

Measurements of Flow Velocity and Scalar Concentration in Turbulent Multi-Component Jets

7th ICHS

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Introduction

Past work

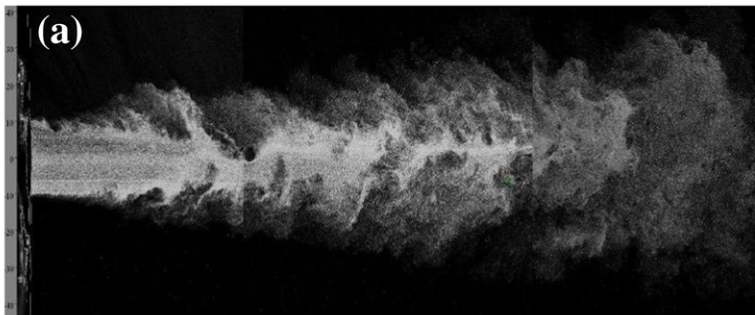


Figure : Turbulent round CO₂ jet ($Ma_c = 0.6$) [De Gregorio 2014].

- Round (axisymmetric) and non-circular (asymmetric) jets through flat surfaces.
- Turbulent and compressible (high Re , $Ma \rightarrow 1$).
- Some previous experimental works [Donaldson et al. 1966, Hussein et al. 1994, Amielh et al. 1996, Ball et al. 2012].

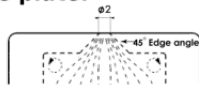


Introduction

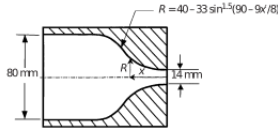
Past work, Round jets through flat surfaces (axisymmetric)

- Initial flow condition can significantly influence jet evolution [Nathan et al. 2006].

Orifice plate:



Smooth contraction:



Long pipe:

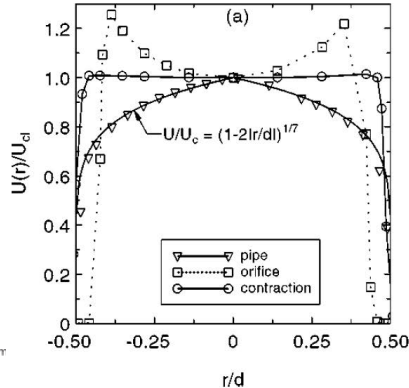
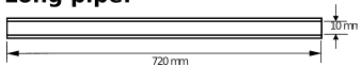


Figure : Radial profiles of mean velocity (U) obtained at $x/D=0.05$ for contoured, orifice plate, and pipe nozzles [Mi et al. 2001].



Introduction

Past work

Effect of nozzle geometry

- Asymmetric behavior lead to increase in mixing, turbulence intensity, and entrainment rates compared to round jets. [Mi et al 2010, Zaman et al 1999]

Buoyancy effect

- Pure vertical jets reach the self-similarity regime slower than plumes. [Carazzo et al. 2006].
- Horizontal jets scale according to jet momentum to buoyancy generated momentum ratio. [Ash 2012].

Realistic pipe leaks not yet considered.

Figure : Different nozzle geometries [Mi et al., 2010].

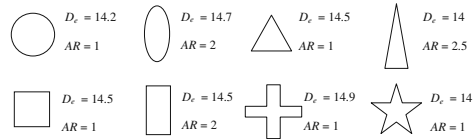
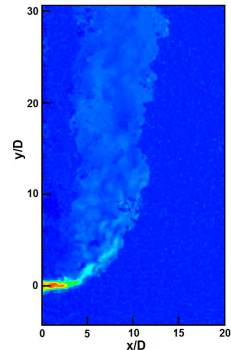


Figure : Buoyant jet [Ash, 2012].



Introduction

Current study

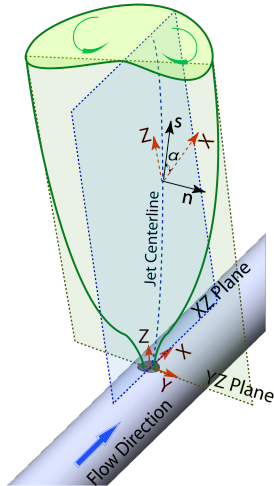


Figure : Jet configuration.

- 1/4 in pipe with $D = 2$ mm hole.
- Simultaneous PIV & PLIF.
- Experimental (air, He only).
- $Ma = 0.4$ to 1.2.
- $Re = 16,000$ to 42,000.
- Momentum flux (force) matched [Panchapakesan and Lumley, 1993].



Introduction

Experimental Facility

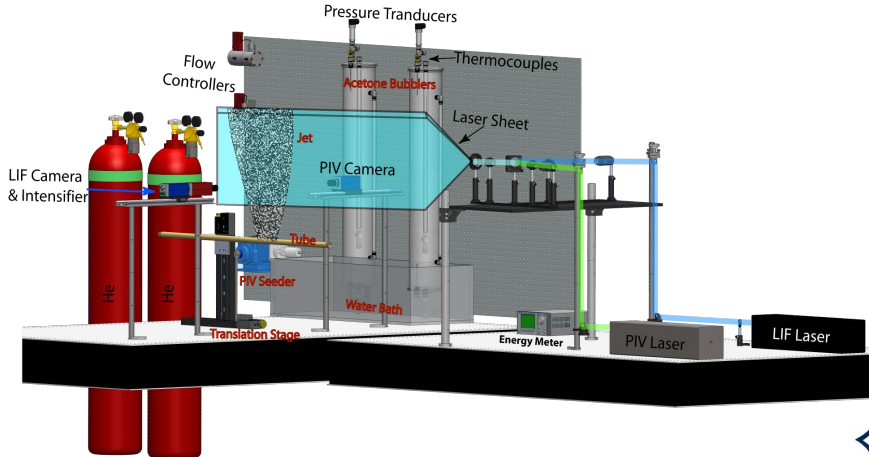


Figure : Experimental Layout.



Results - Instantaneous velocity & concentration contours

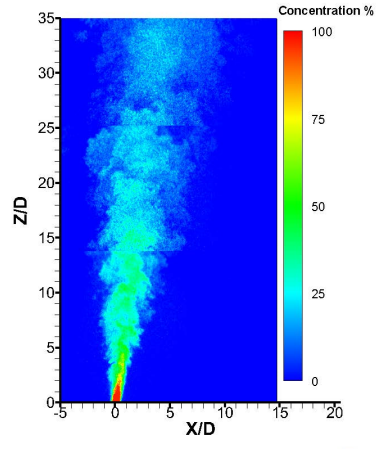
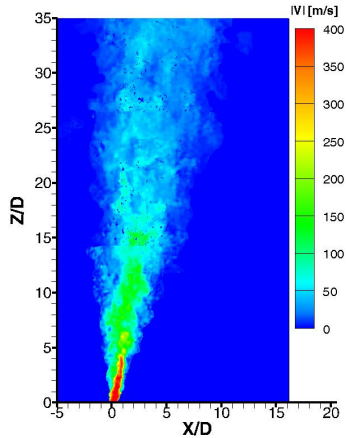


Figure : Instantaneous a) velocity and b) concentration fields obtained from Helium 3D jet in XZ plane.



Results - Time-averaged velocity contours

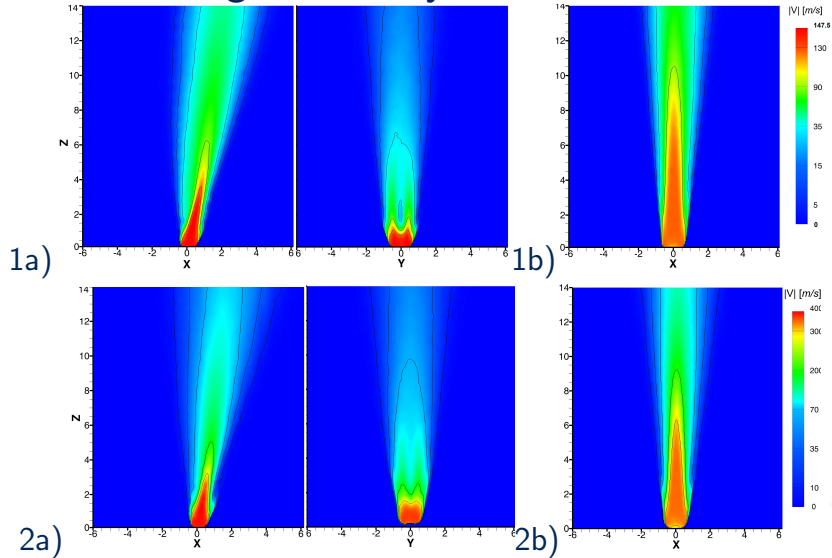


Figure : Average velocity contours in XZ and YZ planes for 1) air and 2) helium, obtained from a) Round jet on side of tube (3D jet) and b) Round orifice plate (OP) jet.

Results - Time-averaged concentration contours

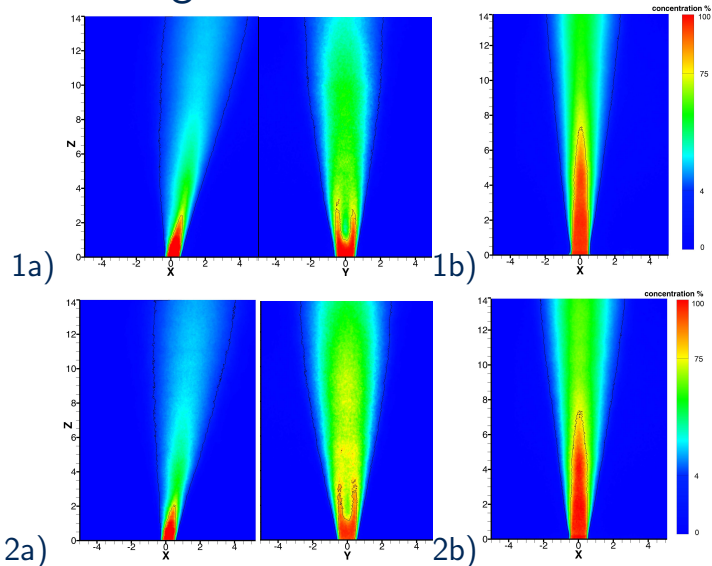


Figure : Average concentration contours in XZ and YZ planes for 1) air and 2) helium, obtained from a) 3D Round jet and b) Round orifice plate jet.



Results - Jet centerline

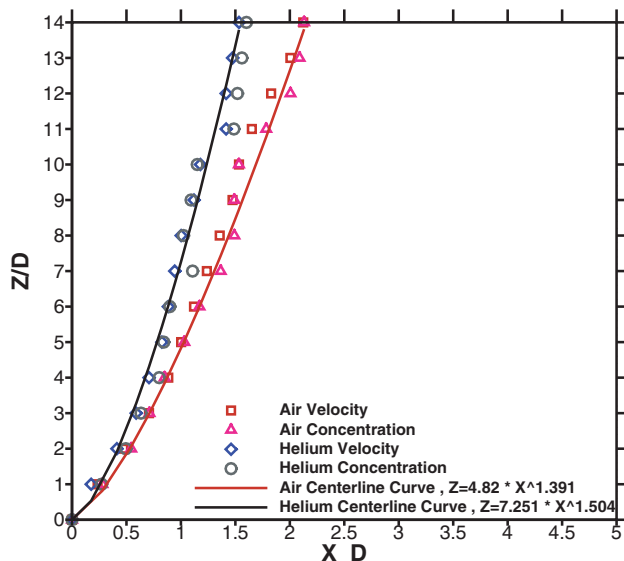


Figure : Jet centerlines taken along the location of maximum velocity ($|V|_{\max}$) locations



Results - Jet centerline properties

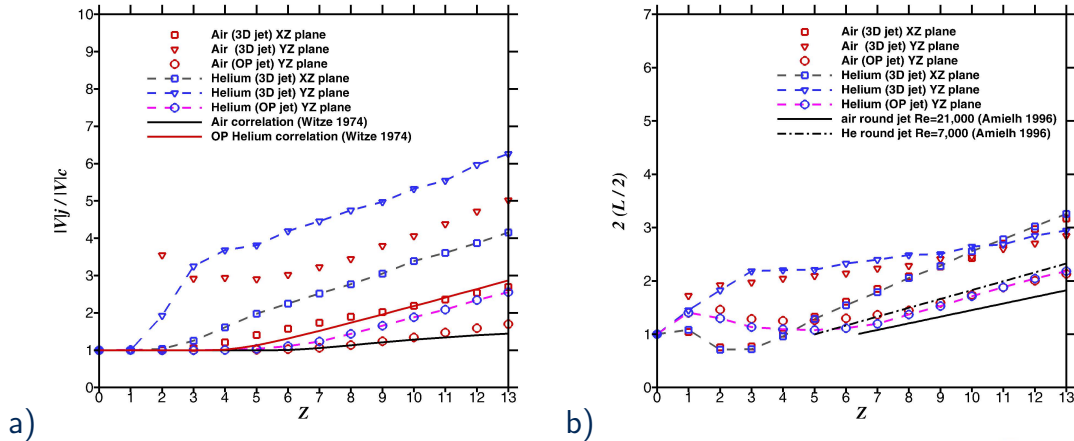


Figure : a) Jet inverse velocity decay and b) jet widths ($2(L/2)$) obtained along the $|V|_c$ centerlines.



Results - Jet centerline properties (air)

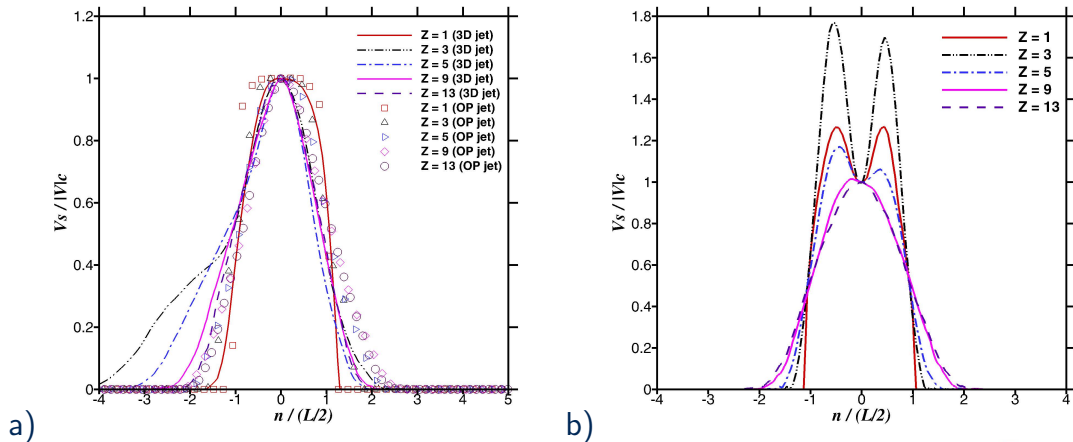


Figure : Average velocity profiles, along jet centerlines, taken at various heights for air, obtained from a) OP & 3D jet in XZ plane and b) 3D jet in YZ planes.



Results - Jet centerline properties (helium)

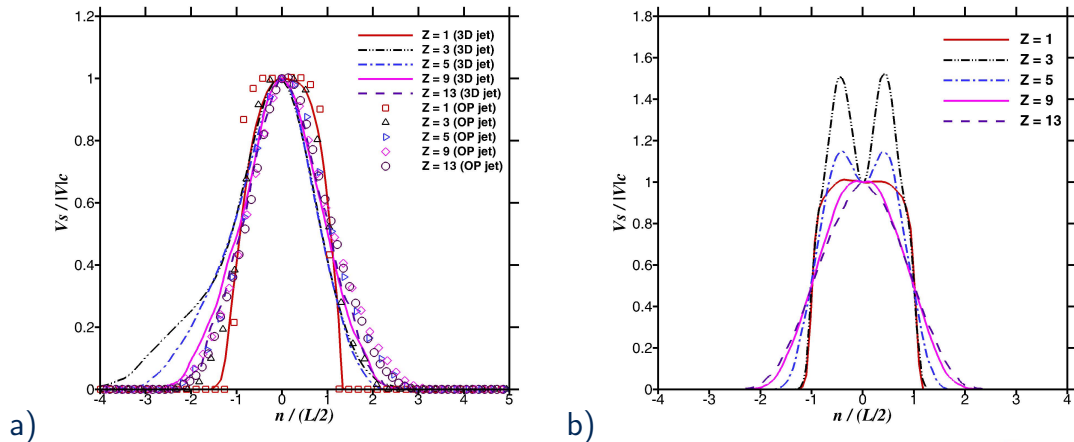


Figure : Average velocity profiles, along jet centerlines, taken at various heights for helium, obtained from a) OP & 3D jet in XZ plane and b) 3D jet in YZ planes.



Results - Jet centerline properties

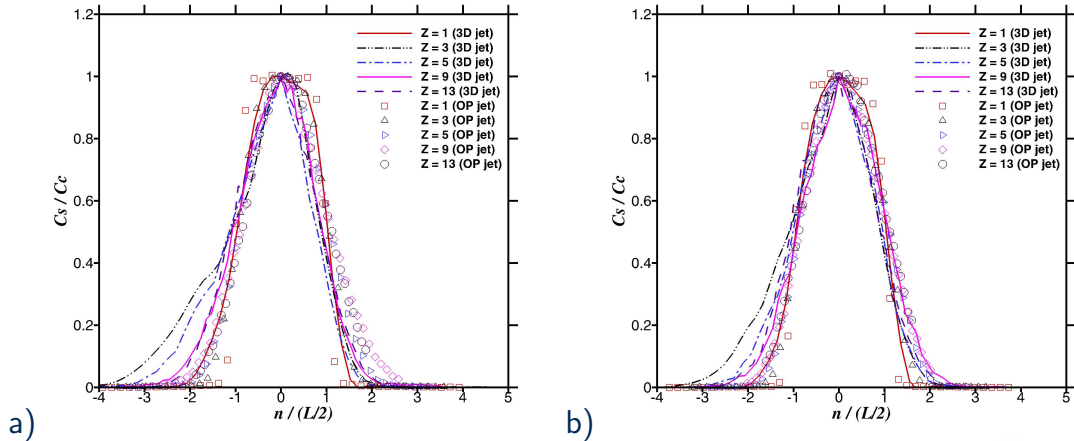


Figure : Average concentration profiles, along jet centerlines, taken at various heights for a) air and b) helium, obtained from OP & 3D jet in XZ plane.



Conclusions

- Initial flow condition causes the jet to deflect from vertical axis.
- Realistic (3D) jets experience more jet spreading compared to the axisymmetric (round) jet experiments.
 - More jet spreading observed on back side of the asymmetric 3D jet compared to round jet.
- Enhanced mixing in the asymmetric case caused:
 - reduction in potential-core length
 - increase in the velocity decay rate.
- Conventional round jet assumptions are inadequate to predict near field:
 - gas concentration and velocity fields
 - entrainment rates
 - extents of the flammability envelope (i.e. for H₂)



Acknowledgement

Funding provided by



Appendix-1

Flow properties

Table : Flow properties

Jet	$Q[\text{L}/\text{min}(N_2)]$	$\bar{u}_{j(max)}[\text{m/s}]$	$\rho_j [\text{Kg}/\text{m}^3]$	$\nu [\text{m}^2/\text{s}]$	$(\overline{\rho_j u_j})_{\text{flux}}[\text{N}]$	Re	Fr
3D Air	15	147.5	1.17	1.59×10^{-5}	0.1018	18554	N/A
OP Air	15	127.6	1.17	1.59×10^{-5}	0.0762	16050	N/A
3D He	35	399.7	0.164	1.91×10^{-5}	0.1048	41853	1144
OP He	35	341.9	0.164	1.91×10^{-5}	0.0767	35801	978



Appendix-2

3D jet

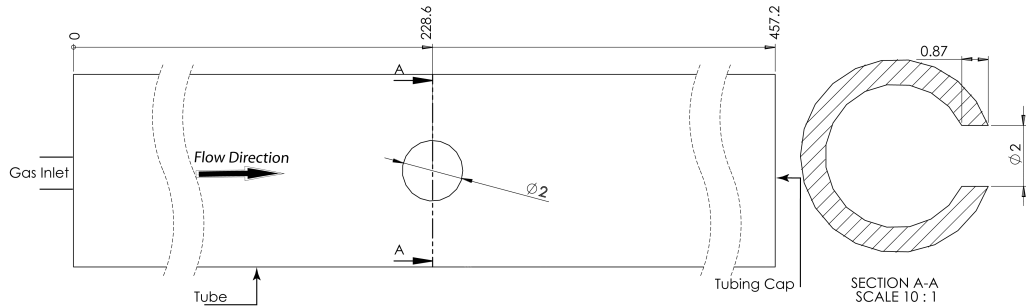


Figure : Schematics of 3D jet and it's Round 2mm slot geometry. All dimensions are in mm.



Appendix-3

Sharp-edged orifice (OP) jet

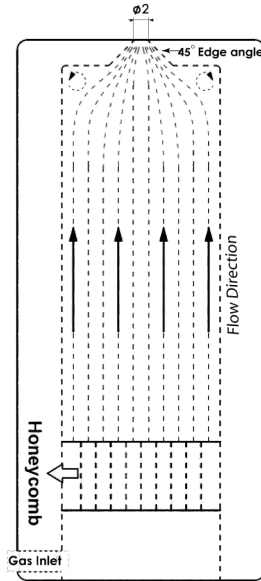


Figure : Schematic of the sharp-edged orifice jet apparatus, OP jet, (dimension in mm)



Appendix-4

Acetone a tracer for Gaseous Planar Laser-Induced Fluorescence (PLIF)

Why Acetone?

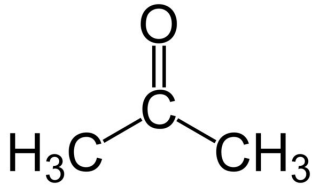


Figure : Acetone (Dimethyl ketone, or 2-Propanone)

- High vapour pressure at room temperature absorbs over a wide band of wavelengths (225-320 nm) and emits fluorescence on even wider broadband of wavelengths (350-550 nm).
- Short fluorescence lifetime (~ 2 ns).
- Low toxicity.
- Negligible oxygen quenching on fluorescence signal.
- It's fluorescence signal in isothermal, isobaric flows is known to be linear with laser power and concentration.



Appendix-5

Acetone PLIF

Fluorescence signal from Acetone PLIF in weak excitation (not saturated):

$$S_f = n_{\text{tracer}}(T, p) dV_c \left[\frac{E}{hc/\lambda} \right] \sigma(\lambda, T) \phi(\lambda, T, p, n_i) \eta_{\text{optic}} \quad (1)$$

where;

- n_{tracer} is the number density of the tracer.
- dV_c is the collection volume.
- E is the laser energy fluence.
- hc/λ is the energy per photon of the laser at wavelength λ .
- σ is the absorption cross-section of tracer molecule.
- ϕ is the fluorescence yield.
- η_{optic} is the collection optics efficiency.
- T, p are temperature and pressure of the tracer, respectively.

