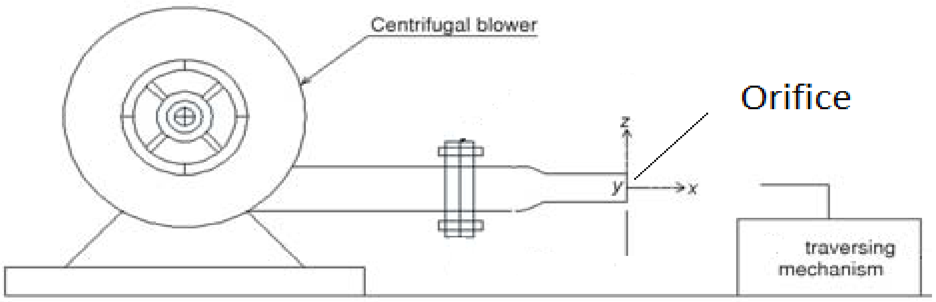
$d - diameter\ of\ the\ orifice$

$a - speed\ of\ sound$

$$Non\ dimensionalized\ velocity = \frac{Vy}{V_e}$$

$$Non\ dimensionalized\ pressure = \frac{p_{0y}}{p_{0e}}$$

Experimental Setup



Procedure

This experiment involves the measurement of total pressure along the transverse direction for jet issuing from circular orifice the basic goals of this experiment are:

- To determine velocity profile in transverse direction at different x location.
- Place pitot tube mounted on 3D traverse at exit plane of orifice.
- Connect the pitot tube to manometer.
- Switch on the blower and wait for 1 min for the blower to reach the steady RPM.
- Now note down the reading in manometer at exit plane of orifice.
- Measure the pressure in transverse direction i.e Y direction in interval 0.5 cm unit the pressure reading in manometer is zero.
- Repeat the above step for different x (2cm, 3cm, and 4cm….etc) location.

Tabulation:

Atmospheric pressure, P_{atm}						Gas constant R=287 J/kg. K				
Gamma =1.4										
Exit Diameter of the Non-Circular orifice =										
S. No.	Location x	Location y	x/d	Digital manometer reading		Dynamic pressure	Velocity at location $V=\sqrt{\frac{2\Delta P}{\rho}}$	Mach number $M=\frac{V}{a}$	$\frac{Vy}{Ve}$	$\frac{P0y}{P0e}$
				Pitot pressure	Static pressure					

Calculation

Graph

Plot the graph x/d vs V_y/V_e

Plot the graph x/d vs P_{0y}/P_{0e}

Result

Thus, the spread rate of Non-Circular jet plot the variation of velocity profile has been done.

EXP NO: 05	ESTIMATION OF CENTRE LINE DECAY IN SUPERSONIC
DATE:	CIRCULAR JETS

Aim

To determine the centre line decay velocity profile and length of the potential core for circular jet and plot the variation of velocity profile along the central axis of jet.

Apparatus Required

- Centrifugal Blower
- Settling Chamber
- Circular Plate with circular orifice
- Pitot Tube
- Manometer
- 3 D traverse mechanism

Tools Required

- Steel rule or Vernier caliper
- Spanner
- Screw driver
- Alien key

Theory

Circular and plane jets are used in a variety of applications. Some of the common applications of jets occur in drying processes, air curtains for room conditioning, heating and ventilating applications. In these, parameters like the jet spread rate and potential core decay play a strong role in deciding the efficiency of mixing for the process. Shear layer is the region in which most of the interactions and mixing between the ambient and jet fluids take place. Therefore, understanding the fluid dynamic phenomena in the shear layer during the downstream evolution of a jet is important

Far away from the nozzle exit, the jet loses any memory of the nozzle cross sectional shape and the flow asymptotically attains the self- similar profile of a round jet. The turbulent flow fluctuations also evolve as the jet spreads with increase in axial distance; the rates of evolution of the mean flow field and turbulent fluctuations however, are quite different.

Free jets can be defined as a pressure driven unrestricted flow of a fluid into a quiescent ambiance, the wall ceiling or obstruction does not influence the jet. Since a fluid boundary cannot sustain a pressure difference across it, the subsonic jet boundary is a free shear layer in which the static pressure is constant throughout.

The boundary layer at the exit of the device develops as a free shear layer, mixing with the ambient fluid thereby entraining the ambient fluid in the jet stream. Thus, the mass flow at any cross section of the jet progressively increases thereby the jet spreads along the downstream direction. In order to conserve momentum, the jet centreline velocity decreases with downstream distance.

Structure and Development of a Free Jet

A free jet is a fluid mass that discharges into an infinitely large environment of

ambient fluid.

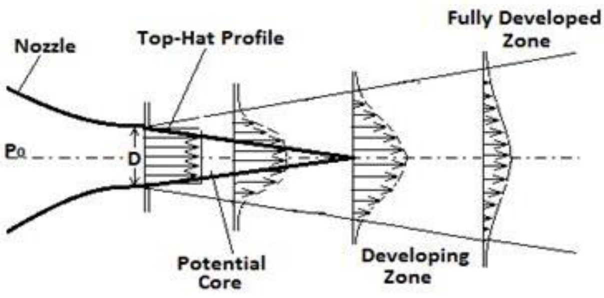


Fig. Structure of Jet

Zone 1:

The convergent zone: This region is called the potential core of the jet where the centreline velocity is equal to the nozzle outlet velocity. This region normally extends up to 4d to 6d, where d is the diameter of the nozzle exit.

Zone 2:

This transition zone: is the region in which the centreline velocity starts to decay. The velocity decay can be approximated as proportional to $x^{-0.5}$, where x is the axial distance. This usually corresponds to a region from 6d to 20d, and it is known as the interaction region where shear layers from both sides merge.

Zone 3:

The self similar zone: In this region transverse velocity profiles are similar at different values of x and the centreline velocity decay is approximately proportional to x^{-1}.

Zone 4:

The termination zone: In this region the centreline velocity decays rapidly. Although this zone has been studied by several researchers, the actual mechanisms in this zone are not understood properly.

Formula used

$$Density,\ \rho_\infty = \frac{p_{atm}}{RT}$$

$$Renolds\ number, R_e = \frac{\rho_\infty V_\infty d}{\mu_\infty}$$

pitot pressure

$$\frac{p_{01}}{p_1} = \left(1 + \frac{\gamma - 1}{2} M_1^2\right)^{\frac{\gamma}{(\gamma-1)}}$$

$$\frac{p_{02}}{p_{01}} = \left(1 + \frac{2\gamma}{\gamma+1}(M_1^2 - 1)\right)^{\frac{-1}{(\gamma-1)}} \left[\frac{(\gamma+1)M_1^2}{(\gamma-1)M_1^2 + 2}\right]^{\frac{\gamma}{(\gamma-1)}}.$$

Rayleigh supersonic pitot formula

$$\frac{p_1}{p_{02}} = \frac{\left[\frac{2\gamma}{\gamma+1}M_1^2 - \frac{\gamma-1}{\gamma+1}\right]^{\frac{1}{(\gamma-1)}}}{\left(\frac{\gamma+1}{2}M_1^2\right)^{\frac{\gamma}{(\gamma-1)}}}.$$

Dynamic pressure

$$p_0 - p = q\left(1 + \frac{M^2}{4} + \frac{M^4}{40}\right).$$

$$q = \frac{p_0 - p}{K},$$

Velocity

$$Velocity, V = \sqrt{\frac{2q}{\rho_\infty}}$$

Where

$\rho_a -$ *Density of air*

$V_e -$ *velocity at the outlet of the orifice*

$R_e -$ *Reynolds number*

$\Delta p -$ *Dynamic presure*

$P_{atm} -$ *atmospheric pressure*

$p_0 -$ *Total pressure*

$R -$ *Gas constant* ($287\ J/kg.K$)

$T -$ *Air temperature*

$x -$ *distance measured along the centerline of the jet from the orifice outlet*

$d -$ *diameter of the orifice*

$a -$ *speed of sound*

k-Correction factor

$$Non\ dimensionalized\ velocity = \frac{Vx}{V_e}$$

$$Non\ dimensionalized\ pressure = \frac{p_{0x}}{p_{0e}}$$

Procedure

This experiment involves the measurement of the centerline velocity profile of the jet from the orifice exit. The basic goals of this experiment are:

- To determine length of potential core and the centerline velocity decay rate.
- Place pitot tube mounted on 3D traverse at exit plane of orifice.
- Connect the pitot tube to manometer.
- Switch on the blower and wait for 1 min for the blower to reach the steady RPM.
- Now note down the reading in manometer at exit plane of orifice.
- Now move the pitot tube 1 cm away from the orifice note the pressure reading.
- Similarly measure the obtain the pressure as function of x with Δx=1 cm for about length of 200 cm.

Tabulation:

Atmospheric pressure, P_{atm}						**Gas constant R=287 J/kg. K**				
Gamma =1.4										
Exit Diameter of the Circular nozzle =										
S. No.	**Location x**	**Location y**	**x/d**	**Digital manometer reading**		**Dynamic pressure**	**Mach number**	**velocity at location V=$\sqrt{\frac{2q}{\rho}}$**	$\frac{Vy}{Ve}$	$\frac{P0y}{P0e}$
				Pitot pressure	**Static pressure**					

Calculation

Graph

Plot the graph x/d Vs Vx/Ve

Plot the graph x/d vs P_{0x}/P_{0e}

Result

Thus, the centre line decay velocity profile and length of the potential core for circular jet and plot the variation of velocity profile along the central axis of jet has been done.

EXP NO: 06 DATE:	ESTIMATION OF CENTRE LINE DECAY IN SUPERSONIC NON-CIRCULAR JETS

Aim

To determine the centre line decay velocity profile and length of the potential core for rectangular and plot the variation of velocity profile along the central axis of jet.

Apparatus Required

- Centrifugal Blower
- Settling Chamber
- Non-circular C-D Nozzle
- Pitot Static Tube
- Manometer
- 3 D traverse mechanism

Tools Required

- Steel rule or Vernier caliper
- Spanner
- Screw driver
- Alien key

Theory

Rectangular jets are popular among jet research community owing to their wide practical applications. Rectangular jets find application in fluidics, ink-jet printing, V/STOL aircraft, military aircraft etc. They are also currently in use on stealthy aircrafts and with other rapid mixing technologies. Rectangular jets combine the aspect ratio features of an elliptic jet with corner (vertex) features of square jets. Nozzle exit shape, aspect ratio, initial turbulence level, and Reynolds number affect the development of the jet. The flow field of the rectangular jet may be subdivided into three main regions: potential core region, followed by characteristic decay region and axisymmetric decay region. In the characteristic decay region, the axial velocity decay is dependent upon orifice configuration and the velocity profiles in the plane of the minor axis of the orifice are found to be similar whereas those in the plane of the major axis plane are non-similar. Three - dimensional turbulent rectangular jets. The nozzle geometry and the aspect ratio play an important role on the jet development through these three-dimensional effects. The spreading rate of a rectangular jet is higher at the wide section than the narrow side. This results in axis-switching. The half-width of the jet varies linearly with downstream distance with different slopes for different aspect ratios and initial geometries The 1distance of the cross-over location from the nozzle was found to be directly proportional to the nozzle aspect ratio. The jet growth rate in minor axis plane was higher; the jet width in the major axis plane was initially reduced due to the vena contracts effect.

Formula used

$$Density,\ \rho_\infty = \frac{p_{atm}}{RT}$$

$$Renolds\ number, R_e = \frac{\rho_\infty V_\infty d}{\mu_\infty}$$

pitot pressure

$$\frac{p_{01}}{p_1} = \left(1 + \frac{\gamma-1}{2} M_1^2\right)^{\frac{\gamma}{(\gamma-1)}}$$

$$\frac{p_{02}}{p_{01}} = \left(1 + \frac{2\gamma}{\gamma+1}(M_1^2 - 1)\right)^{\frac{-1}{(\gamma-1)}} \left[\frac{(\gamma+1)M_1^2}{(\gamma-1)M_1^2+2}\right]^{\frac{\gamma}{(\gamma-1)}}.$$

Rayleigh supersonic pitot formula

$$\frac{p_1}{p_{02}} = \frac{\left[\frac{2\gamma}{\gamma+1}M_1^2 - \frac{\gamma-1}{\gamma+1}\right]^{\frac{1}{(\gamma-1)}}}{\left(\frac{\gamma+1}{2}M_1^2\right)^{\frac{\gamma}{(\gamma-1)}}}.$$

Dynamic pressure

$$p_0 - p = q\left(1 + \frac{M^2}{4} + \frac{M^4}{40}\right).$$

$$q = \frac{p_0 - p}{K},$$

Velocity

$$Velocity, V = \sqrt{\frac{2q}{\rho_\infty}}$$

Where,

$\rho_a -\ Density\ of\ air$

$V_e -\ velocity\ at\ the\ outlet\ of\ the\ orifice$

$R_e - Reynolds\ number$

$q - Dynamic\ presure$

$P_{atm} - atmospheric\ pressure$

$p_0 - Total\ \ pressure$

$R - Gas\ constant(\ 287\ J/kg.K)$

$T - Air\ temperature$

$x - distance\ measured\ along\ the\ centerline\ of\ the\ jet\ from\ the\ orifice\ \ outlet$

$d - diameter\ of\ the\ orifice$

$a - speed\ of\ sound$

k-Correction factor

$$Non\ dimensionalized\ velocity = \frac{Vx}{V_e}$$

$$Non\ dimensionalized\ pressure = \frac{p_{0x}}{p_{0e}}$$

Procedure

This experiment involves the measurement of the centerline velocity profile of the jet from the rectangular orifice exit. The basic goals of this experiment are:

- To determine length of potential core and the centerline velocity decay rate.
- Place pitot tube mounted on 3D traverse at exit plane of orifice.
- Connect the pitot tube to manometer.
- Switch on the blower and wait for 1 min for the blower to reach the steady RPM.
- Now note down the reading in manometer at exit plane of orifice.
- Now move the pitot tube 1 cm away from the orifice note the pressure reading.
- Similarly measure the obtain the pressure as function of x with Δx=1 cm for about length of 200 cm.

Tabulation:

Atmospheric pressure, P_{atm}						**Gas constant R=287 J/kg. K**				
Gamma =1.4										
Exit Diameter of the Non Circular nozzle =										
S. No.	**Location x**	**Location y**	**x/d**	**Digital manometer reading**		**Dynamic pressure**	**Mach number**	**velocity at location V=$\sqrt{\frac{2q}{\rho}}$**	$\frac{Vy}{Ve}$	$\frac{P0y}{P0e}$
				Pitot pressure	**Static pressure**					

Calculation

Graph

Plot the graph x/d Vs Vx/Ve

Plot the graph x/d vs P_{0x}/P_{0e}

Result

Thus, the centre line decay velocity profile and length of the potential core for Non-circular jet and plot the variation of velocity profile along the central axis of jet has been done.

EXP NO: 07 DATE:	STUDY OF FLOW VISUALTION IN HIGH-SPEED FLOWS USING SCHLIEREN TECHNIQUE

Aim:

To visualize the flow patter in a supersonic nozzle using schlieren technique

Description:

The Schlieren method is a technique for visualizing the density gradients in a transparent medium for supersonic flow visualization. Light from a source is collimated by the first lens and then passed through the test-section. It is then brought to a focus by the second lens and projected on the screen. At the focal point of the second lens, where the image of the source is formed, a knife-edge (which is an opaque object) is introduced to cut off part of the light. The screen is made to be uniformly illuminated by the portion of the light escaping the knife-edge, by suitably adjusting it to intercept about half the light when there is no flow in the test-section. For the sake of simplicity, for instance, let us assume the test-section to be two dimensional, with each light ray passing through a path of constant air density. When flow is taking place through the test-section, the light rays will be deflected, because any light ray passing through a region in which there is a density gradient normal to the light direction will be deflected as though it had passed through a prism. In other words, if the medium in the test-section is homogeneous (constant density) the rays from the source will continue in their straight-line path. If there is a density gradient in the medium, the rays will follow a curved path, bending toward the region of higher density and away from the region of lower density. Therefore, depending on the orientation of the knife-edge with respect to the density gradient, and on the sign of the density gradient, more or less of the light passing through each part of the test-section will escape the knife-edge and illuminate the screen. Thus, the Schlieren system makes density gradients visible in terms of intensity of illumination. A photographic plate at the viewing screen records density gradients in the test-section as different shades of gray. Let us assume that the flow through the test-section is parallel and in the xy-plane. Let the light pass through the test-section in the z-direction. From the theory of light it is known that the speed of a wavefront of light varies inversely with the index of refraction of the medium through which the light travels. Therefore, a given wavefront will rotate as it passes through a gradient in the refractive index n. Hence, the normal to the wavefront will follow a curved path. This effect is stated earlier in other words as "the ray will follow a curved path bending towards the region of higher density and away from the region of lower density." In such a case, the radius of curvature R of the light ray is proportional to 1/n. It can be shown that

$$\frac{1}{R} = \text{gradient } n.$$

The total angular deflection of the ray in passing through the test-section of width L is therefore given by

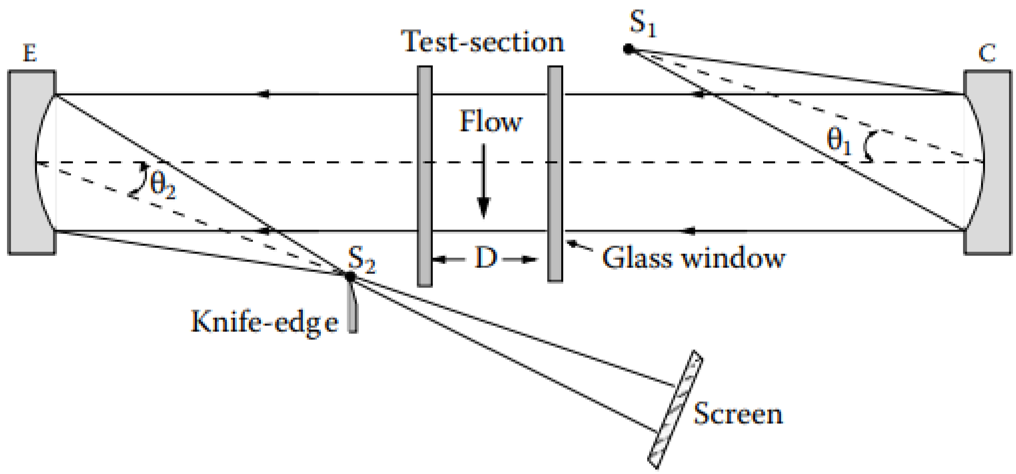
$$\epsilon = \frac{L}{R} = L \text{ grad } n.$$

$$\epsilon_x = L\frac{\partial n}{\partial x} \qquad \epsilon_y = L\frac{\partial n}{\partial y}.$$

$$\boxed{\epsilon_x = LK\frac{\partial \rho}{\partial x}}$$

$$\boxed{\epsilon_y = LK\frac{\partial \rho}{\partial y}}.$$

Figure



Twin-mirror Schlieren system

it can be visualized that if the knife-edge is aligned normal to the flow (i.e., in the y-direction) only deflection x will influence the light passing the knife-edge. Therefore, only density gradients in the x-direction will be made visible, and the gradients in the y-direction will not be visible. Similarly, if the knife-edge is aligned parallel to the x-direction, only the gradients in the y-direction will be visible. A typical Schlieren picture of a free jet is shown in Figure 4.10. At this stage, we should note that the Schlieren lenses must not only be of high optical quality but also must have large diameters and long focal lengths. The large diameter is necessary to cover the required portion of the flow field, which is often large in size (say 200 mm in diameter). The long focal length is necessary in order to get the "required" precision and image size. Furthermore, the Schlieren lens should be free of chromatic and spherical aberrations. Also, the astigmatism must be as small as possible. In experiments where the region under study has a large cross-section as in the case of many modern wind tunnels, it is difficult to obtain lenses of sufficient diameter and focal lengths, and at the same time with the required optical properties. Even if such lenses are made specially for such use they will prove to be extremely expensive. As a result concave mirrors have been widely used. They are comparatively free from chromatic aberration and mirrors of large diameters and long focal lengths are much easier to grind and correct than lenses. A twin-mirror Schlieren system that gives good resolving power. The mirrors C and E are a carefully matched pair. Usually they are made of glass and their front surfaces are parabolized to better than one-tenth of a wavelength of light. The excellence of their optical quality bears a direct relation to the image quality produced. Also, due to their size (often more than 300 mm in diameter) and weight they must be carefully mounted to avoid distortions. In the Schlieren setup arrangement, it is essential that the angle θ1 must be approximately equal to angle θ2 and their values should be as small as possible although angles up to about 7◦ are used successfully to obtain flow visualization of acceptable quality. The distance between the mirrors is not critical but it is good practice to make it greater than twice the focal length of the mirrors. Also, the optical system beyond S2 is simplified if the distance from the disturbance to be observed at test-section D to the mirror E is greater than the focal length of E. The parallel rays entering the region D are bent by the refractive index gradient and are no longer parallel to the beam from C and hence, cannot be focused by the second mirror unless the distance from D to the second mirror E is greater than the focal length of E. The image of the test-section flow field (with the model) focused at the focal point at S2 will diverge and proceed further. This image can be made to fall on a flat screen. The clarity of the image can be modified by adjusting the knife-edge. Proper adjustment of the knife-edge can result in sharp images of the shock (or compression) and expansion waves prevailing in the flow to fall on the screen. A still or video camera can record the image on the screen. When a video camera is used, the image can be made to fall on the camera lens. This will avoid the parallax error associated with capturing the image from the screen with a still camera kept at an angle from the screen, without cutting the light rays from S2;

Range and Sensitivity of the Schlieren System

Let us assume that the contrast on the screen is increased by reducing the size of the image. That is, the knife-edge is made to cut off most of the light, any ray deflecting beyond a certain limit will be completely cut off by the knife-edge, and further deflection will have no effect on the contrast. This means that the range is limited. Increase in sensitivity affects the range of density gradient for which the system could be used. The contrast or sensitivity requirement depends on the problem to be studied. Hence, to adjust the contrast the knife edge is generally mounted on a vertical movement so that its position can be altered with respect to the image.

Optical Components' Quality Requirements

The quality of the optical equipment to be used in the Schlieren setup depends on the type of investigation carried out. The cost increases rapidly with the quality of the optical components. The vital components are the mirrors and the light source. Now, optical quality mirrors are easily available. The following specifications are sufficient to meet the visualization requirements of a 200 mm diameter flow field.

Schlieren Mirrors

• Two parabolic mirrors of 200 mm diameter

• Focal length of the mirrors about 1.75 m

• Thickness of the mirror glass about 25 mm

The reflecting surface of the mirrors is ground to an accuracy of 1/4 wavelength of sodium light and aluminized. Parabolic mirrors are the most suitable even though they are more expensive than spherical mirrors which also will serve the purpose. It is important to note here that, although an optical finish of $\lambda/4$ is good enough for visualization of shock waves, if the aim is to study the structure of the flow field (e.g., shear layers in a free jet, etc.) with ultra-short Schlieren photography, a mirror surface finish of the order of $\lambda/20$ is essential.

Light Source

• Small intense halogen lamp of 30 watts is commonly used.

• Mercury vapor lamp of suitable intensity (say 200 watts) may also

be employed.

• Provision to vary the intensity of light will prove to be useful

Knife-Edge

Any straight, sharp-edged opaque object mounted on an adjustable stand will be sufficient to serve as a knife-edge. The Schlieren technique is generally used only for qualitative work, even though in principle it can be used for quantitative work. If quantitative measurements are to be done the density of the image has to be measured and this can be done with a photo densitometer. This instrument contains a photo cell and it is scanned over the photographic film of the Schlieren image. By properly adjusting the exposure time the brightness of the pattern on the photographic print can be made proportional to the brightness of the Schlieren system

Color Schlieren

If the knife-edge which is kept at the focal point of the second mirror is replaced by a colored filter containing different colors, the image formed on the screen will have different colors depending on which way the beam bends. The contrast in the ordinary black and white Schlieren will now be represented by colors. Usually the colors red, yellow, and green are used. These filters are of 1 or 2 mm in width and placed side by side. When there is no flow the image of the source is allowed to fall on the yellow portion of the filter. Now the image on the viewing screen will be completely yellow. When the density gradient is introduced, the image is displaced and falls partly on the neighboring filter thus altering the color on the screen. In the three-filter color Schlieren screen the color also indicates the size of the density gradient. The color effect described can also be achieved with a dispersion prism placed at the knife-edge location.

Experimental Tasks

The experiment is divided into four separate tasks:

1. Assembly and alignment of the visualization system

2.. Visualization of an expanded jet

3. Visualization of a phenomena of your choice

Result:

Thus, the expanded shock wave pattern captured with help of schlieren flow visualization technique.

EXP NO: 08 DATE:	STUDY OF UNDER EXPANDED AND OVER EXPANDED JETS.

Aim:

To study the Under expanded and Over expanded Jets.

Description:

The variation in flow patterns inside the nozzle obtained by changing the back pressure, with a constant reservoir pressure, was discussed early. It was shown that, over a certain range of back pressures, the low was unable to adjust to the prescribed back pressure inside the nozzle, but rather adjusted externally in the form of compression waves or expansion waves. We can now discuss in detail the wave pattern occurring at the exit of an under expanded or overexpanded nozzle.

Consider first, flow at the exit plane of an underexpanded, two-dimensional nozzle. Since the expansion inside the nozzle was insufficient to reach the back pressure, expansion fans form at the nozzle exit plane

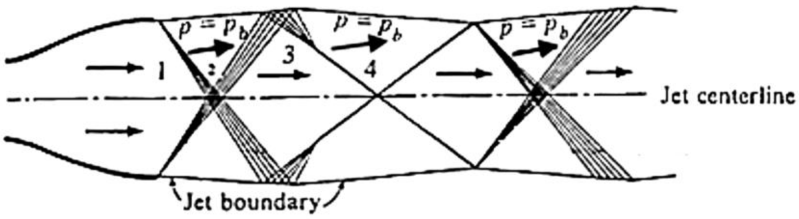


Fig. 1. Underexpanded Jets.

flow at the exit plane is assumed to be uniform and parallel, with. For this case, from symmetry, there can be no flow across the centerline of the jet. Thus, the boundary conditions along the centerline are the same as those at a plane wall in nonviscous flow, and the normal velocity component must be equal to ero. The pressure is reduced to the prescribed value of back pressure in region 2 by the expansion fans. However, the flow in region 2 is turned away from the exhaust-jet centerline. To maintain the zero normal -velocity components along the centerline, the flow must be turned back toward the horizontal. Thus, the intersection of the expansion fans centered at the nozzle exit yields another set of expansion waxes, just as did the reflection of the expansion fan from a plane wall reflected Pradtl-Myer waves. he second expansion, however, produces a pressure in region 3 less than the back pressure, so the expansion waves reflect from the external air as oblique shocks. These compression waves produce a static pressure in region 4 equal to the back pressure, but again turn the flow away from the centerline. The intersection of the oblique shocks from either side of the jet then requires another set of oblique shocks to turn the flow back toward the horizontal, with the shocks reflecting from the external air as expansion waves. The process thus goes through a complete cycle and continues to repeat itself. The flow pattern discussed appears as a series of diamonds, often visible at the exit of high - speed rocket nozzles. Theoretically, the wave pattern should extend to infinity. Actually, however, mixing of the jet with ambient air along the jet boundaries eventually causes the wave pattern to die out.

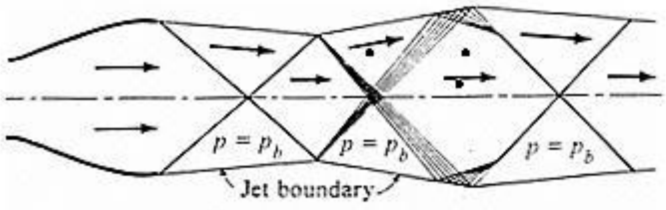


Fig. 2. Over expanded Jets.

Since the exit plane pressure is less than the back pressure, oblique shock waves form at the nozzle exit. The intersection of these shocks at the centerline yields a second set of oblique shocks, which in turn reflect from the ambient air as expansion waxes. Thus, except for being out of phase with the wave pattern from the underexpanded nozzle, the jet flow of the overexpanded nozzle exhibits the same characteristics as the underexpanded nozzle.

Result:

Thus, the Under expanded and Over expanded jets are studied.