Multiphase Flow in Metering Systems

ADVANCED MODELLING & SIMULATION – AMS –

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Model Applications (1)

PHASE CHANGE/INVERSION IN COMPRESSIBLE MULTIPHASE FLOW:

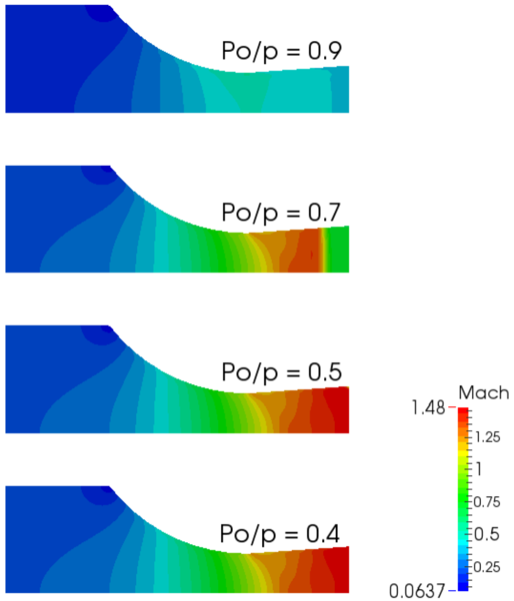
- Choking of multiphase flow in a nozzle
- Flashing of multiphase flow in a throat
- Condensation induced shocks
- Condensing high-speed shocking jets

Choking of multiphase flow nozzle

DESIGN AND SAFETY

Single phase (well known)

- Steam chokes at a pressure ratio of 0.7, but recovers through a normal shock
- At a pressure ratio of 0.5 and 0.4 the flow is overexpanded



Multiphase critical flow in a nozzle

- Depends on assumptions on thermal equilibrium or frozen flow
- Practical cases are in between frozen and equilibrium
- Choking is based on mixture sound speed
- Effect of multicomponent flow
- Effect of different geometries is not characterized very well
- Very important flow phenomenon in many different industries

Choking of multiphase flow nozzle

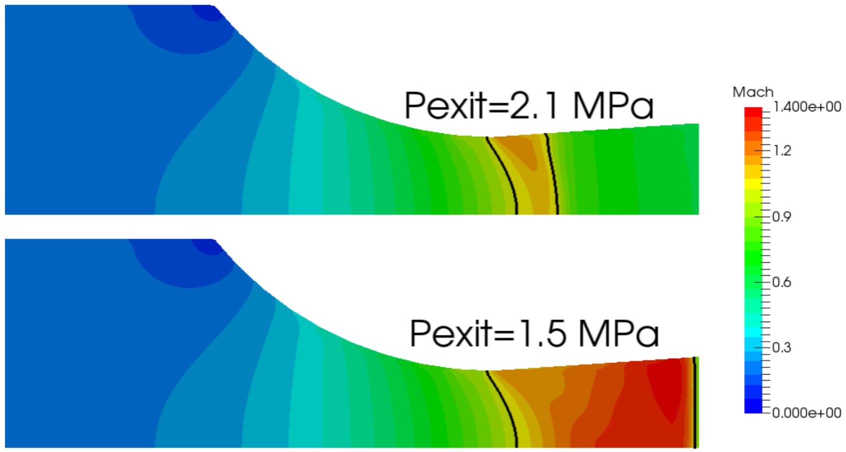
INLET VOID FRACTION 0.65 (HIGH)

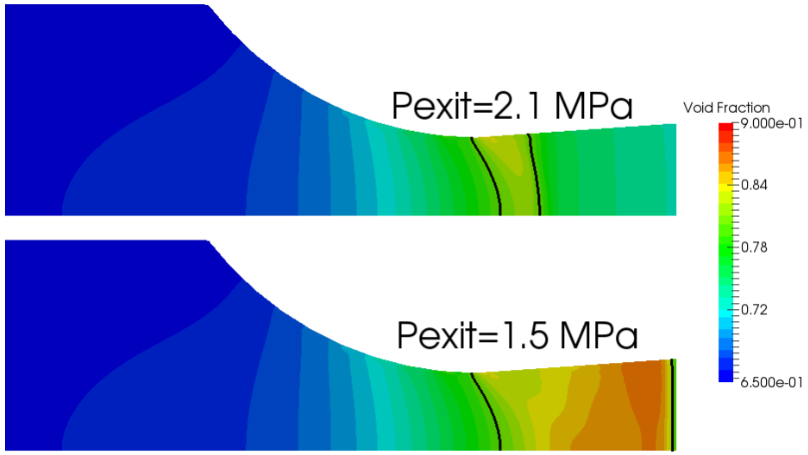
Water-steam system

- Inlet P_0, T_0: 3 MPa, 507 K
- Effect of inlet void fraction
  - High void fraction: 0.65
  - Low void fraction: 0.1

High void fraction behaves similar to single phase vapour flow:

- Flow is choked at a p_{ratio} of 0.7
- Not fully expanded at p_{ratio} of 0.5
- Void fraction increases due to boiling





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Choking of multiphase flow nozzle

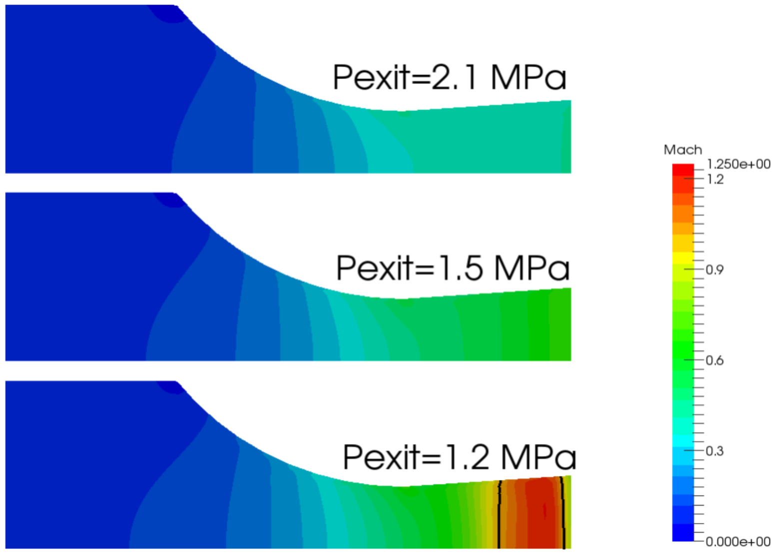
INLET VOID FRACTION 0.1 (LOW)

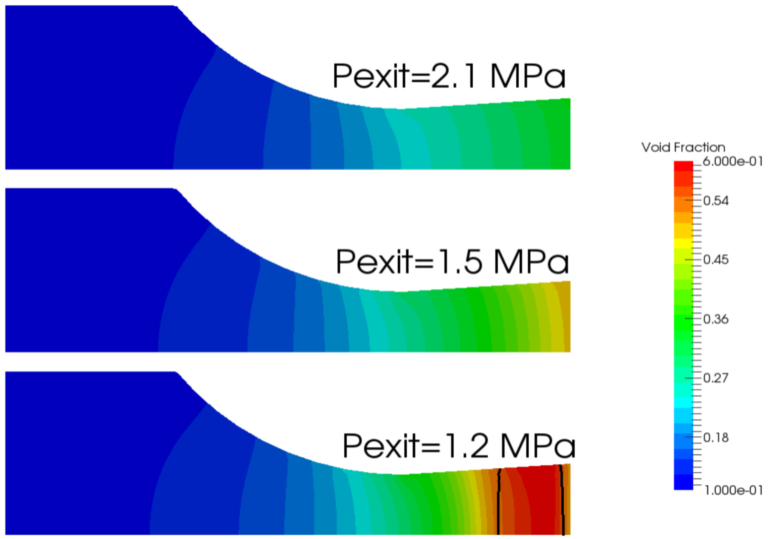
Water-steam system

- Inlet P_0, T_0: 3 MPa, 507 K
- Effect of inlet void fraction
  - High void fraction: 0.65
  - Low void fraction: 0.1

Low void fraction critical flow is much delayed

- Flow is choked at a p_{ratio} of 0.4 (1.2 MPa)
- Void fraction increases due to boiling
- Mixture sound speed is much lower than vapour sound speed
- Velocity is therefore lower for M = 1





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Flashing of multiphase flow in a throat

SUPER MOBY DICK BENCHMARK

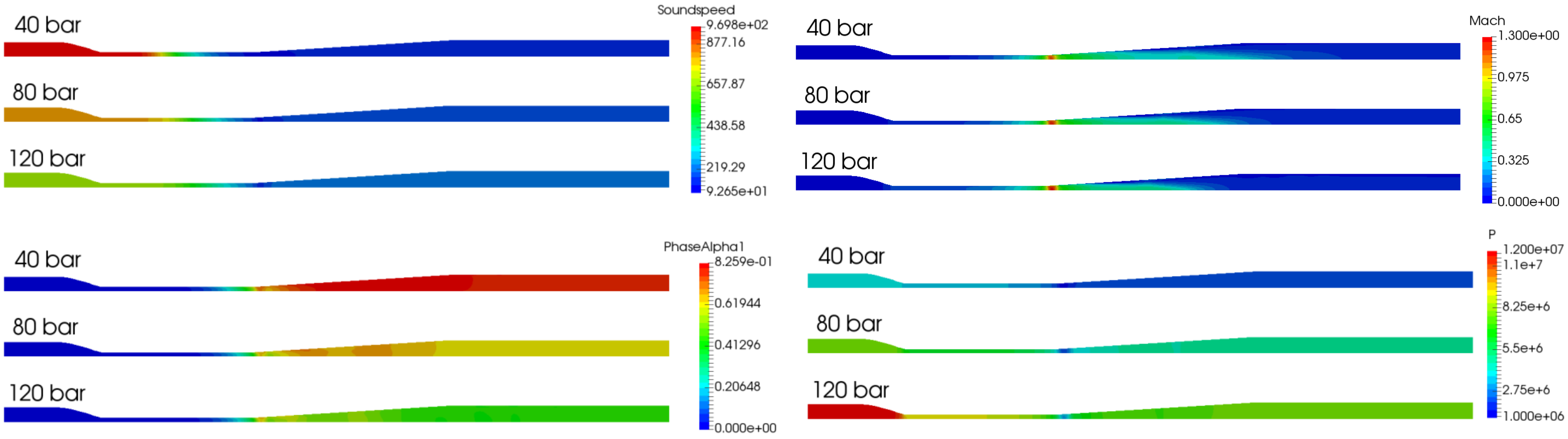
- Ref. Rousseau, Multiphase Sc. Tech. (1987)
- $P_{0,inlet}$ = 40, 80 and 120 bar
- Mass flow: 10, 17 and 20kg/s
- 7% divergence section case
- Inlet is around 15-20° subcooled
- Saturation pressure is higher than P_{out}
- Liquid density decreases with pressure
- Vapour density increases with pressure

P inlet (bar)	T inlet (K)	P out (bar)	Psat (T_{in}) (bar)	Density (L) (kg/m³)	Density (V) (kg/m³)	Tsat (P_{in}) (K)
40	513.65	23	33.76	779	16	523.51
80	551.65	48	62.74	706	31	568.16
120	578.85	77	92.99	642	48	597.83

Non-equilibrium multiphase model

- Each phase has separate EoS.
- Phases can be in metastable states (Superheated liquid; Subcooled vapour)
- Thermodynamic effects in the cavitation model are significant.
- Typical cavitation models ignore the latent heat and variation in C_p.

Flashing of multiphase flow in a throat



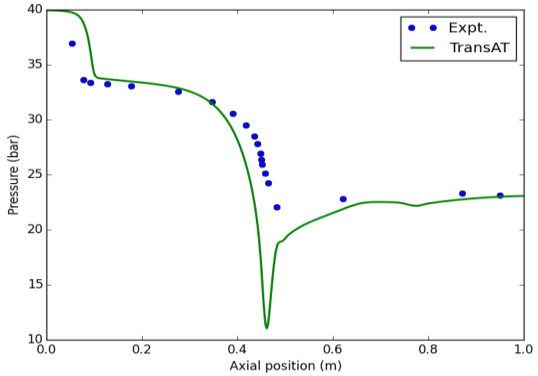
Flashing of multiphase flow in a throat

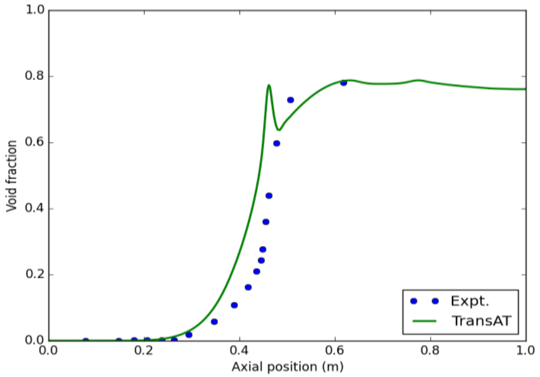
RESULTS: MASS FLOW RATES & PRESSURE RECOVERY.

Compressible
Variable P_{sat}, C_p, Latent heat

Case	Mass flow rate (kg/s)	
	Expt	TransAT
		$n_b = 5.10^2$
40B240C	10.3	9.65
80B276C	16.8	15.29
120B305C	19.6	18.27
	Error	~7-9%

- Mass flow rates are well predicted





- The void fraction evolution is well captured.
- P sharply reduces in the throat and recovers with a shock.

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Condensation induced shocks

ASHRAE RESEARCH PROJECT

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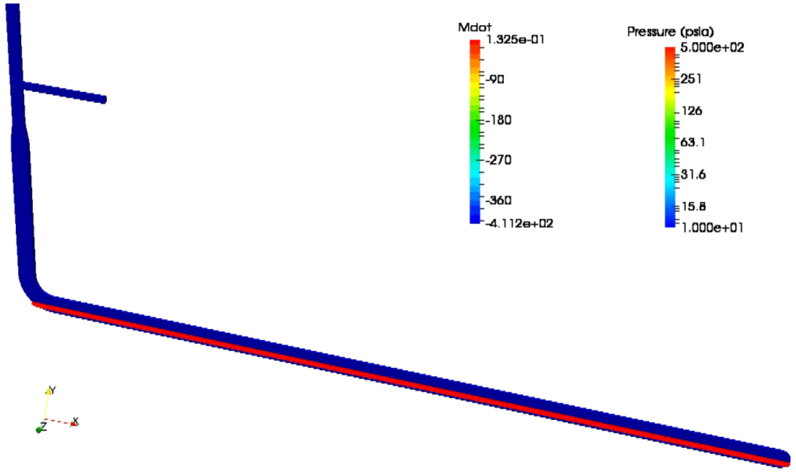
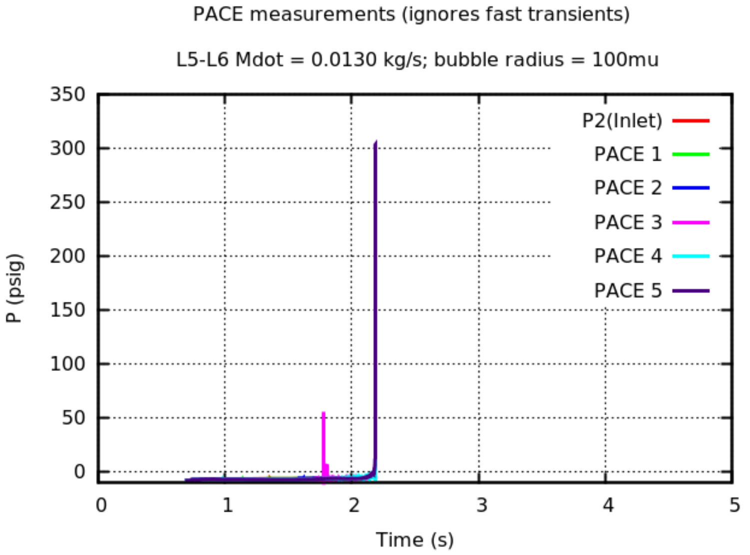
- Slug forms due to inflow of vapour and condensation of vapour on cold liquid interface
- Compression of trapped vapour results in fast condensation and Shock formation
- Shock formation is a big risk in commercial refrigeration systems





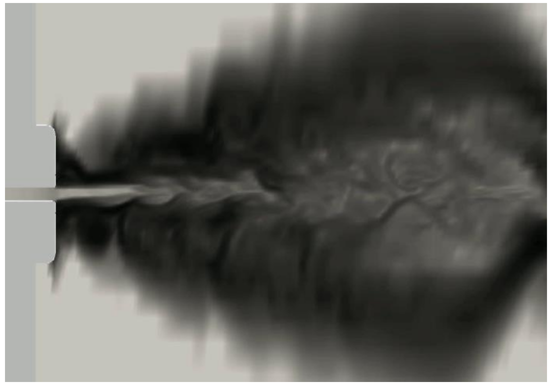
Modelling:

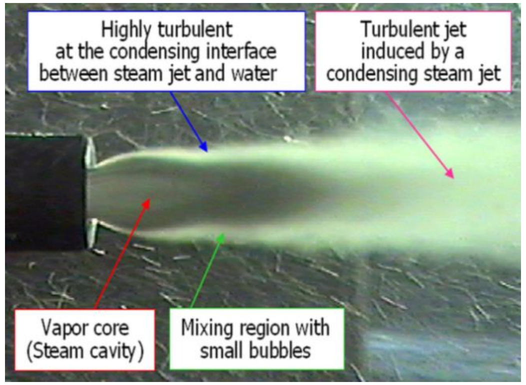
- Compressible two-phase mixture model
- Specific properties for Ammonia liq. & vapour
- Variable T_{sat} vs. pressure
- Mass transfer model

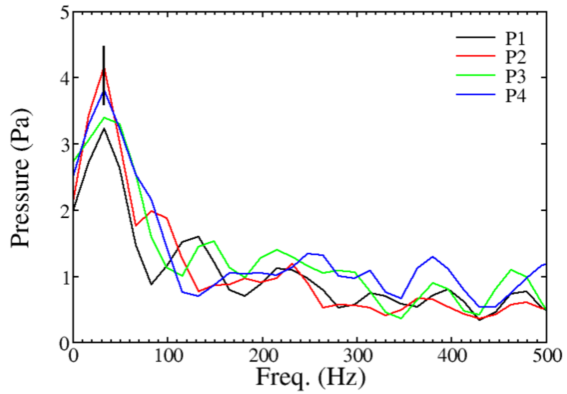
Condensing steam jet in a pool

KEPCO (KOREA) PROJECT

- Highly underexpanded compressible steam jet in cold water.
- Steam jet expansion through oblique shock waves.
- Steam condensation.
- Effect of phase change on pressure wave sound speed.
- Predict pressure fluctuation due to condensing steam jet.

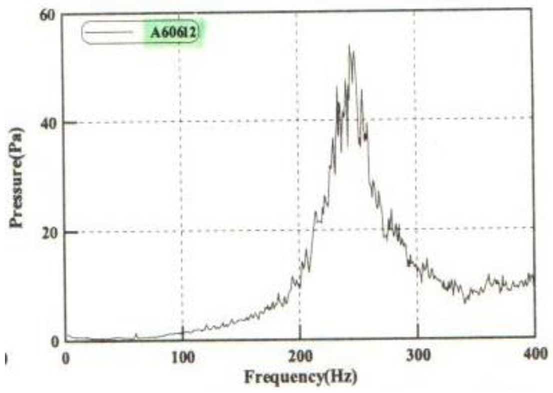






- Mass-flux 600 kg/m^2s
- 10 mm diameter jet
- Inlet velocity: 500 m/s
- Water Saturated (100^{o}C)
- Large-eddy Simulation

Exp.: S.J. Hong (2001) →



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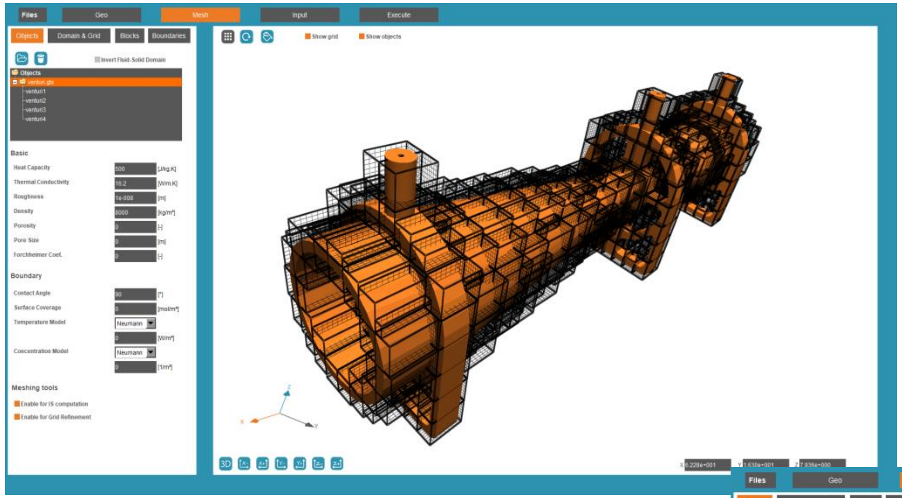
Model Applications (2)

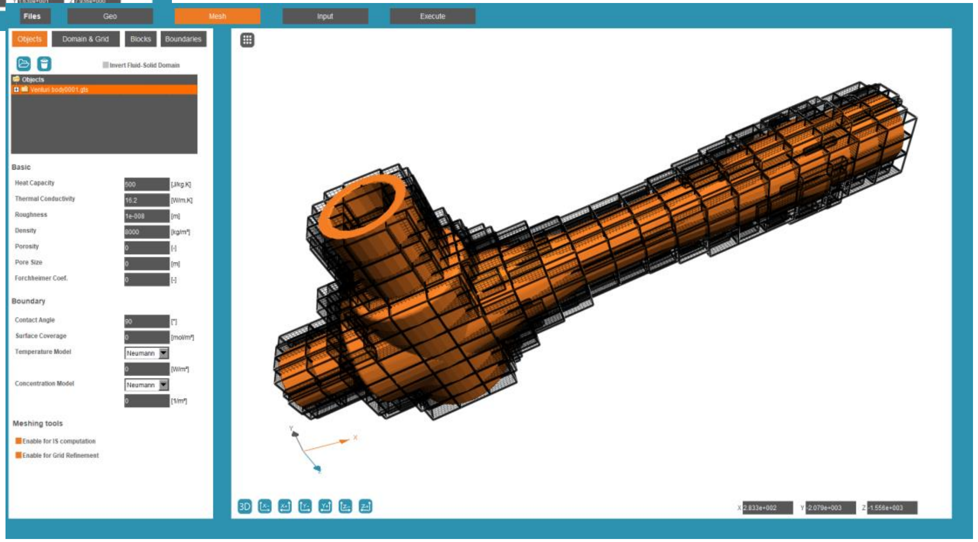
MULTIPHASE FLOW IN FLOW-METERING SYSTEMS:

- Setup and meshing in TransAT
- Bubbly flow in a Venturi tube
- Bubbly flow in a tube with a V-cone
- Flow past bluff body in a stratified free-surface flow

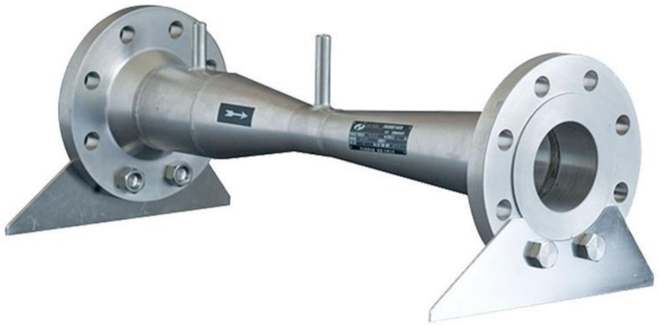
Setup & meshing in TranSAT

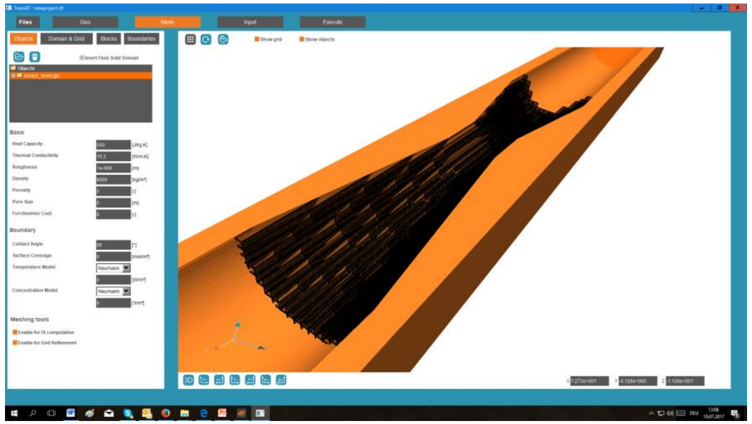
MESHING USING TRANSAT IS A 10M TASK

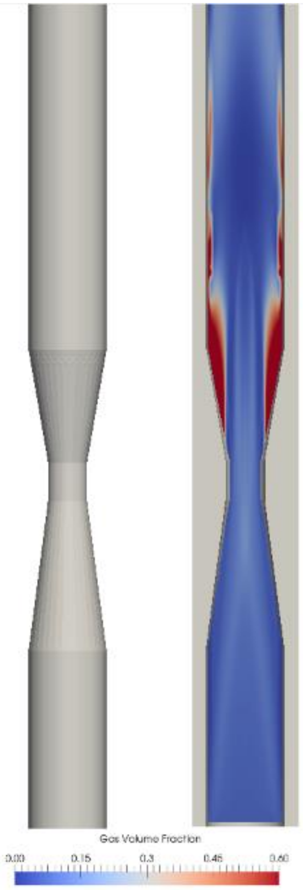


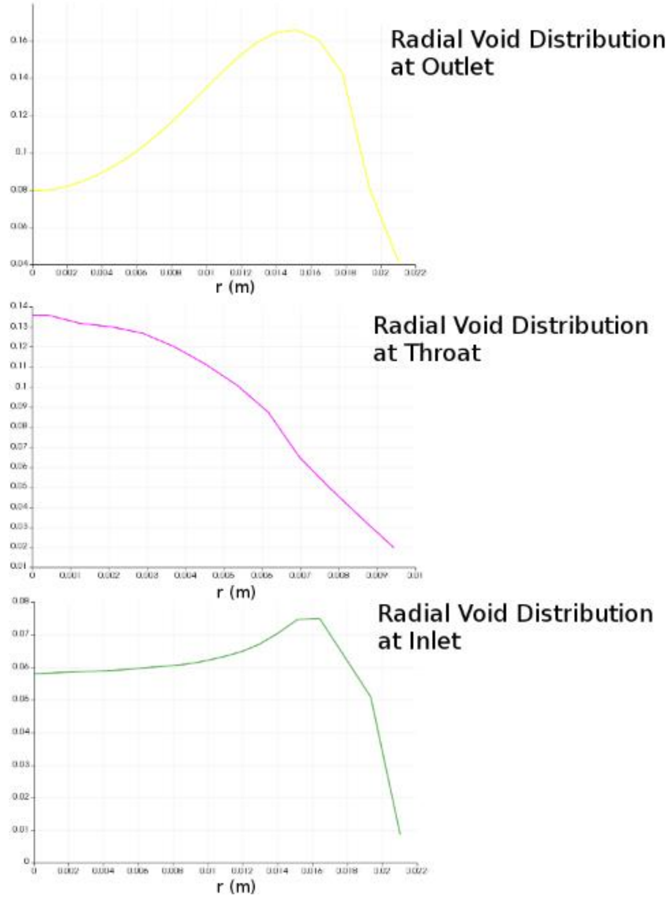


Bubbly flow in a Venturi flowmeter

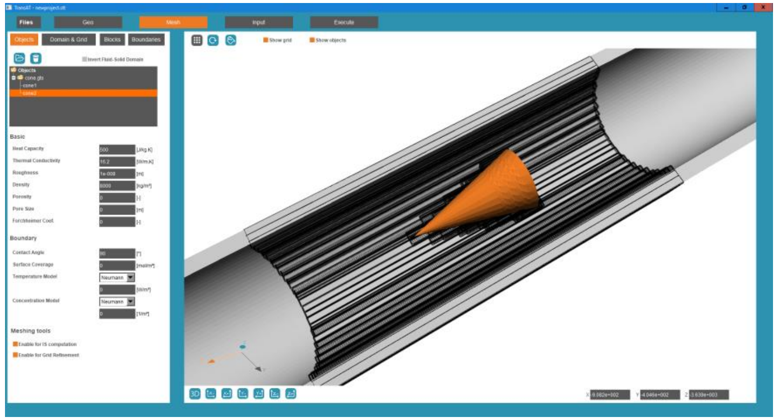


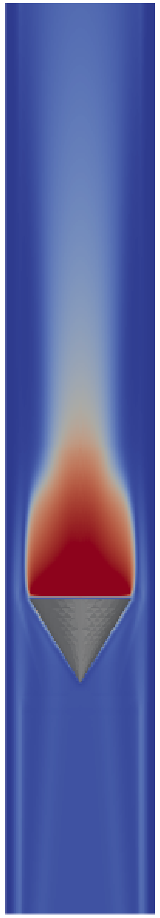


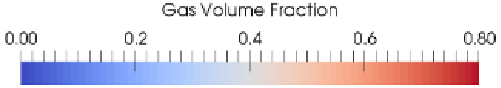


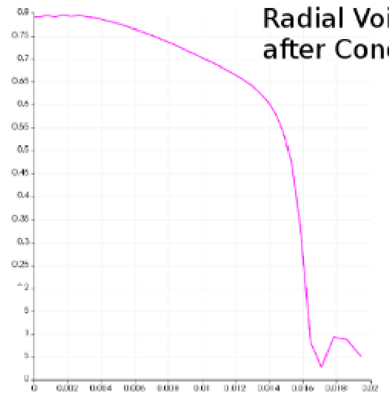


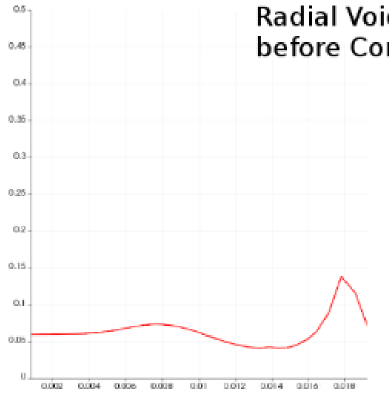
Bubbly flow in V-Cone flowmeter











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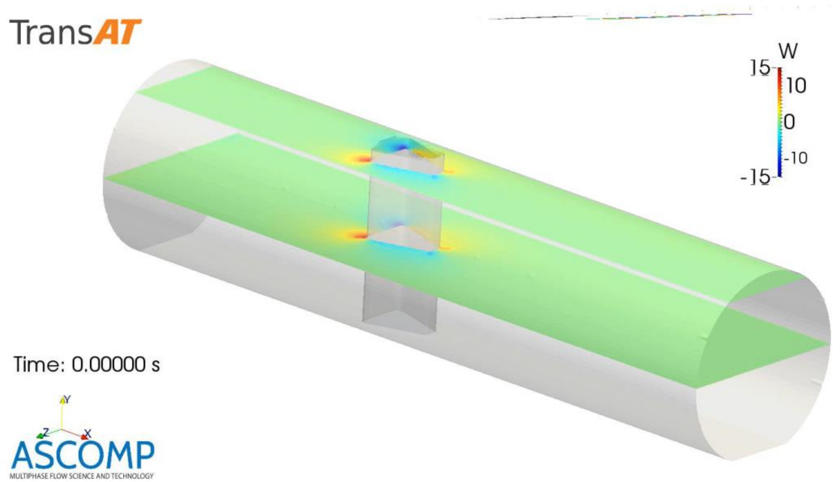
Bluff-body in stratified flowmeter

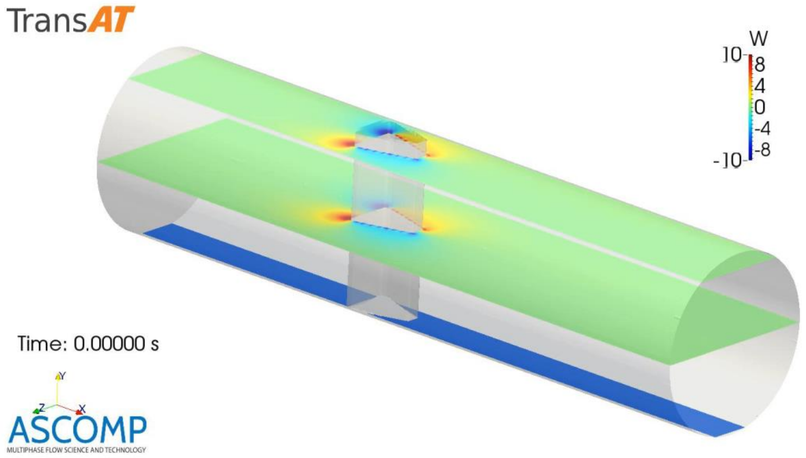
FLOW OVER BLUFF BODY

Click on videos to play



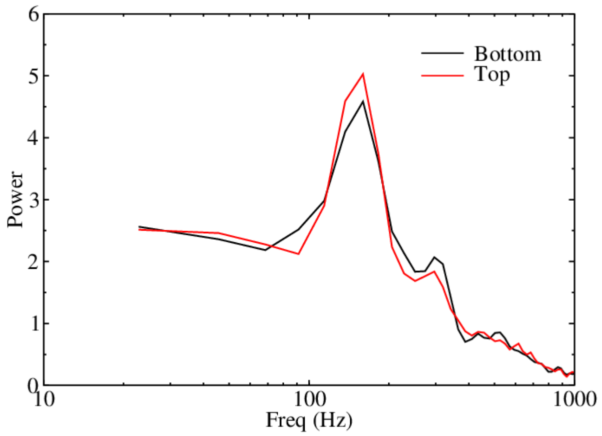
Liquid film treated as a solid wall

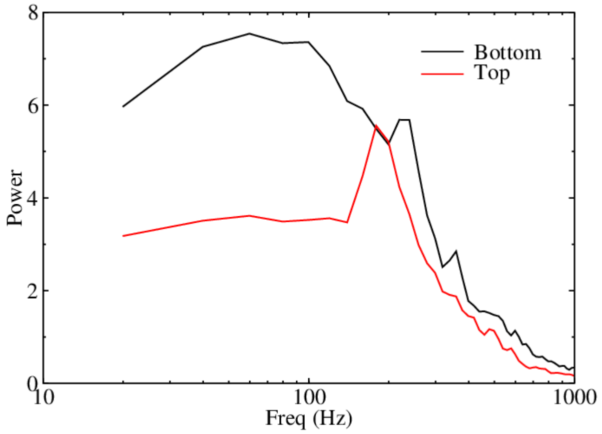
Liquid film simulated using VOF method

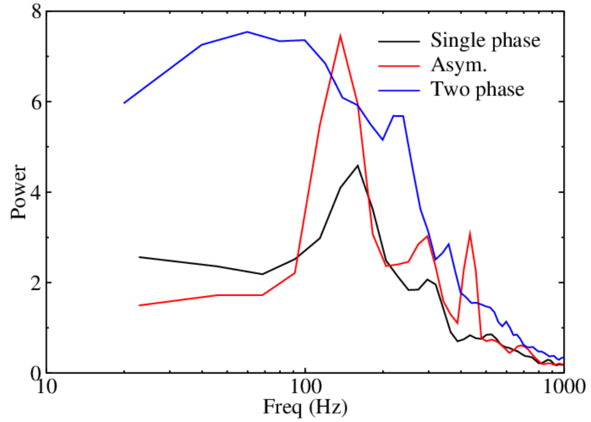


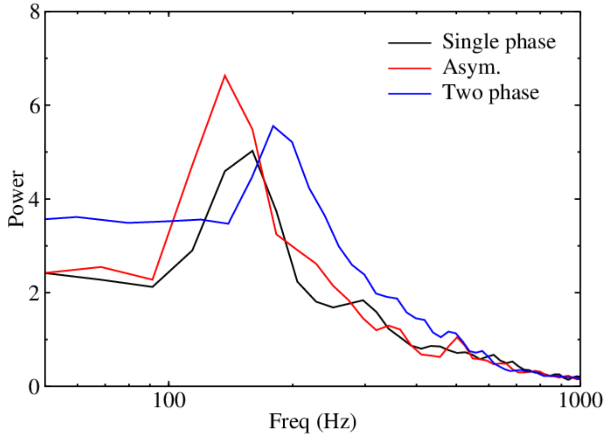
Bluff-body in stratified flowmeter

FLOW OVER BLUFF BODY









Signal at the bottom probe

Signal at the top probe

Single phase: 159 Hz
Two phase: 179 Hz

D = 13 mm
V = 10 m/s
St = 0.21, 0.18, 0.23

Making Future

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