Experimental Investigation of laminar length for Impinging Jet

by

AP17110030016 Akash Yadav AP17110030018 Raja Swarnakar

AP17110030010 Akshay

Department of Mechanical Engineering, SEAS, SRM University AP, Amravati

Overview

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- Literature review
- Experimental setup and procedure
- Result Comparison
- Result
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- Applications

Background

Jet: A jet is a stream of fluid that is projected into a surrounding medium, usually from some kind of a nozzle, aperture or orifice.

Impinging Jet: The impinging jet is defined as a high-velocity jet of cooling fluid forced through a hole or slot which impinges on the surface to be cooled, which results in high heat transfer rate between the wall and the fluid.

Laminar flow: At low velocities, the fluid appeared to move in layer or lamina, and hence the nature of this flow is termed laminar flow or stream line.

Transition zone : The region of flow bounded by the lower and upper critical velocities is termed as the transition zone.

Turbulent: Further increase in velocity of flow the streamline remains in a diffused state and the nature of this type of flow is termed turbulent.

Literature Review

Table 1: Brief overview of Literature on submerged jets

Author	Experimental method	Dimensions of test tank	Jet dimension D_j (mm)	Fluid used in jet	Range of Reynolds number $Re = \frac{\rho U D_j}{\mu}$	Remarks
Reynolds A. J (1962)	Observations of Liquid into Liquid jets.	Cylindrical tank (glass) L = 1200 mm D = 300 mm	0.32 mm ± 0.05 mm	Water and Dyed water (Eosine dye)	$10 < Re < 300$ $Re > 300$	Long steady jet at relatively low Re i.e. ($10 < Re < 30$). For $150 < Re < 300$, Longer jet with complex breakdown. For $Re > 300$, jet become disordered near nozzle.
K.J Mc Naughton and C.G Sinclair (1965)	Submerged jets in short cylindrical flow vessels.	Cylindrical vessel (discharging) D= 30 mm L = 1200 mm	Circular jet diameter = 0.32 mm	Water and Dyed water	$Re < 300$, $300 < Re < 1000$, $1000 < Re < 3000$, $Re > 3000$	Dissipated Laminar Jet, Fully laminar jet, Semi turbulent Jet and Fully turbulent jets are observed. Furthermore, Equation correlated with laminar length 'a': $a/d = 9.97 \times 10^{7} Re^{-2.46} \times (D/d)^{-0.48} \times (L/d)^{0.74}$

Literature Review

T. Chafekar, Nishant Nayan, Ranjit Kumar, V. Katti and S.V.Prabhu. (2008)	Flow visualization studies on submerged free and impinging jets.	Cubical vessel of 500*500*500 mm^3. Impinging plate 300 mm * 300 mm.	Circular jet of Diameter = 7.3 mm.	Water and Dyed water	$1000 < Re < 3500$	Flow visualization on submerged free jet (free and free orifice jet) and impinging jet. For $Re < 2000$, the flow is observed to be laminar for free and impinging jets. At $Re = 2200$ and $Re = 2500$, transition zone for free jet and impinging jet. $Re > 2700$, turbulent zone started for all jets.
Vadiraj Katti, S.V. Prabhu (2008)	Experimental study and theoretical analysis of local heat transfer between smooth flat surface and impinging air jet from a circular straight pipe nozzle.	Stainless steel target plate of 80 mm * 160 mm having 0.06 mm thickness.	Impinging circular jet on flat plate with length to diameter ratio = 83 and diameter = 7.35 mm	High Pressure Air at 4 bar	$12000 < Re < 28000$	Local heat transfer characteristics are estimated and heat transfer at stagnation point and transition region obtained from laminar boundary. Increase in Re, increases the heat transfer.

Experimental set-up and Procedure

1. **Dyed tank.**
2. **U-tube manometer with scale.**
3. **Table stand**
4. **Flow Pipe**
5. **Visualization tank**
6. **Festo Needle valve (0.5 in.)**
7. **High Shutter speed Camera**
8. **Tripod stand**
9. **Drain Valve.**

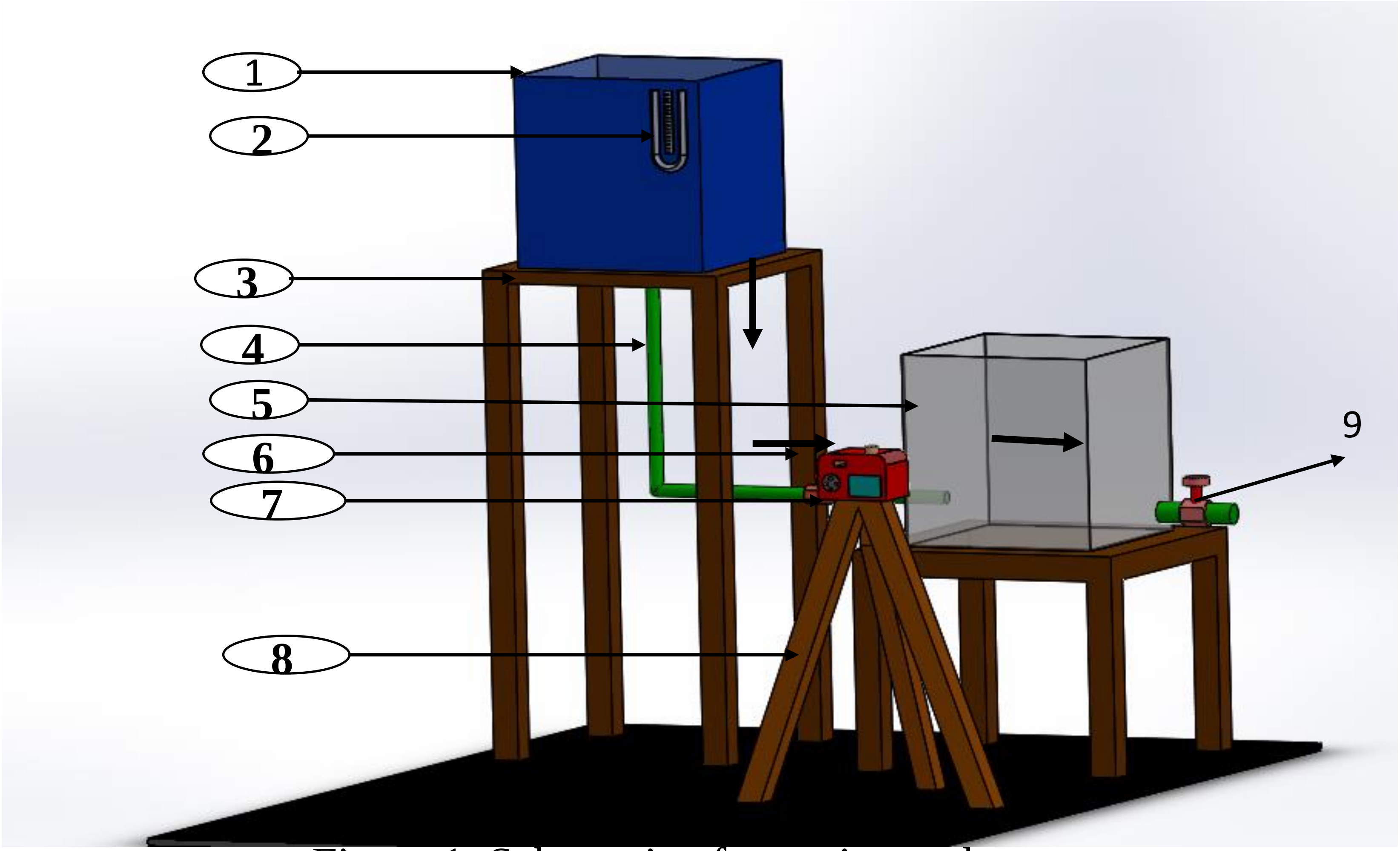

Figure 1: Schematic of experimental set up

Formulae

- Flow rate (Q) = Area x Velocity ; where Area = $\frac{\pi D^2}{4}\, m^2$ and Velocity = $\frac{(initial - final) reading\ of\ peizometer}{total\ time\ taken}\ \frac{m}{s}$

- Velocity of Jet (V_{jet}) = $\left[\left(\frac{D^2}{d^2}\right) \text{ x } \left(\frac{(initial - final) reading\ of\ peizometer}{total\ time\ taken}\right)\right] \frac{m}{s}$

  where D = Diameter of Dye Tank ,
  d = Diameter of Jet

- Reynold's Number (Re) = $\frac{\rho v d}{\mu}$; where ρ = density of dye ink = 997 kg/m³ at 25 °C
  v = velocity of jet (m/s)
  d = diameter of jet (m)
  μ = Dynamic Viscosity of Dye ink (Pa.s)

Result Comparison

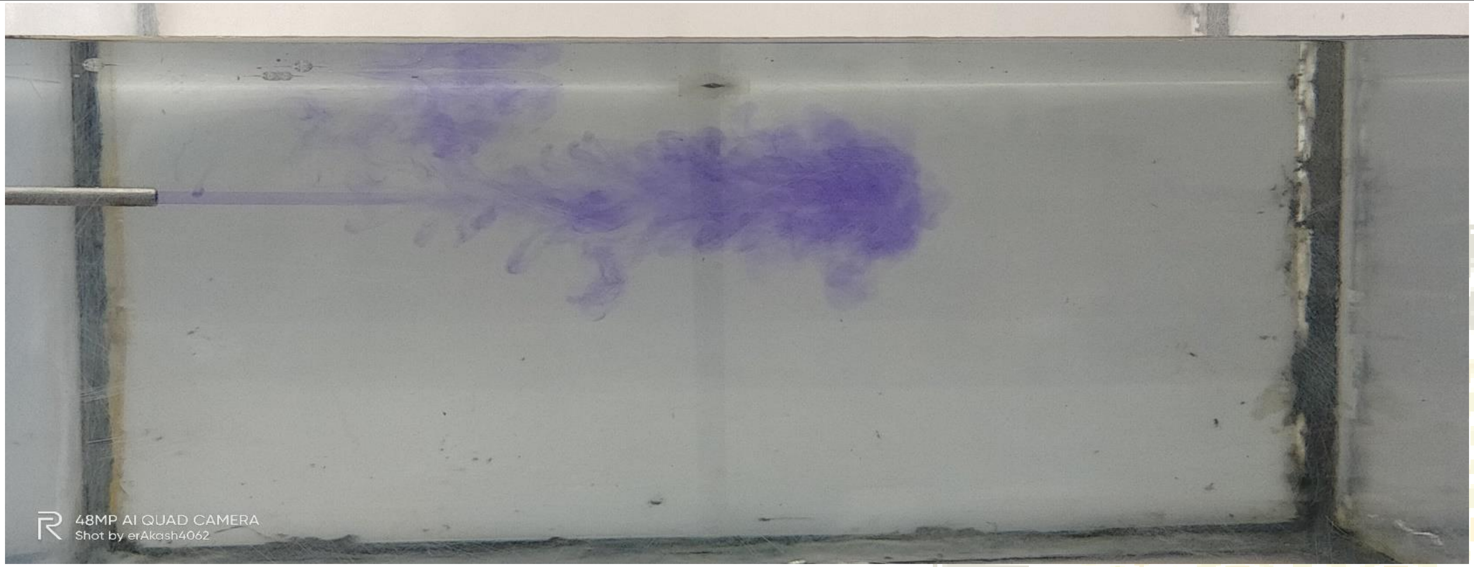

Fig.2. Submerged Free Jet

Fig.2. Free Jet
Image Source: C. Cornaro et al. / Experimental Thermal and Fluid Science 20 (1999)

- **Non Eddying Jet rose into a vessel up to certain length and then it mushroomed or pedal breakdown takes place.**
- **Indication of higher Reynolds Number than 240.**
- **Dissipated Laminar Jet.**

Results

- **Diameter of Jet = 8mm**
- **Viscosity = 8.6840 × 10^{-4} Pa·s**
- **Density of Water = 997 kg/m^3**
- **Flow Rate = 5.3162 $\mu m^3/s$**
- **Velocity = 0.1058 m/s**
- **Reynolds Number = 1010.3**
- **Laminar Length = 9.59 cm**

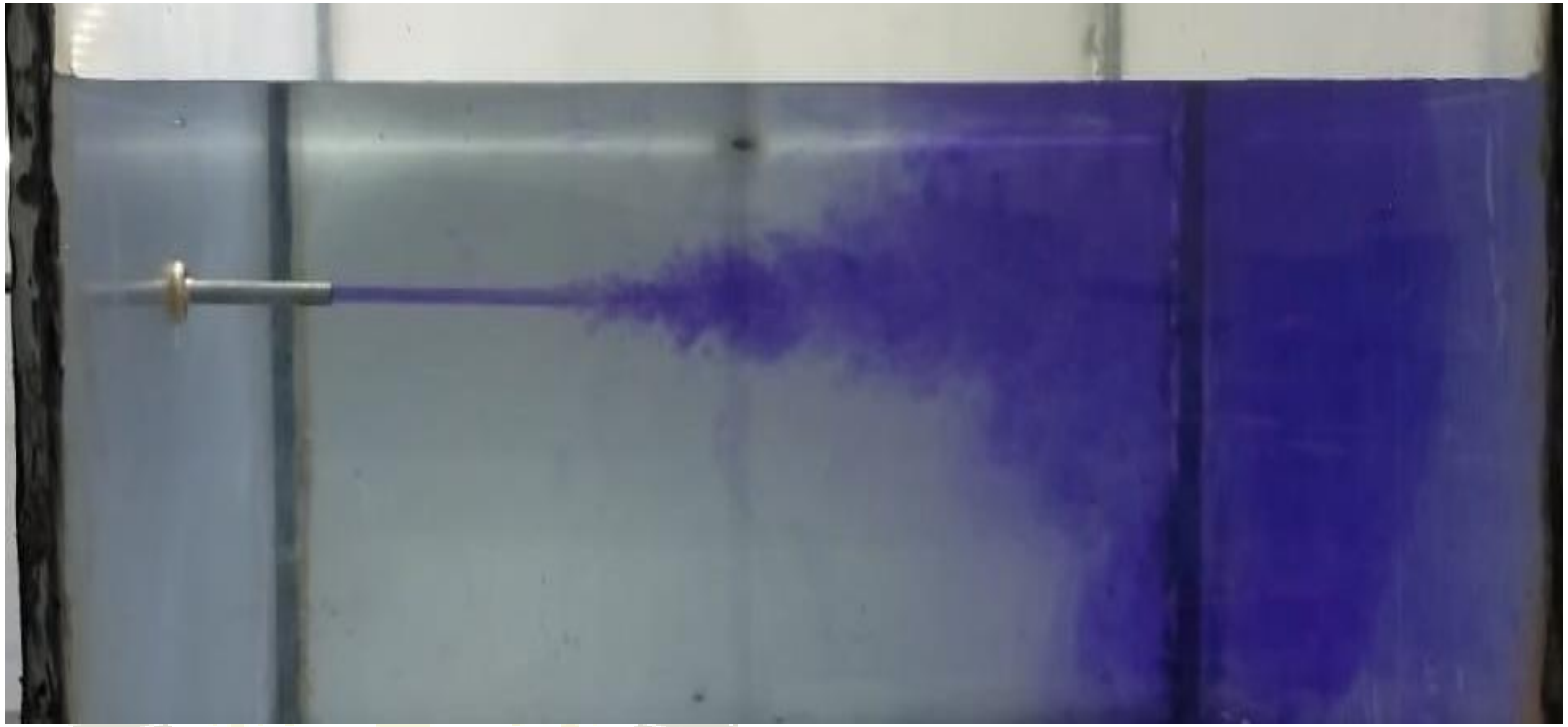

Fig.4. Laminar Jet at Re = 1010.3

Results

- **Diameter of Jet = 8mm**
- **Viscosity = 8.6840 × 10^{-4} Pa·s**
- **Density of Water = 997 kg/m^3**
- **Flow Rate = 2.8213 $\mu m^3/s$**
- **Velocity = 0.0563 m/s**
- **Reynolds Number = 514.3**
- **Laminar Length =11.15 cm**

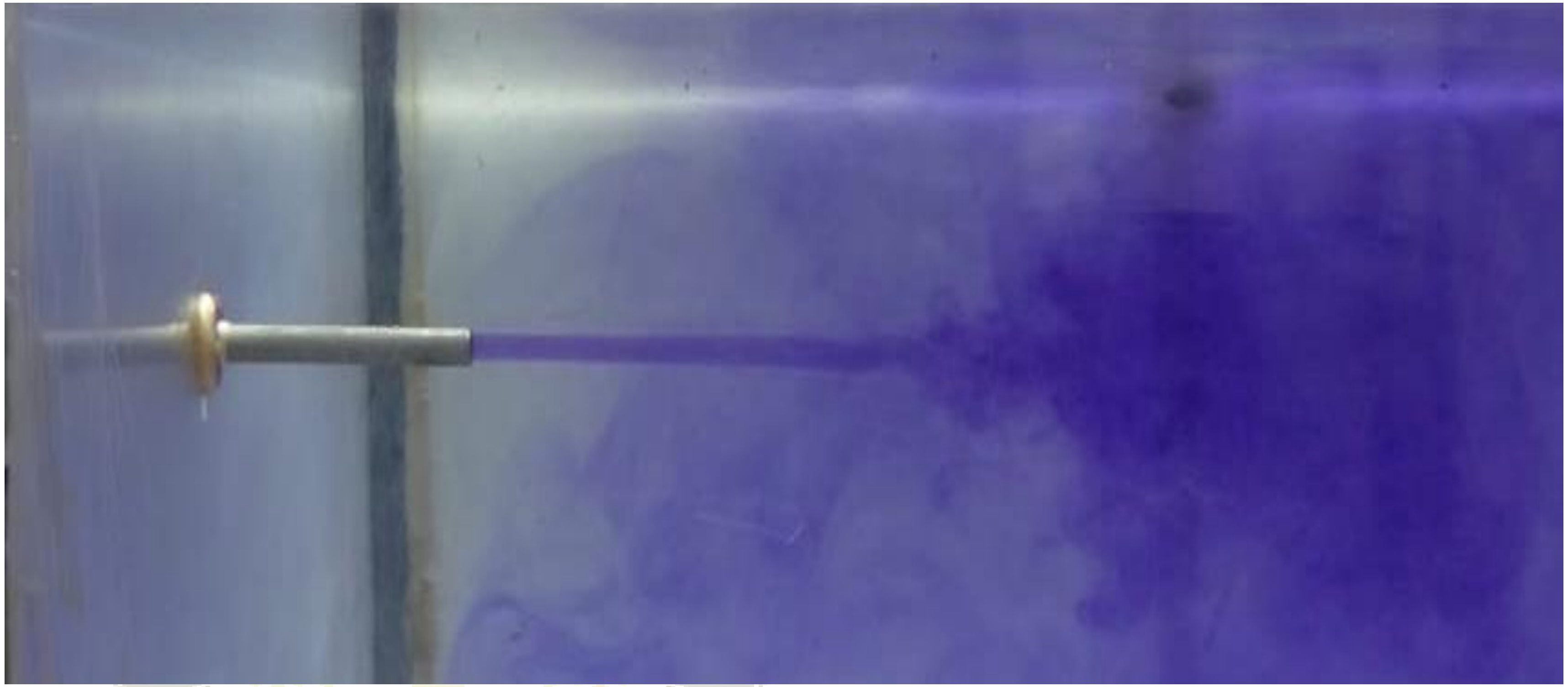

Fig.5. Laminar Jet at Re = 514.3

Results

- **Diameter of Jet = 8mm**
- **Viscosity = 8.6840 × 10^{-4} Pa·s**
- **Density of Water = 997 kg/m^3**
- **Flow Rate = 2.1551 $\mu m^3/s$**
- **Velocity = 0.0429 m/s**
- **Reynolds Number = 395**
- **Laminar Length = 18 cm**

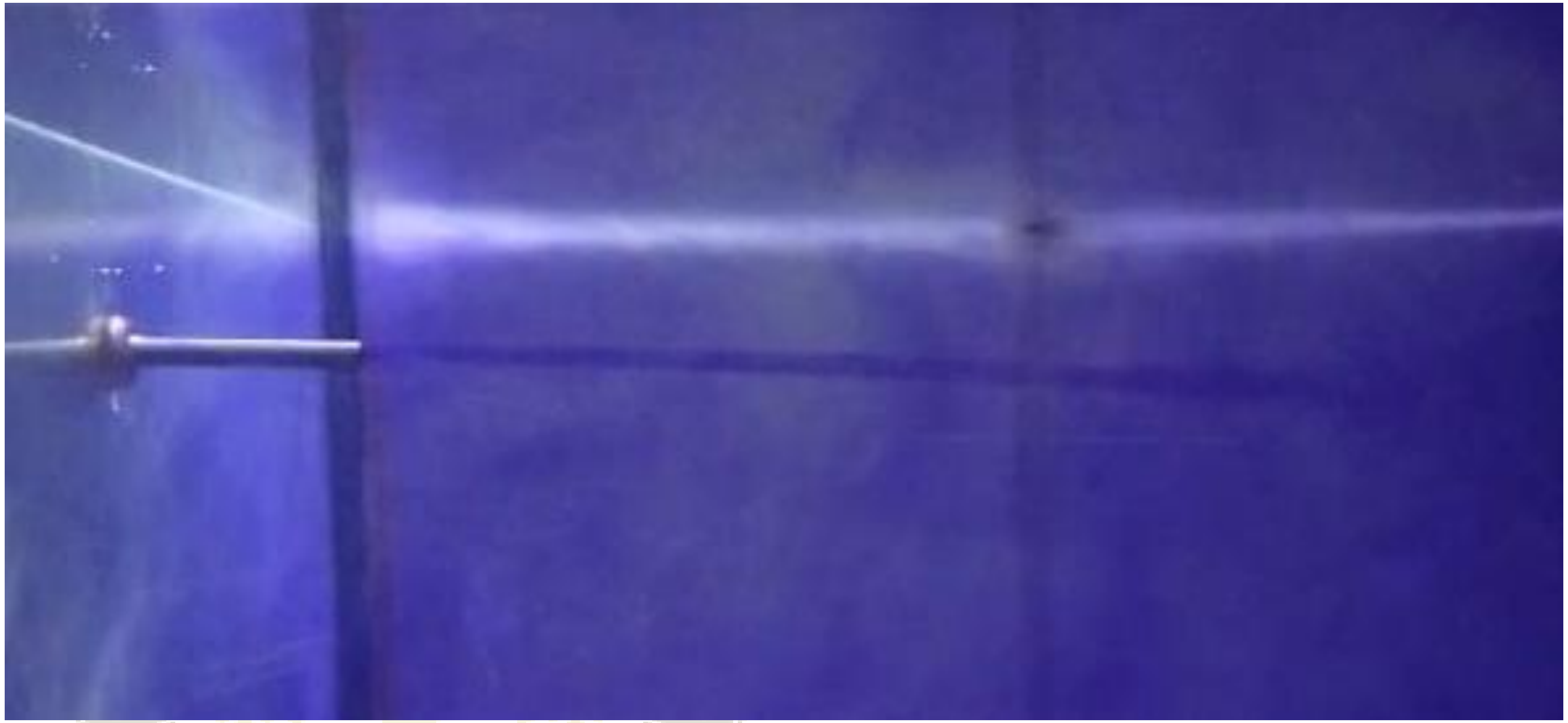

Fig.4. Laminar Jet at Re = 395

Uncertainty

- **Uncertainty in Velocity(ω_v):**

$$\omega_v = \sqrt{\left(\frac{2D\Delta l}{d^2 t}\omega_D\right)^2 + \left(\frac{-2D^2\Delta l\omega_d}{d^3\, t}\right)^2 + \left(\frac{D^2\omega_L}{d^2\, t}\right)^2 + \left(\frac{-D^2\Delta l\omega_t}{d^2\, t^2}\right)^2} = \pm\,(2.6\,\% - 8.3\,\%)$$

where D = Diameter of Dye Tank (m),
d = Diameter of Jet (m) ,
$\Delta l = (initial - final)\,reading\ of\ peizometer\ \ (\mathrm{m})$
t = total time taken (sec)

Here , ω_D = 1 mm, ω_L = 1 mm, ω_d = 1 mm, ω_t = 0.1 sec.

- **Uncertainty in Reynolds Number(ω_{Re}) =** $\sqrt{\left(\frac{\rho d}{\mu}\omega_v\right)^2 + \left(\frac{\rho v}{\mu}\omega_d\right)^2}$ **= ± (10.3 % - 14.5 %),**

where ρ = density of dye ink = 997 kg/m³ , v = velocity of jet (m/s)
d = diameter of jet (m) and
μ **= Dynamic Viscosity of Dye ink (Pa.s)**

Conclusion

For Low Jet Exit Velocity

↓

Reynolds Number is Low, which indicate Laminar Region

↓

As the Reynolds Number decreases, the Laminar Length Increases respectively

Applications

Fig.1: Jet Blast Deflector
Image Courtesy: F-35C

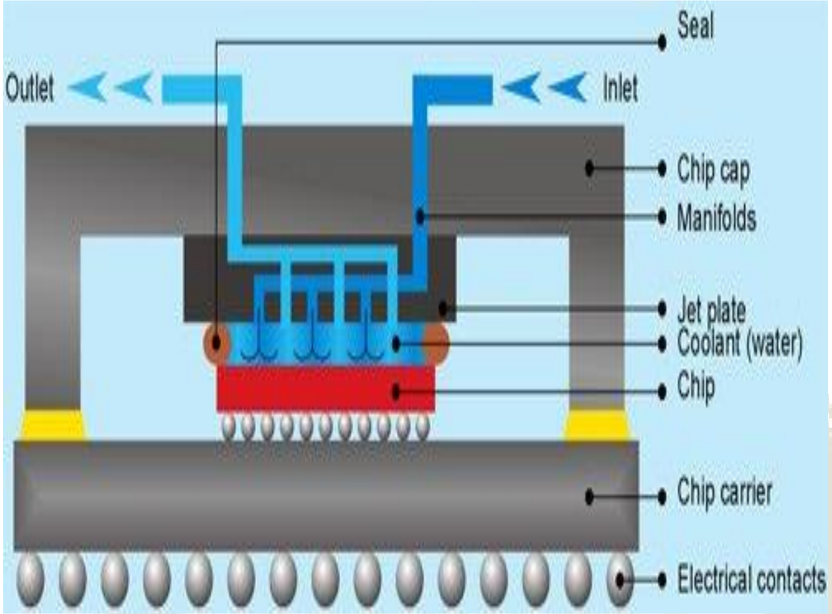

Fig.2: Cooling of Processors and IGBTs
Image Courtesy: Google

Fig.3: Water Jet Cutting
Image Courtesy: Aqua technology

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Any Queries ???

Image Courtesy: FSSAI

Image Courtesy: Julie Blais Comeau