MAP 2012 Winter Meeting,SLAC, March 4^{th} ,2012

Stony Brook University

Nozzle and Jet Studies

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Outlines

- Mercury Flow in Target Delivery Pipe (Without Weld)
- Mercury Flow in Target Delivery Pipe (With Weld)
- Jet Flow Using CLSVOF in FLUENT
  - Coupled Level Set Volume of Fluid (CLSVOF)
  - ANSYS FLUENT
    - Computational Fluid Dynamics (CFD) code used for simulation, visualization and prediction of fluid flow, heat and mass transfer as well as reactions
    - User Defined Function (UDF) gives user rights to define his own functions in C language.

Hg Flow in Target Delivery Pipe Without Weld (1)

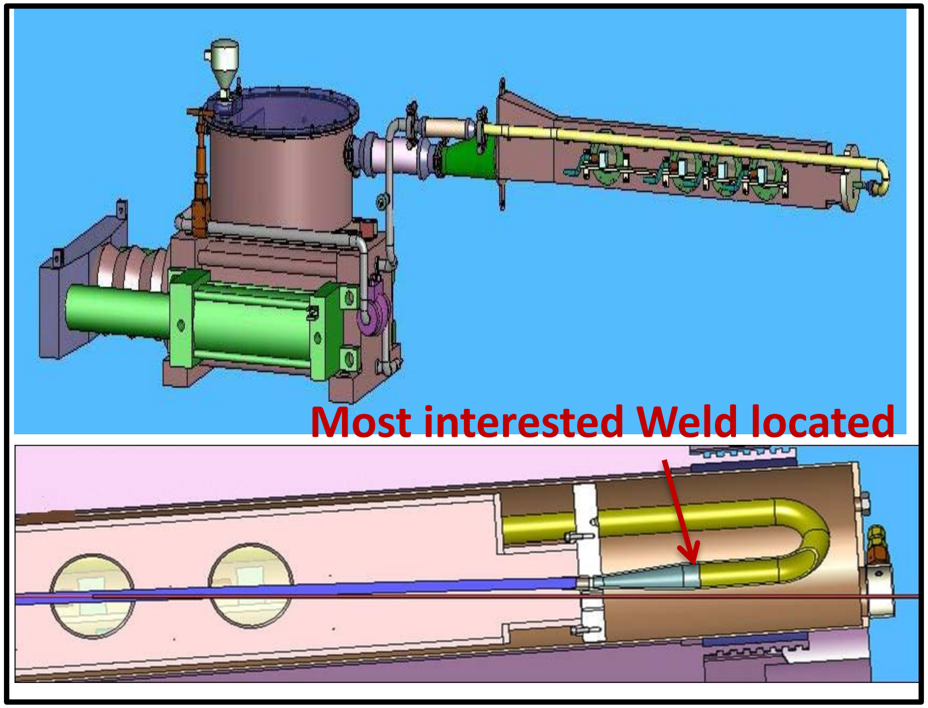

Fig. 1 Target supply pipe of the MERIT experiment

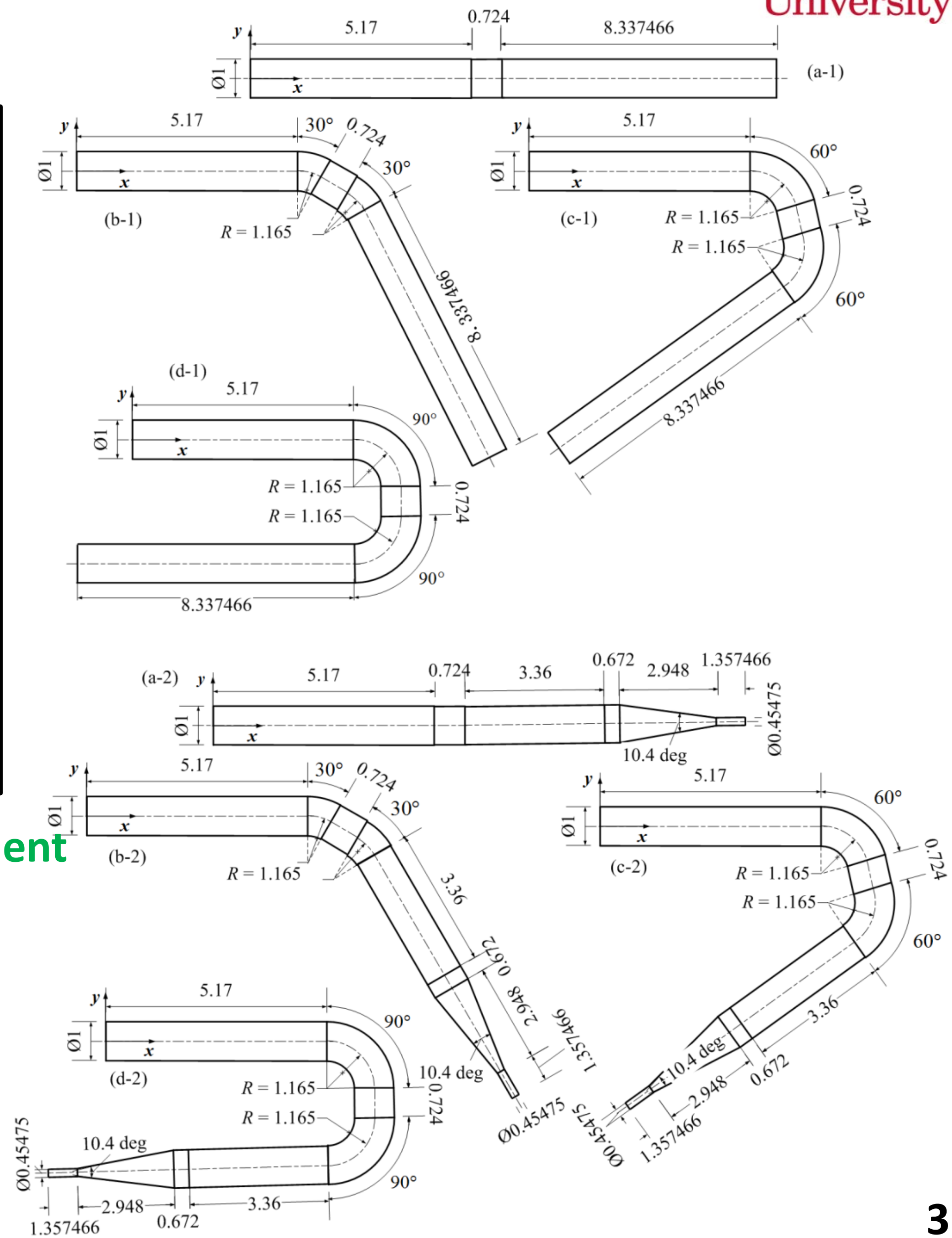

Fig. 2 Configurations of pipes investigated

Hg Flow in Target Delivery Pipe Without Weld (2)

- Theoretical analysis (laminar flow)
  - Assessment of the extra terms
- Numerical simulations (turbulent flow)
  - Evaluation of turbulent models: Realizable k-ε (RKE)
  - Numerical solutions for the studied eight geometries
    - Axial velocity distribution

$$U^* = \frac{U}{U_b}, \text{where } U_b \equiv \frac{\int u d\Omega}{|\Omega|}$$

    - Momentum thickness distribution at the exit (instability mode)

$$\theta_t = \int_0^a \frac{U}{U_{\max}}(1 - \frac{U}{U_{\max}})dr$$

    - Turbulence intensity distribution at the exit (fluctuation)

$$I \equiv \frac{u'}{U_b} = \frac{\sqrt{2k/3}}{U_b}$$

Hg Flow in Target Delivery Pipe Without Weld (3)

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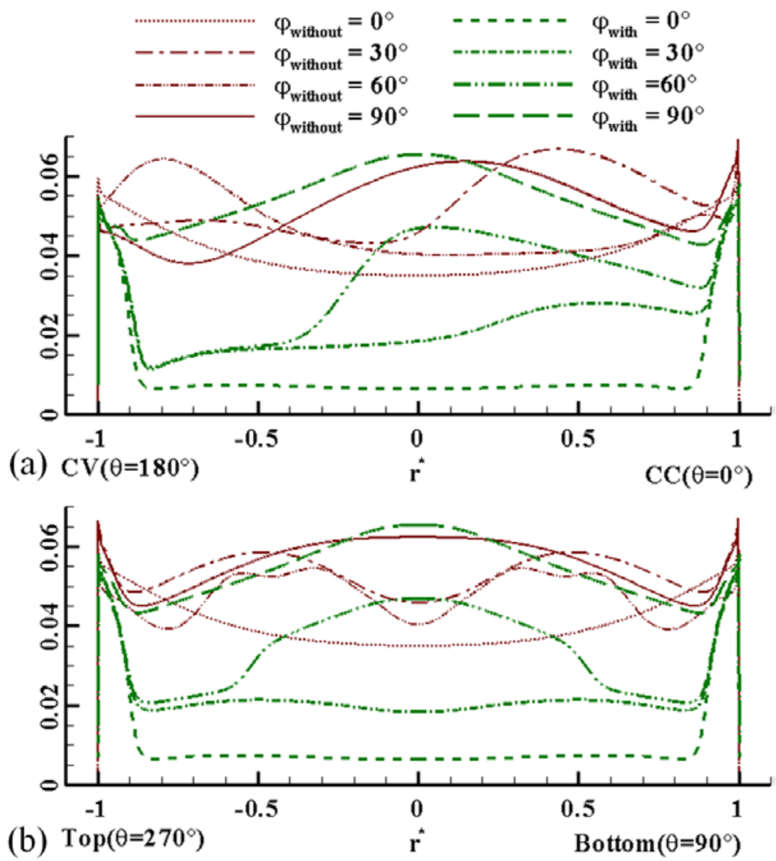


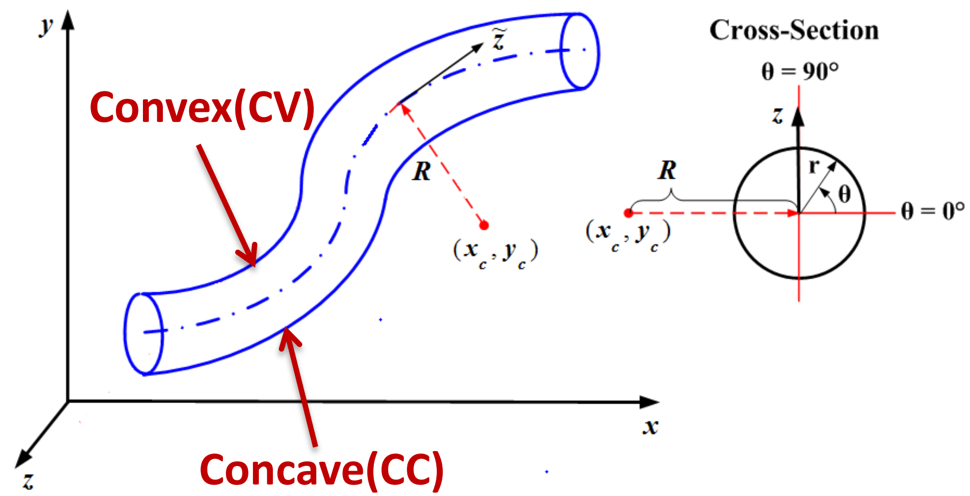


Fig. 4 Coordinates ($r, \theta, \tilde{z}$) defined for curved pipe

Fig. 3 Turbulence level at the exit ($\varphi_{with} / \varphi_{without}$: Pipe of half bend angle φ with/without a nozzle)
(a) horizontal distribution, (b) vertical distribution

The straight pipe with a convergent nozzle has the lowest intensity level at the exit plane

Hg Flow in Target Delivery Pipe With Weld (1)

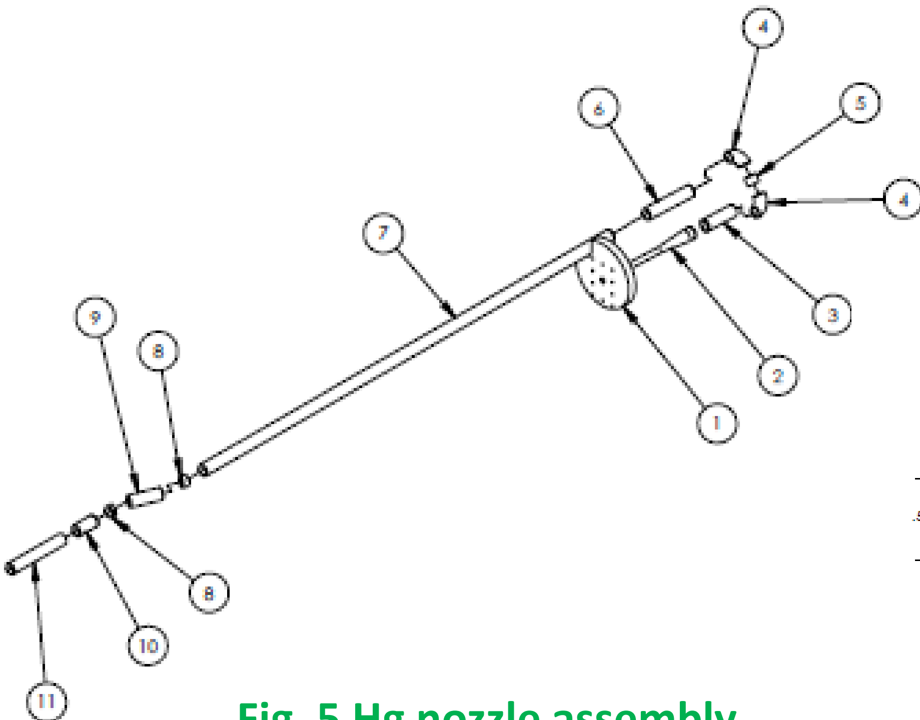


Fig. 5 Hg nozzle assembly

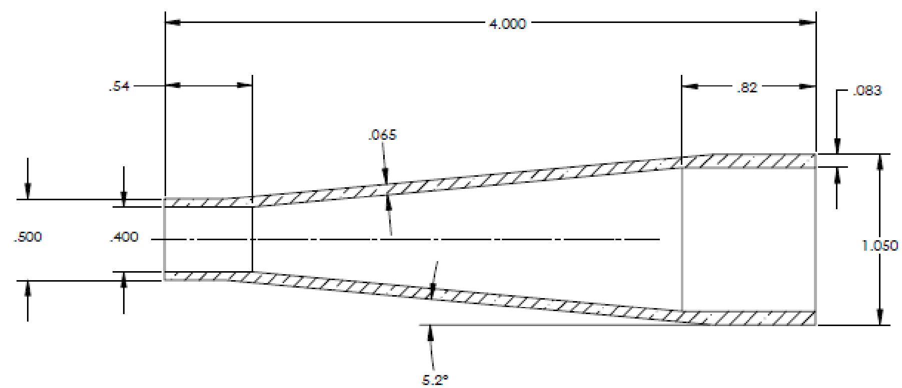


Fig. 6 Dimensions of item 2 (unit: inch)

Location of interests: welded-joint between items 2 and 3;
item 2: Ti-6Al-4V; item 3: Ti Grade 2.

Hg Flow in Target Delivery Pipe With Weld (2)

- To understand the effect of bead geometry on the turbulence level of the flow at pipe exit.
  - Flat surface
  - Whole azimuthal weld with semi-circle cross section
    - Major radius = 0.884”
    - Minor radius = 1/16”
  - Partial azimuthal weld with semi-circle cross section
    - only has 30^o of azimuth from –15^o to +15^o relative to “up”

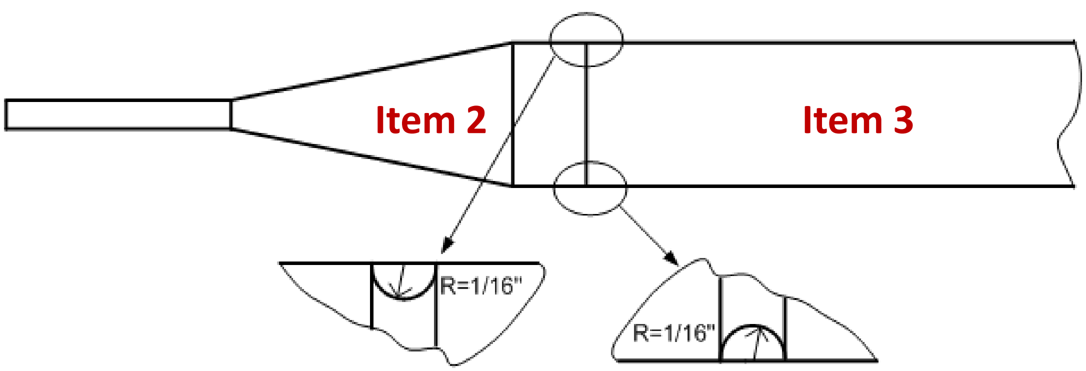


Fig. 7 The semi-circle topology of the Weld

Hg Flow in Target Delivery Pipe With Weld (3)

No. of Mesh (EWT)
mesh0: n_θ=32, n_r=65, n_z=260, n_{tot}=5.33e5
mesh1: n_θ=40, n_r=77, n_z=274, n_{tot}=8.33e5
mesh2: n_θ=48, n_r=90, n_z=294, n_{tot}=1.26e6

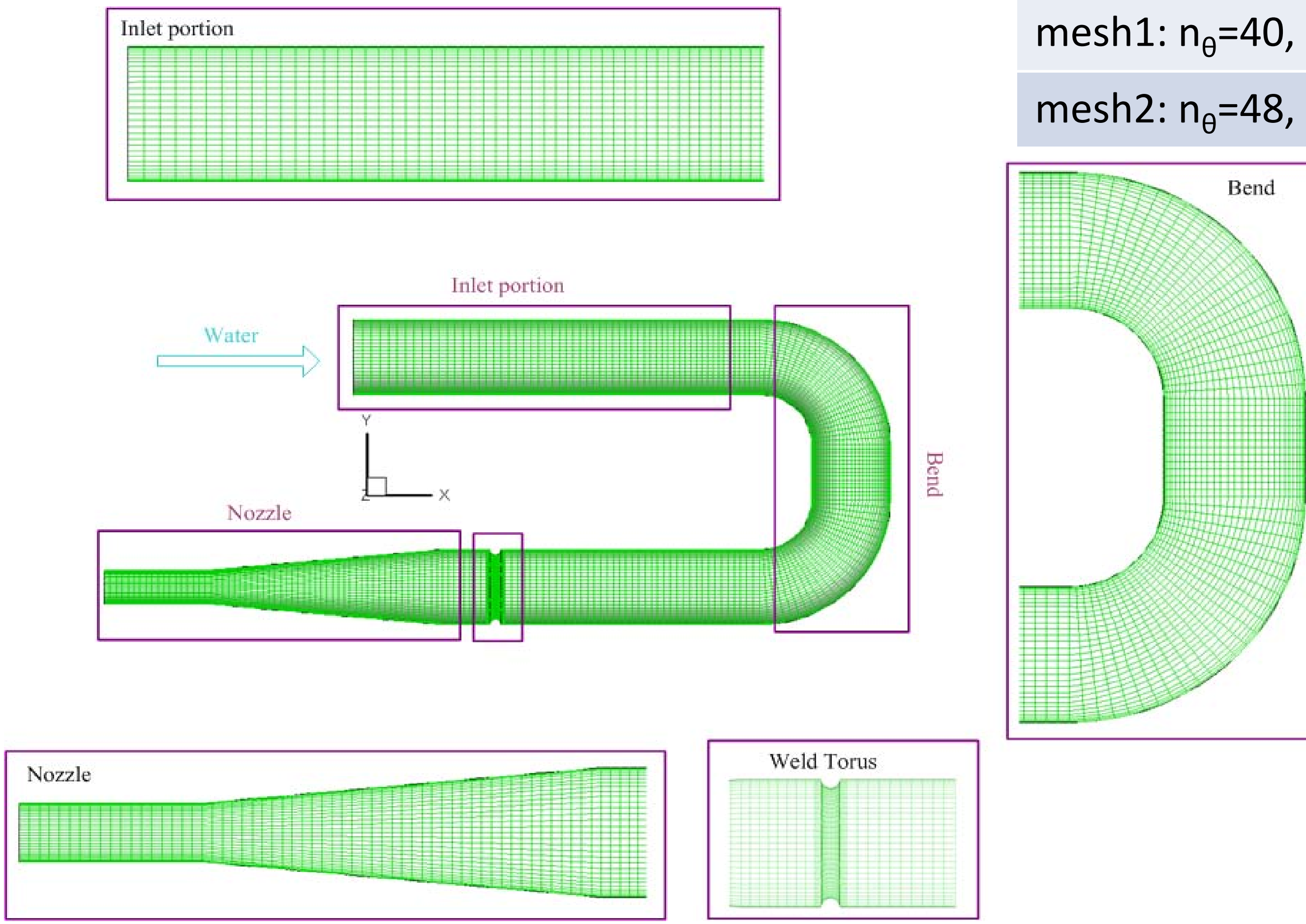
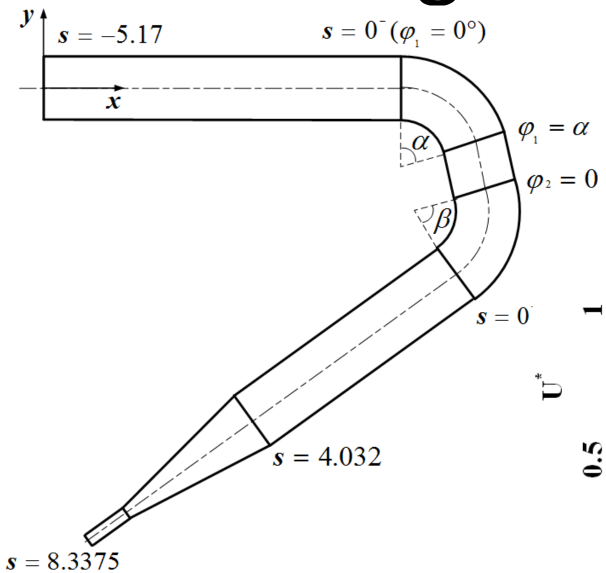


Fig. 8 Three meshes for the $90^0/90^0$ pipe

Hg Flow in Target Delivery Pipe With Weld (4)



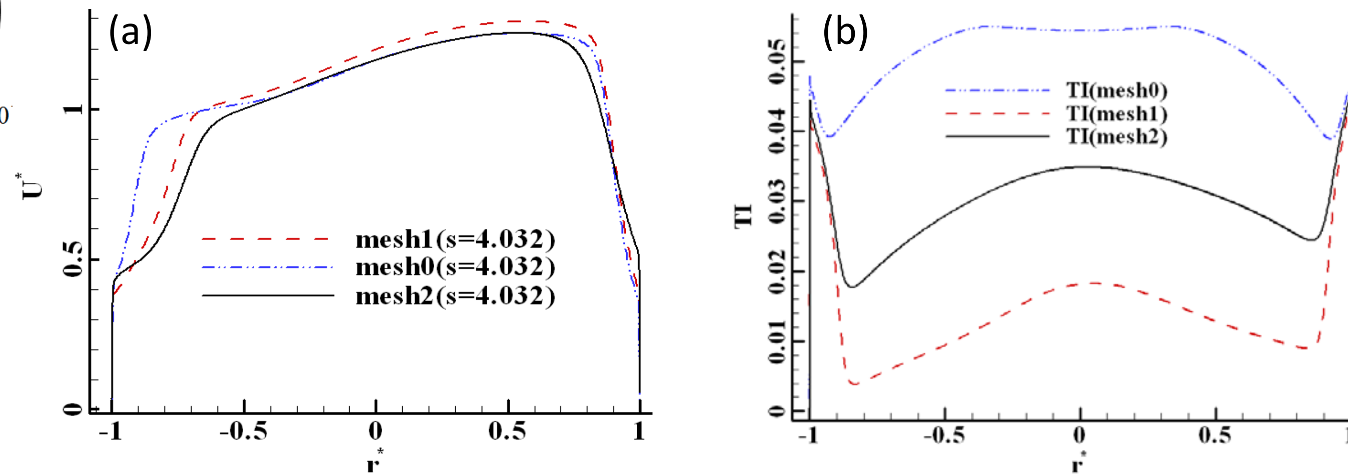


Fig. 9 Comparison among three meshes (a) U* (b) Turbulence Intensity (TI)

Next: Run FLUENT in the Feynman Cluster At Princeton University

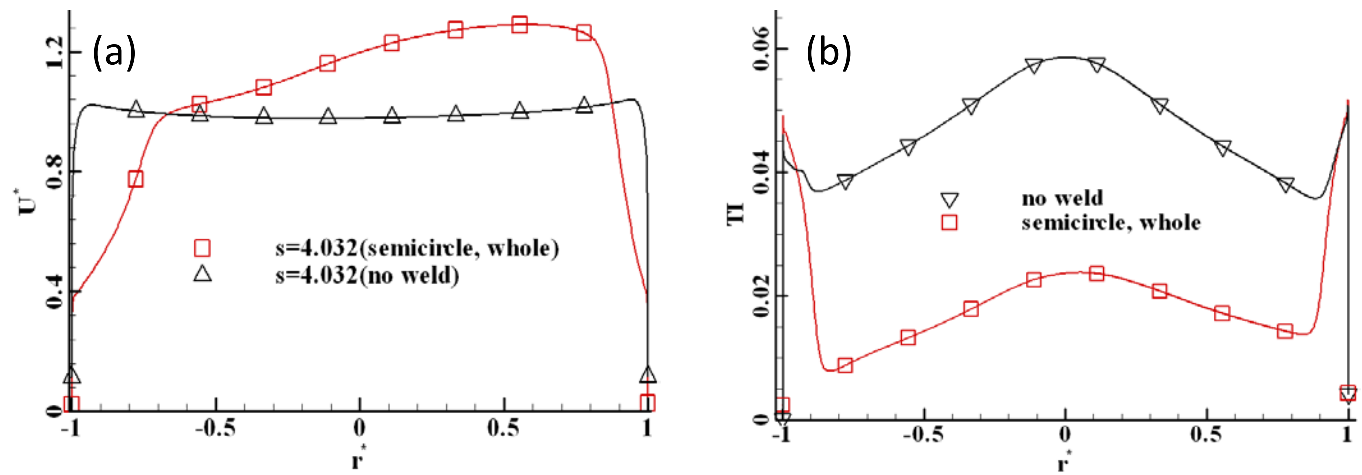


Fig. 10 Comparison for pipes with/without a weld for mesh 1
(a) U* (b) Turbulence Intensity (TI)

Jet Flow Using CLSVOF in FLUENT (1)

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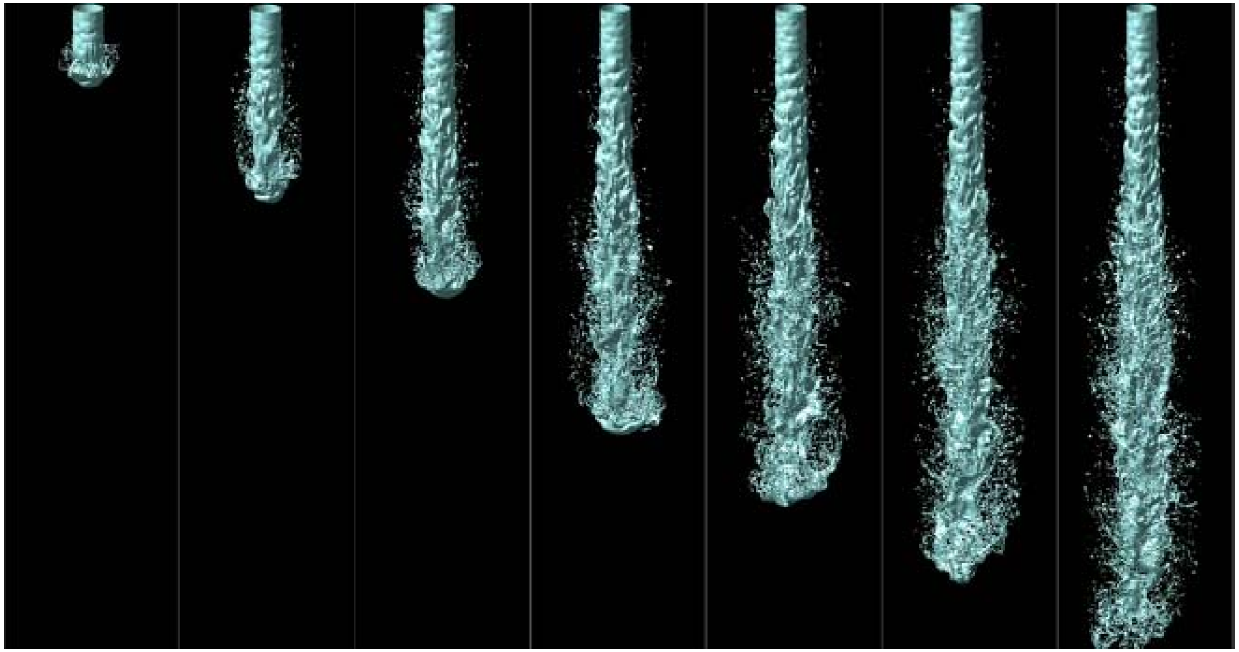

Fig. 11 (a) Development of the liquid jet (time step is 2.5 μm) (Menard, 2007)

Volume of Fluid (VOF)	
Volumetric phase fraction *F*	
Phase 1	*F=1*
Phase 2	*F=0*
Interface	*0<F<1*

Level Set (LS)	
Level-Set function *Φ*	
Phase 1	*Φ>0*
Phase 2	*Φ<0*
Interface	*Φ=0*

Jet characteristics

Diameter, D (μm)	Velocity (m s^{-1})	Turbulent intensity	Turbulent length scale
100	100	$u'/U_{liq} = 0.05$	0.1 D
Phase	**Density (kg m^{-3})**	**Viscosity (kg $m^{-1}s^{-1}$)**	**Surface tension (N m^{-1})**
Liquid	696	1.2×10^{-3}	0.06
Gas	25	1×10^{-5}	

Jet Flow Using CLSVOF in FLUENT (2)

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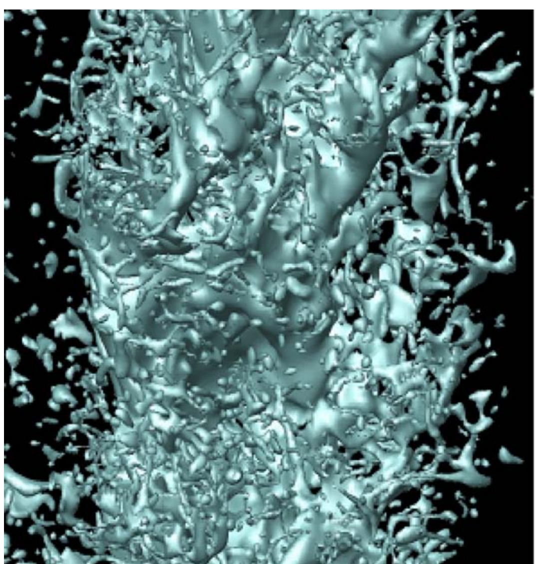
Fig. 11 (b) Liquid jet surface and break-up near the jet nozzle



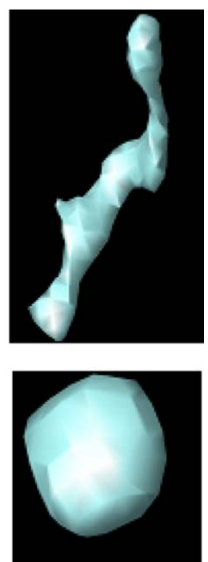


Fig. 11 (c) Liquid parcels

Jet Flow Using CLSVOF in FLUENT (4)

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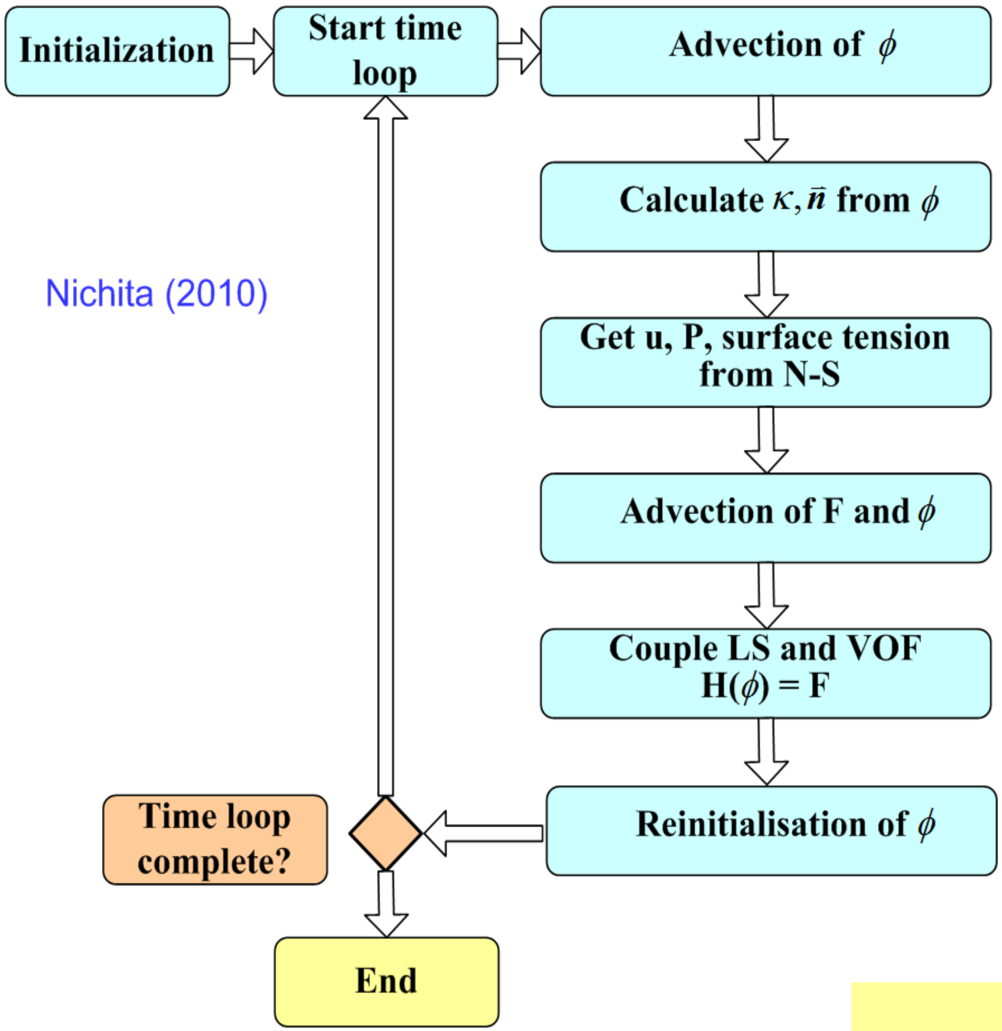
Nichita (2010)



$$\kappa = \nabla \cdot \frac{\nabla \phi}{|\nabla \phi|}, \vec{n} = \frac{\nabla \phi}{|\nabla \phi|}$$

$$\rho(U_t + U \cdot \nabla U) = -\nabla P + \nabla \cdot (2\mu D) - \gamma \kappa \nabla H + G$$

$$\phi_t + U \cdot \nabla \phi = 0 \qquad F_t + U \cdot \nabla F = 0$$

$$F_{ij} = \frac{1}{|\Omega_{ij}|} \int_{\Omega_{ij}} (H\phi) d\Omega_{ij}$$

$$\phi_t + \omega \cdot \nabla \phi = S(\phi^0), \quad \text{where } \omega = S(\phi^0) \frac{\nabla \phi}{|\nabla \phi|}$$

$$\rho = \rho_g (1 - H) + \rho_l H, \mu = \mu_g (1 - H) + \mu_l H$$

$$H(\phi) = \begin{cases} 0 & \text{if } \phi < -\varepsilon \\ (\phi + \varepsilon)/(2\varepsilon) + \sin(\pi\phi/\varepsilon)/(2\pi) & \text{if } |\phi| < \varepsilon \\ 1 & \text{if } \phi > \varepsilon \end{cases}$$

B. A. Nichita, 2010, An improved CFD tool to simulate adiabatic and diabatic two-phase flows

Jet Flow Using CLSVOF in FLUENT (5)

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Finite Volume Discretization of Level Set Equation

$$\phi_t + \nabla \cdot (U\phi - D_T \nabla \cdot \phi) = 0$$

where $D_T = 0.129\bar{k}^2 / \varepsilon$

- Temporal Term ϕ_t

  3rd order TVD R-K (total variation diminishing Runger-Kutta)

- Convective Term $\nabla \cdot (U\phi)$

  3rd order ENO (Essentially Non-Oscillatory)

- Diffusive Term $\nabla \cdot (D_T \nabla \cdot \phi)$

  2nd Central Difference