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CFD Jet Mixing Model Validation against Zero-Boil-Off Tank (ZBOT) Microgravity Experiment

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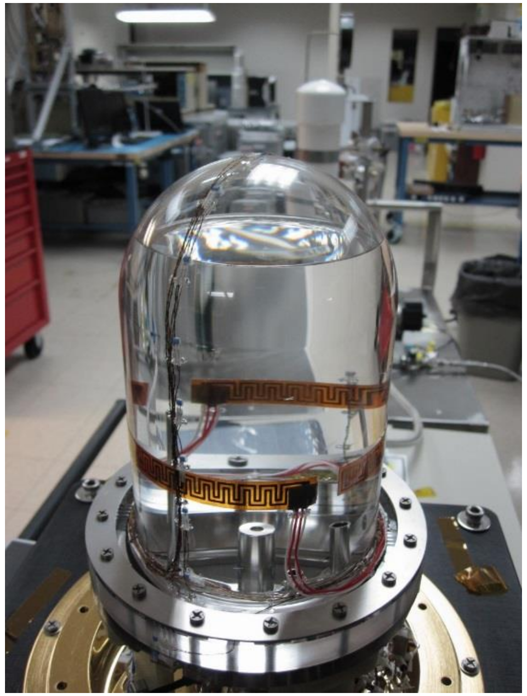
Outline

- Experiment description
- Computational model description
- Results
  - Parametric Studies
  - 70% fill level
    - 6 cm/s jet speed
    - 10 cm/s jet speed
    - 25 cm/s jet speed
  - 90% fill level
    - 4 cm/s jet speed
    - 10 cm/s jet speed
    - 25 cm/s jet speed
- Conclusions

ZBOT Experimental Setup

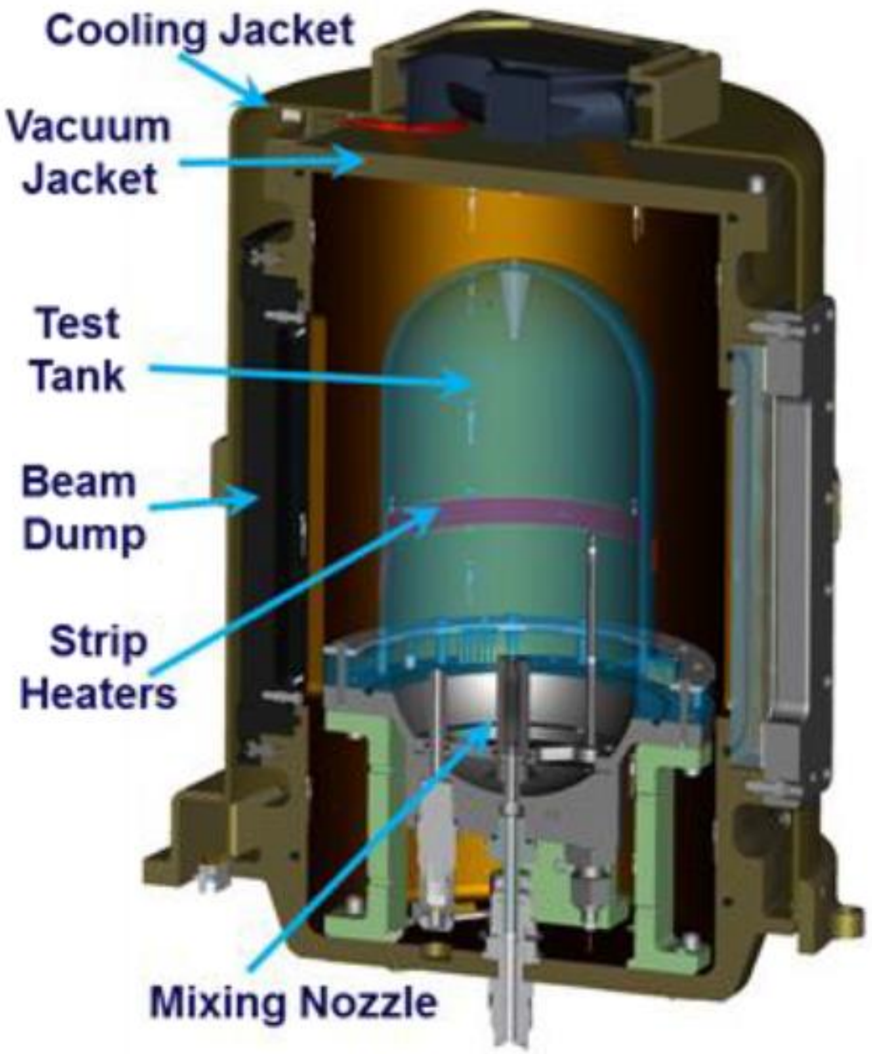


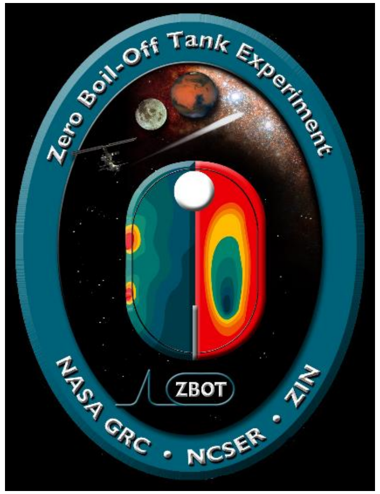
Simulant fluid Zero Boil-Off Tank (ZBOT) microgravity experiment conducted aboard the International Space Station (ISS) in September-December 2017

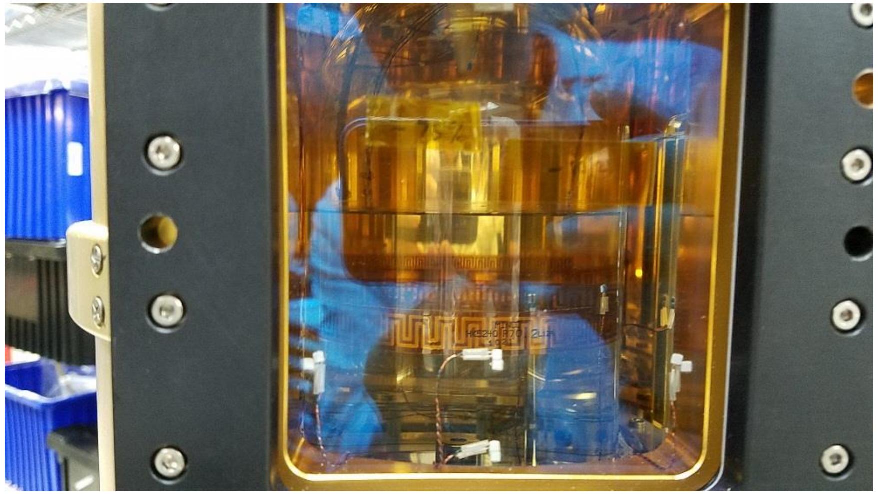
Small tank: Inside D = 4 in
Simulant fluid: perfluoro-n-pentane

Types of tests at different fill levels (70, 80 and 90%):
Self-Pressurization (tank heater, vacuum jacket heating or both)
Jet Mixing (4, 6, 10, 15, 20 and 25 cm/s)
Subcooled Jet Mixing (T0-1, T0-2 and T0-4)

Types of data collected:
Pressure and temperature evolutions, white light images, DPIV images







Computational Model Description

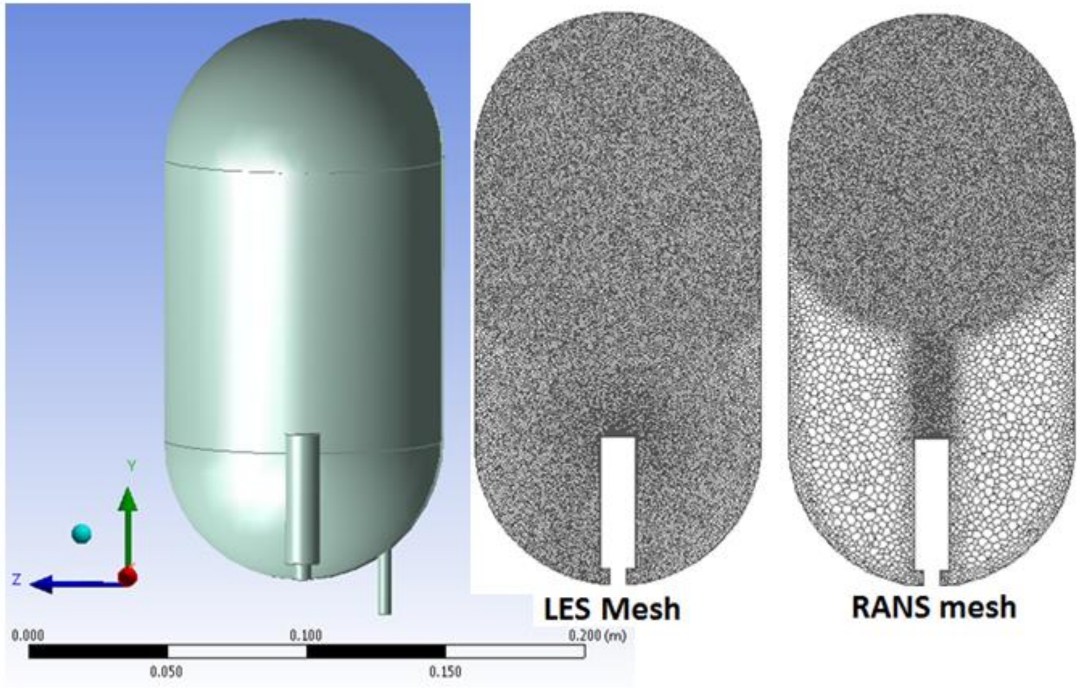
- Simulations performed using ANSYS Fluent version 19
- **3D** geometry was modeled
- Compressible ideal gas
- Surface tension effects via Continuum Surface Force method of Brackbill et al.
- Contact angle 0°

RANS

- Second Order Upwind scheme was used for discretization of the Energy, Momentum and Turbulence equations (cell values)
- PISO scheme was used for the Pressure-Velocity coupling (cell values)
- Least Squares Cell Based scheme was used for the gradient calculations (face values)
- Body Force Weighted scheme was used for the Pressure interpolation (face values)
- Point Implicit (Gauss-Seidel) linear equation solver with Algebraic Multi-Grid (AMG) method was used for solving linearized systems of equations
- First Order Implicit temporal discretization was used with explicit VOF model (Δt = 1e-2 s)

LES

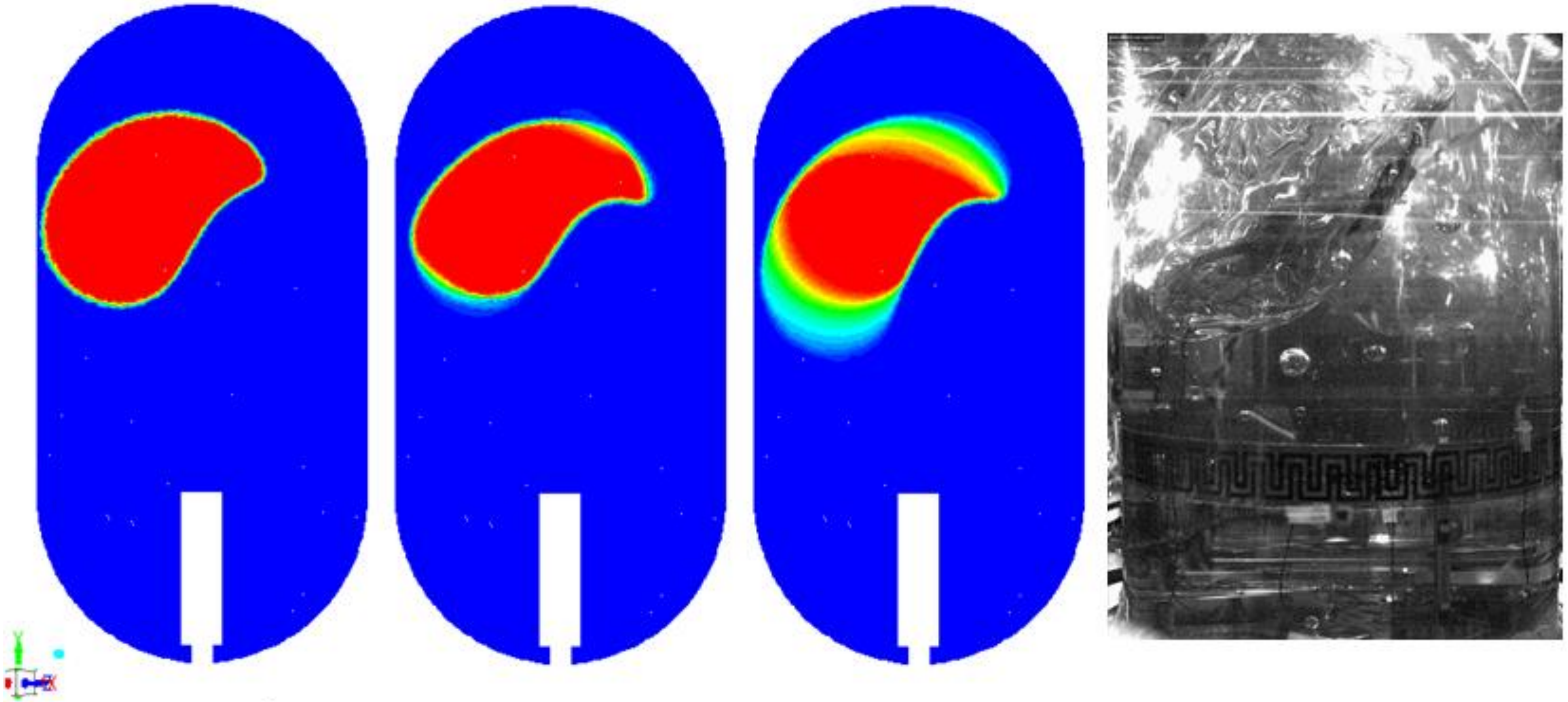
- Bounded Central Differencing scheme was used for discretization of the Momentum equation (cell values)
- Second Order Upwind scheme was used for discretization of the Energy equation (cell values)
- PISO scheme was used for the Pressure-Velocity coupling (cell values)
- Least Squares Cell Based scheme was used for the gradient calculations (face values)
- Body Force Weighted scheme was used for the Pressure interpolation (face values)
- Point Implicit (Gauss-Seidel) linear equation solver with Algebraic Multi-Grid (AMG) method was used for solving linearized systems of equations
- First Order Implicit temporal discretization was used with explicit VOF model (Δt = 5e-4 s)
- Geometric Reconstruction VOF discretization scheme



Cases modeled

Jet Speed	Fill Level: 70%	Fill Level: 90%
4 cm/s		260
6 cm/s	9	
10 cm/s	24	254
25 cm/s	27	258

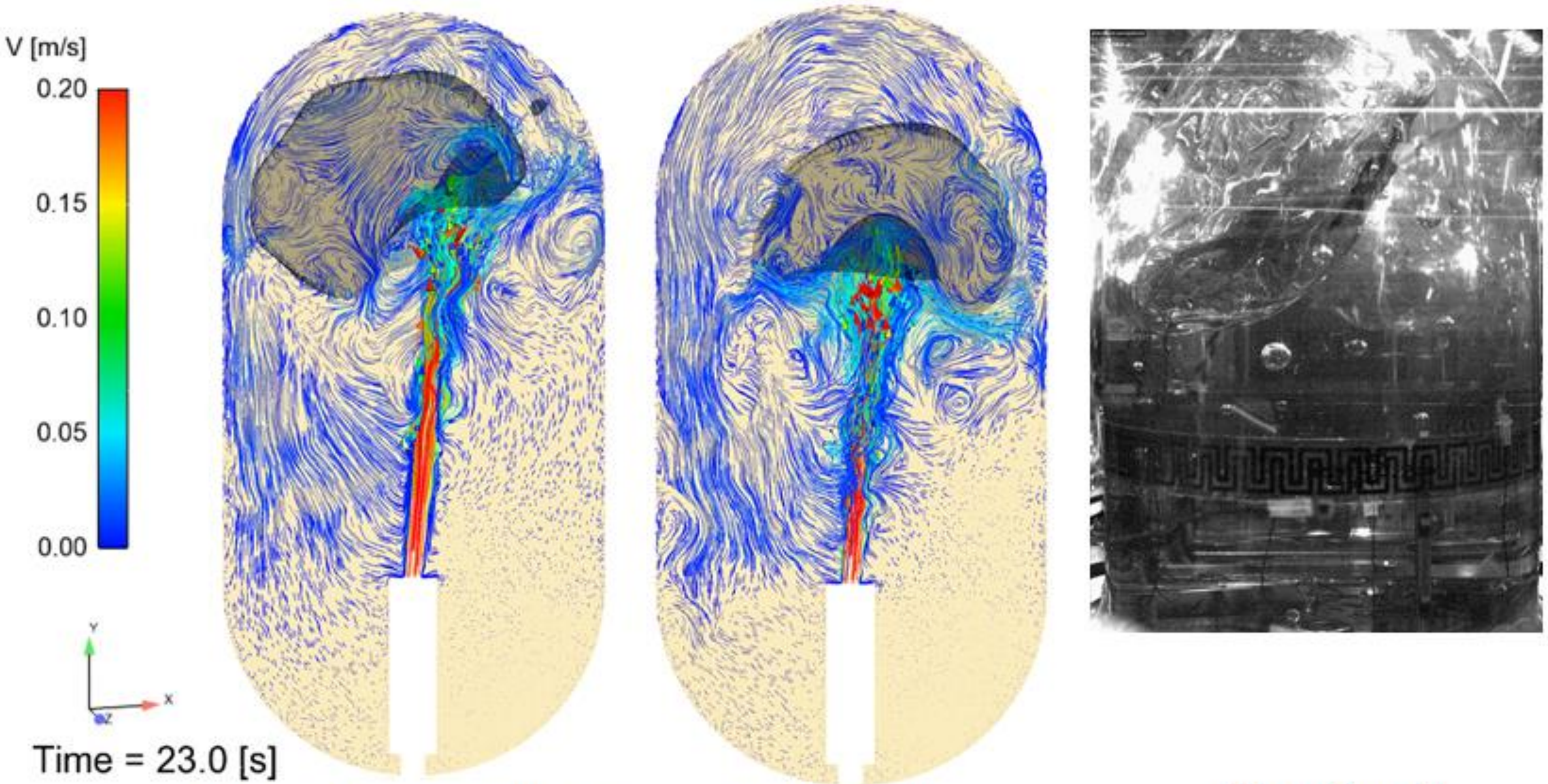
Parametric Studies: Effect of VOF discretization scheme



Geometric Reconstruction | Compressive | Modified HRIC | Experiment

RANS

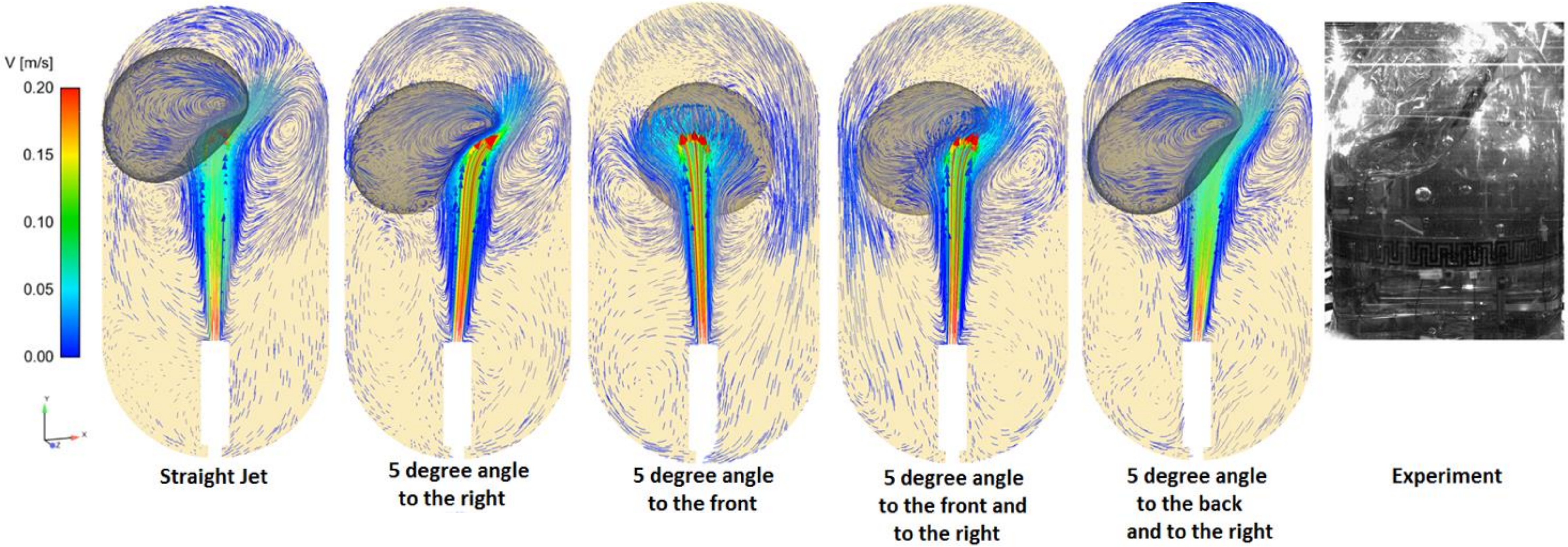
Parametric Studies: Effect of VOF discretization scheme



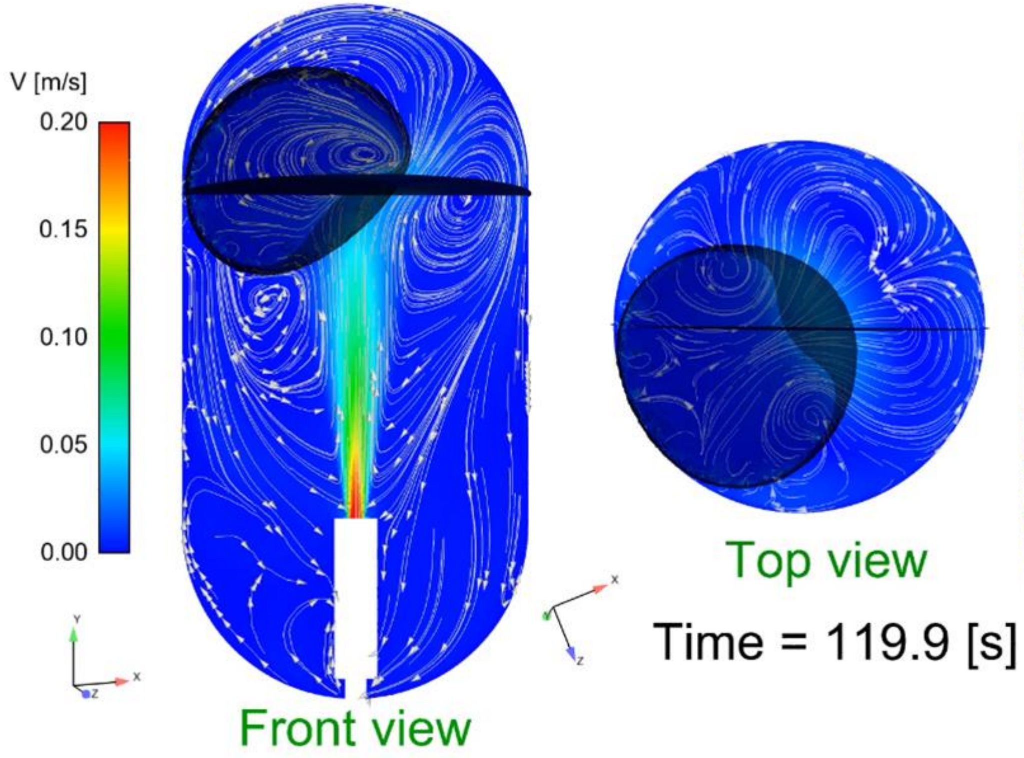
Geometric Reconstruction | Compressive | Experiment

LES

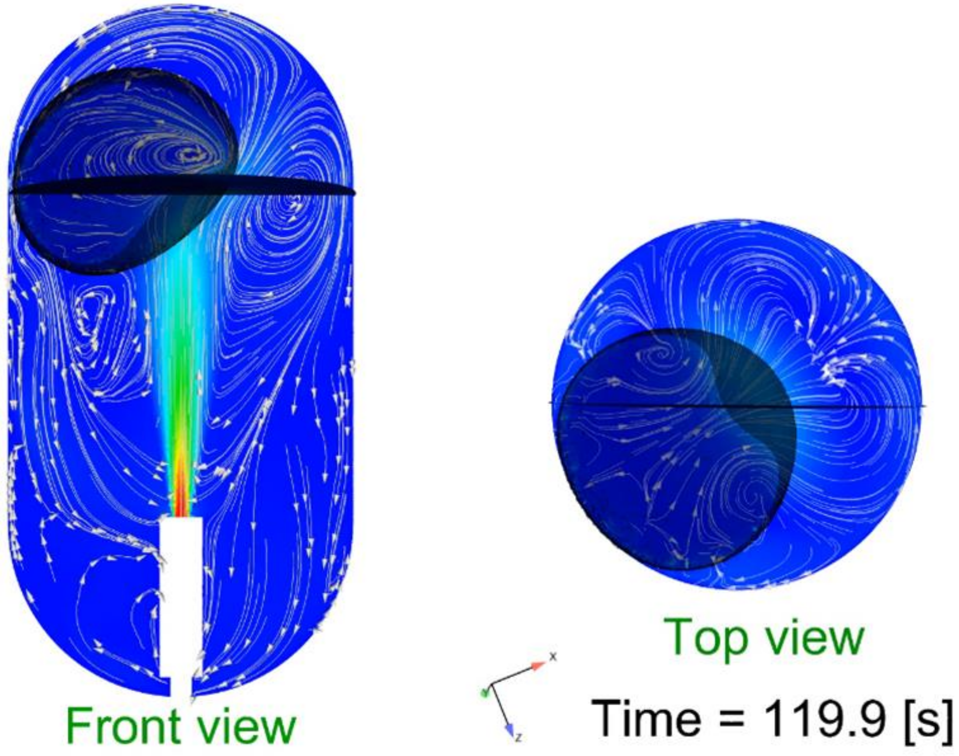
Parametric Studies: Effect of jet orientation



Parametric Studies: Effect of gravity

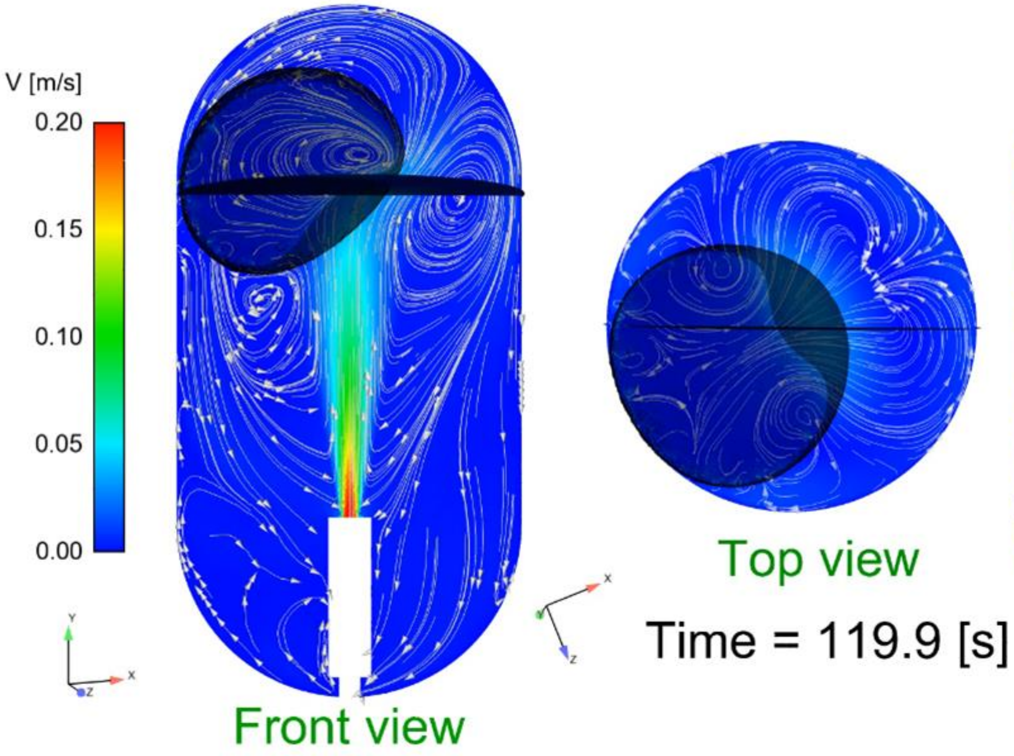


Nominal (measured) gravity

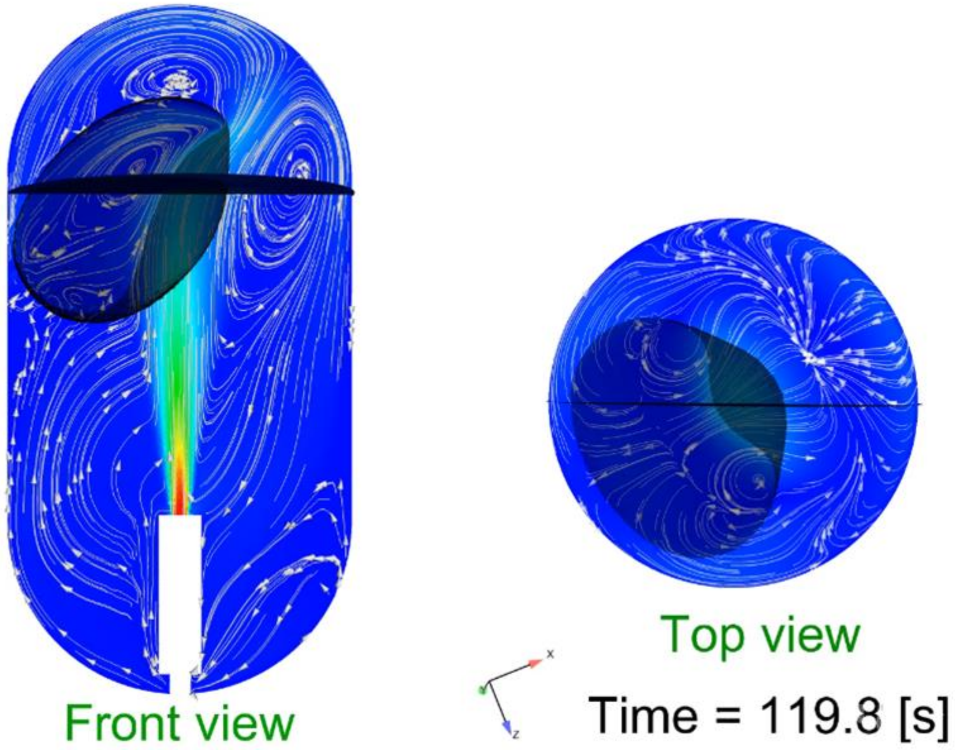


10 x Nominal (measured) gravity

Parametric Studies: Effect of surface tension



Nominal Surface Tension

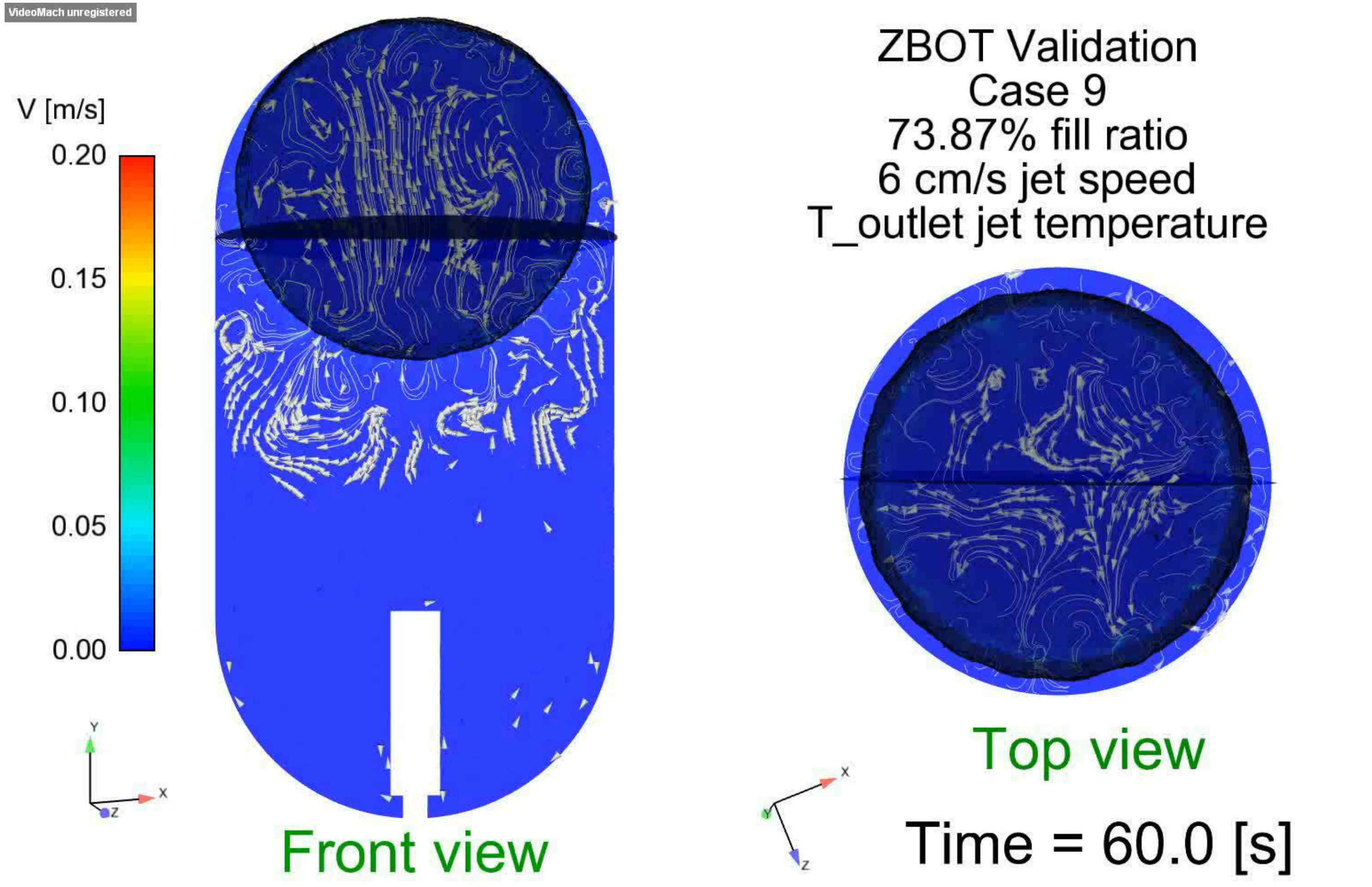


2 x Nominal Surface Tension Value

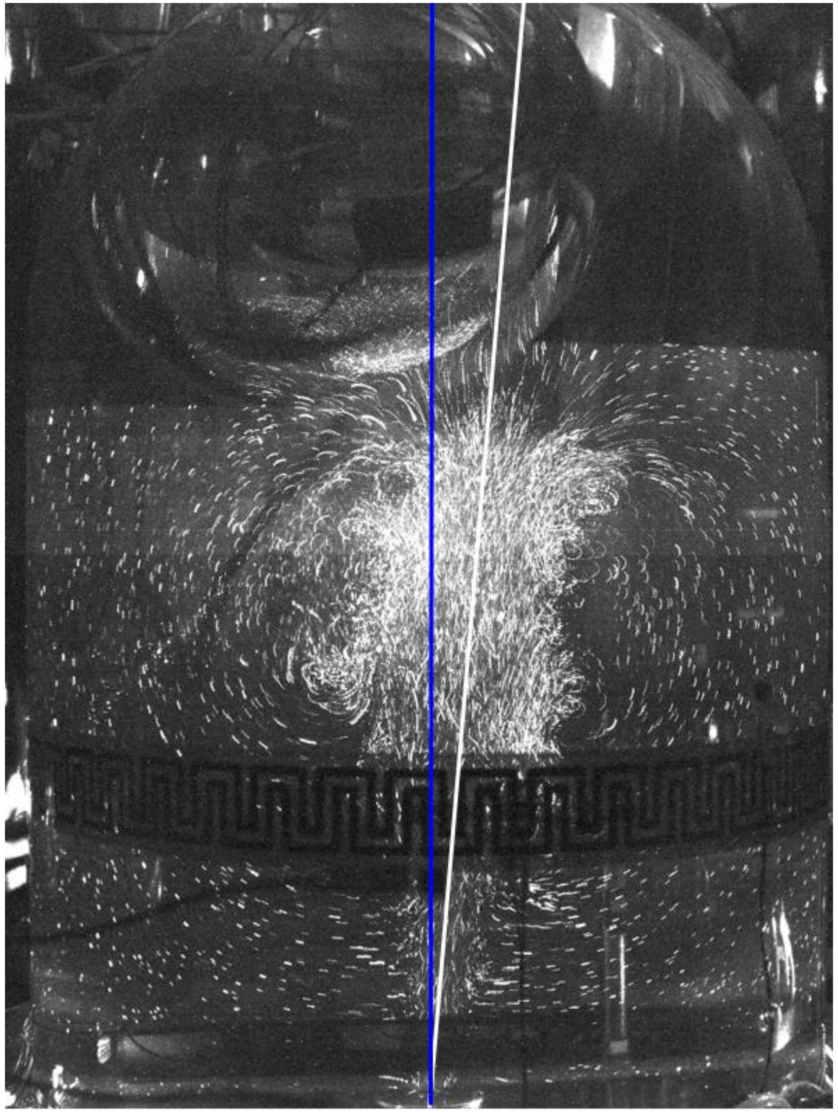
Results

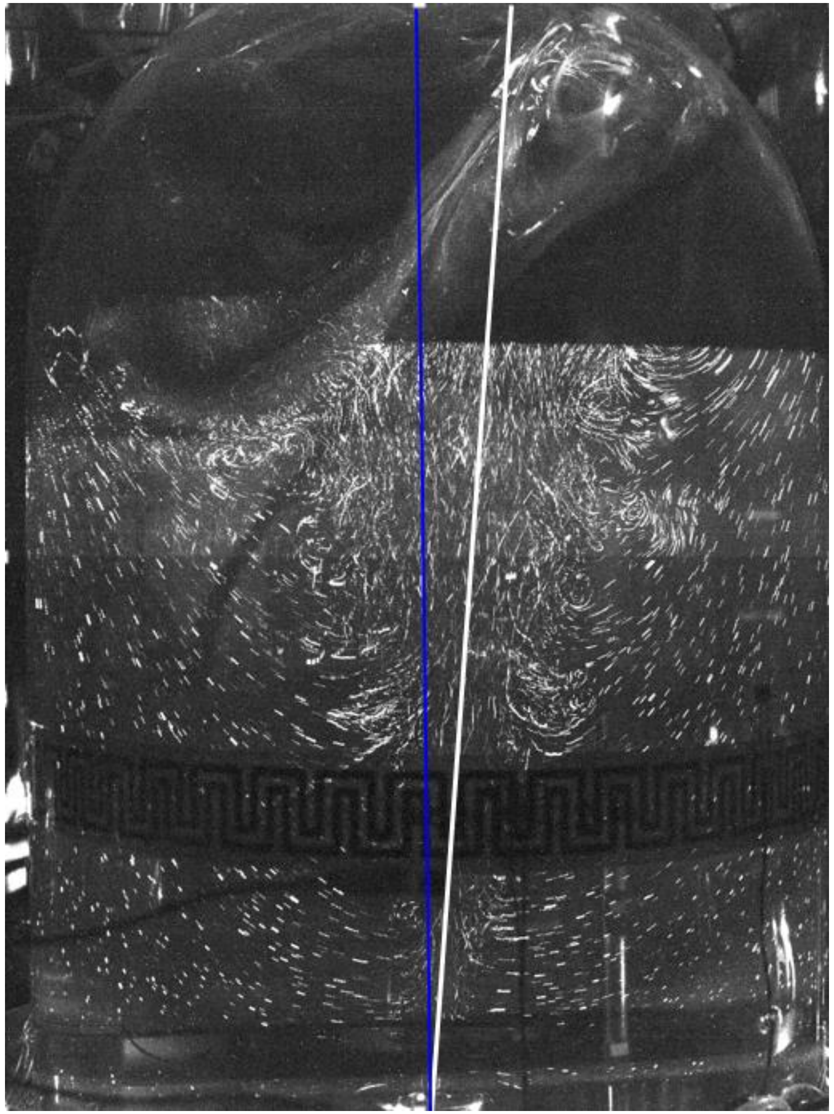
Jet Speed	Fill Level: 70%	Fill Level: 90%
4 cm/s		260
6 cm/s	9	
10 cm/s	24	254
25 cm/s	27	258

Results: Case 9 - 70% fill, 6 cm/s jet speed

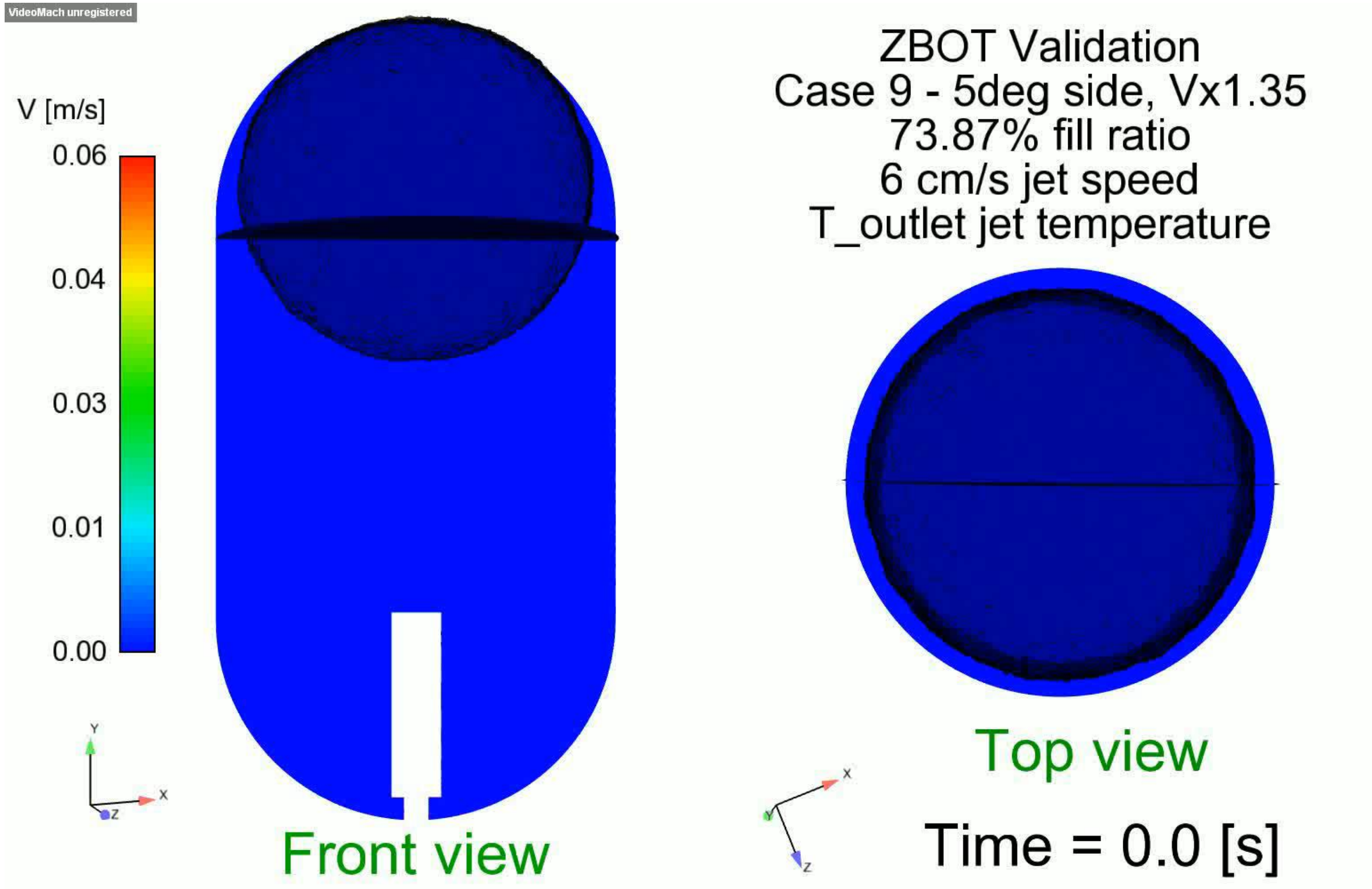


Results: DPIV – Jet Angle

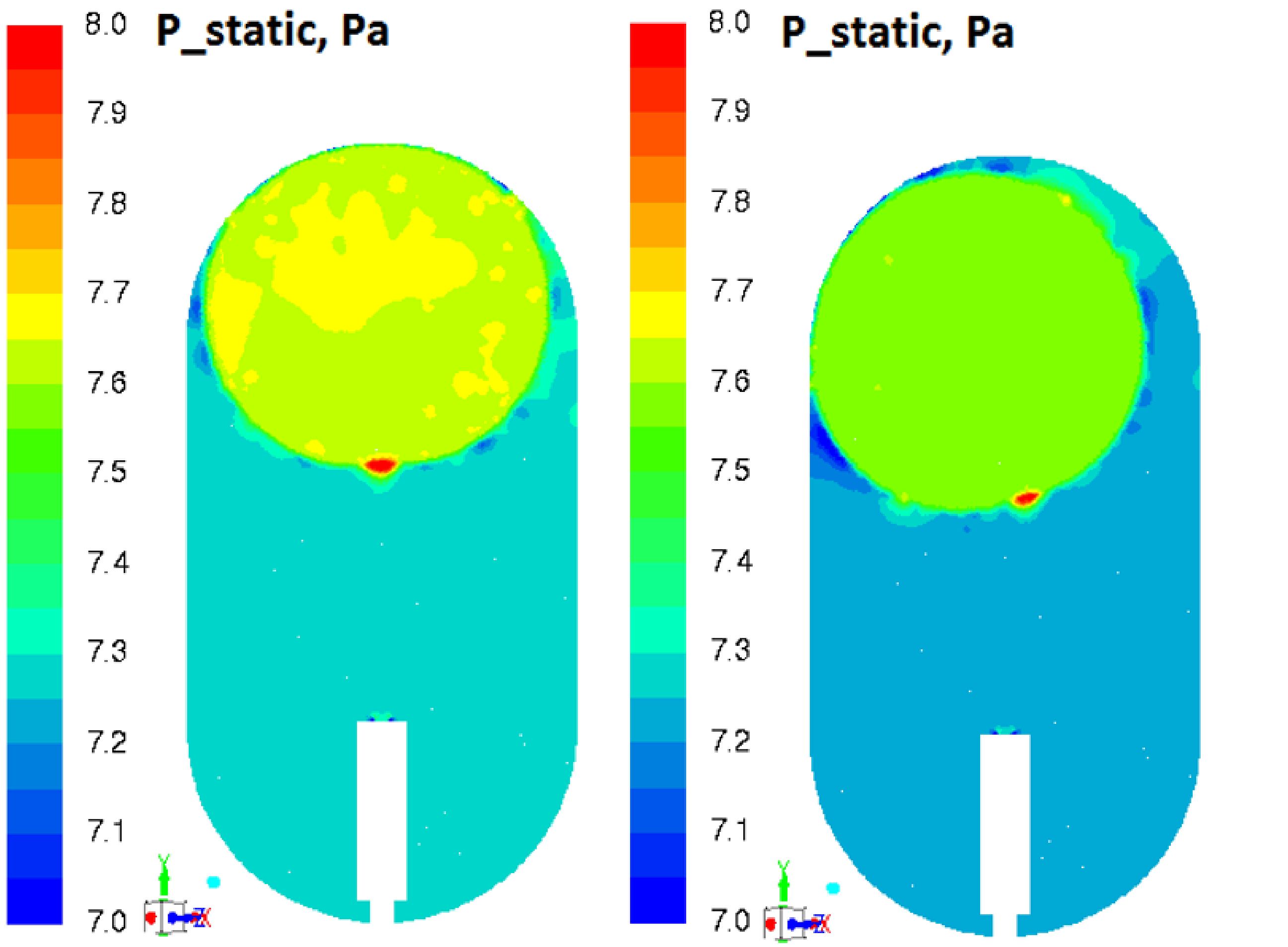




Results: Case 9 - 70% fill, 6 cm/s jet speed



Results: Case 9 - 70% fill, 6 cm/s jet speed

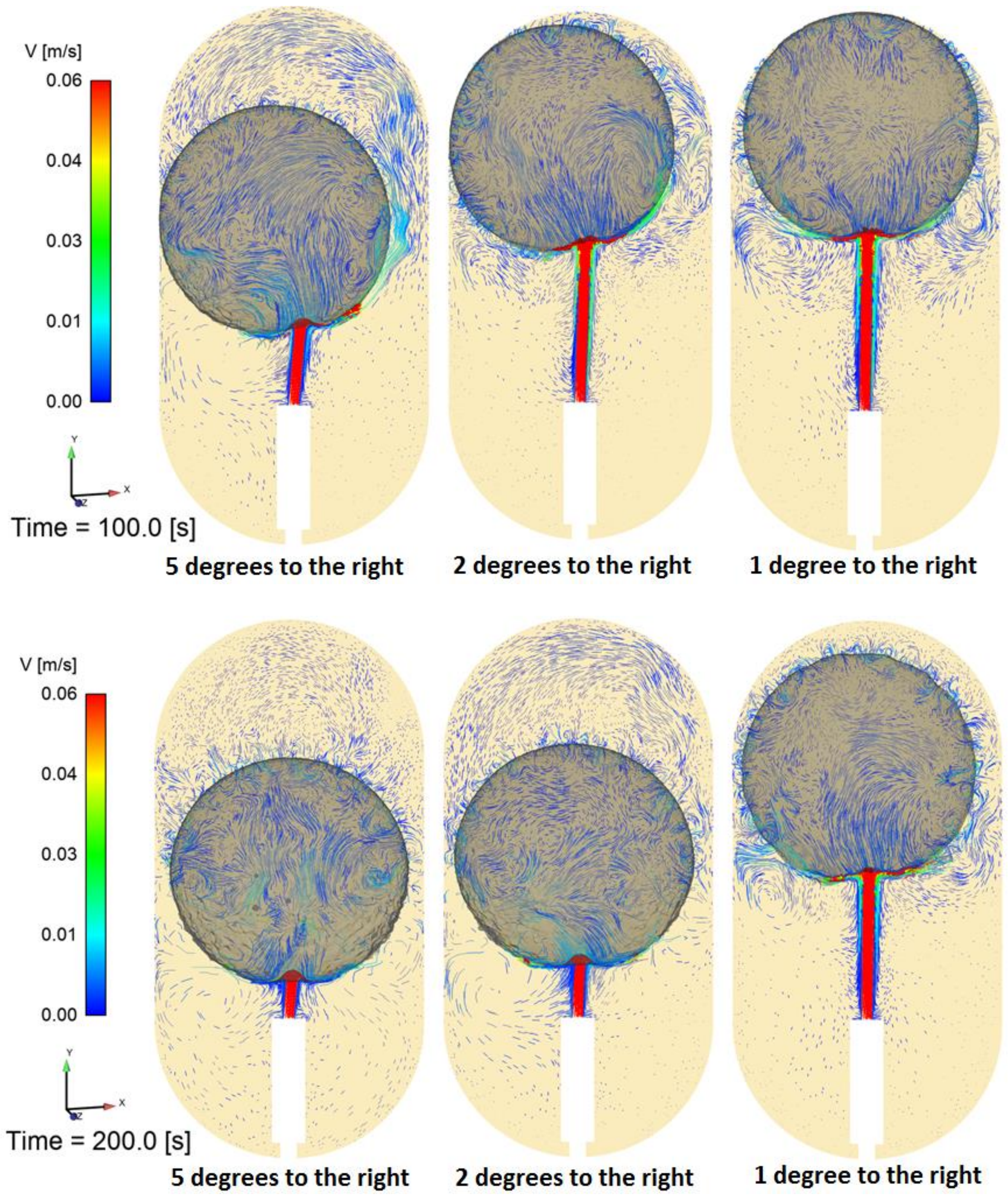


Straight jet

Jet Tilted 5 degrees to the right

After 60 seconds of mixing

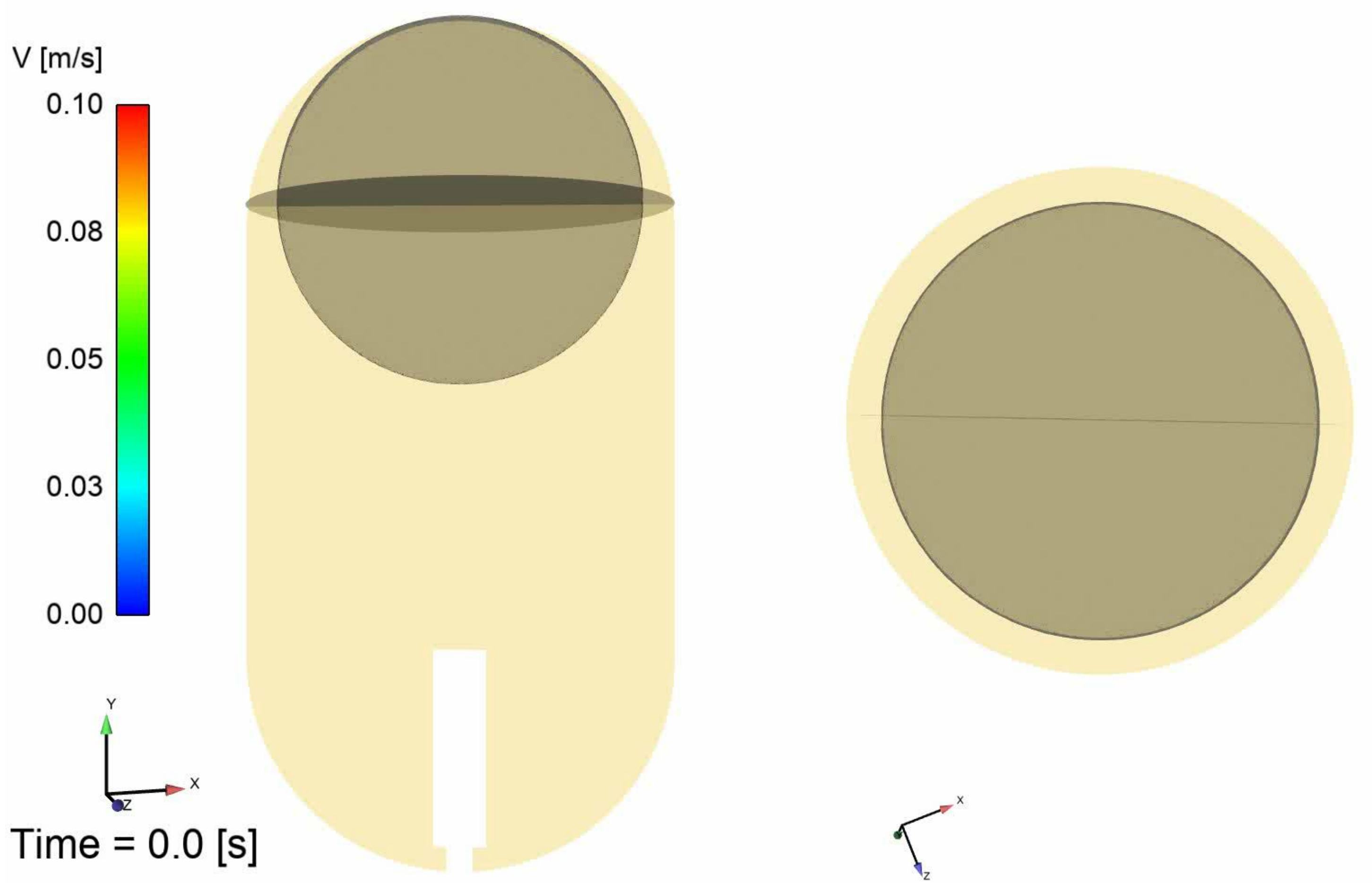
Parametric Studies: Effect of jet angle value



Results

Jet Speed	Fill Level: 70%	Fill Level: 90%
4 cm/s		260
6 cm/s	9	
10 cm/s	24	254
25 cm/s	27	258

Results: Case 24: 70% fill level, 10 cm/s jet speed

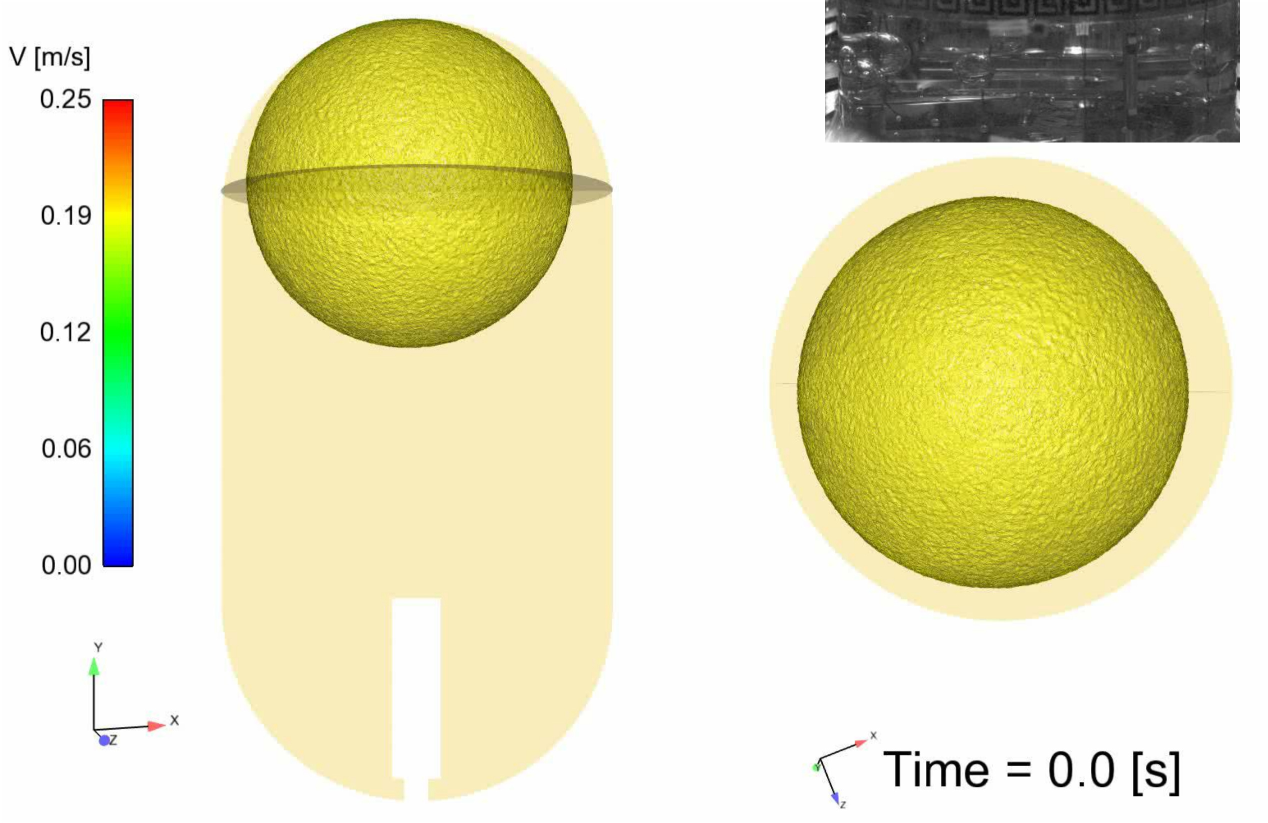


Results

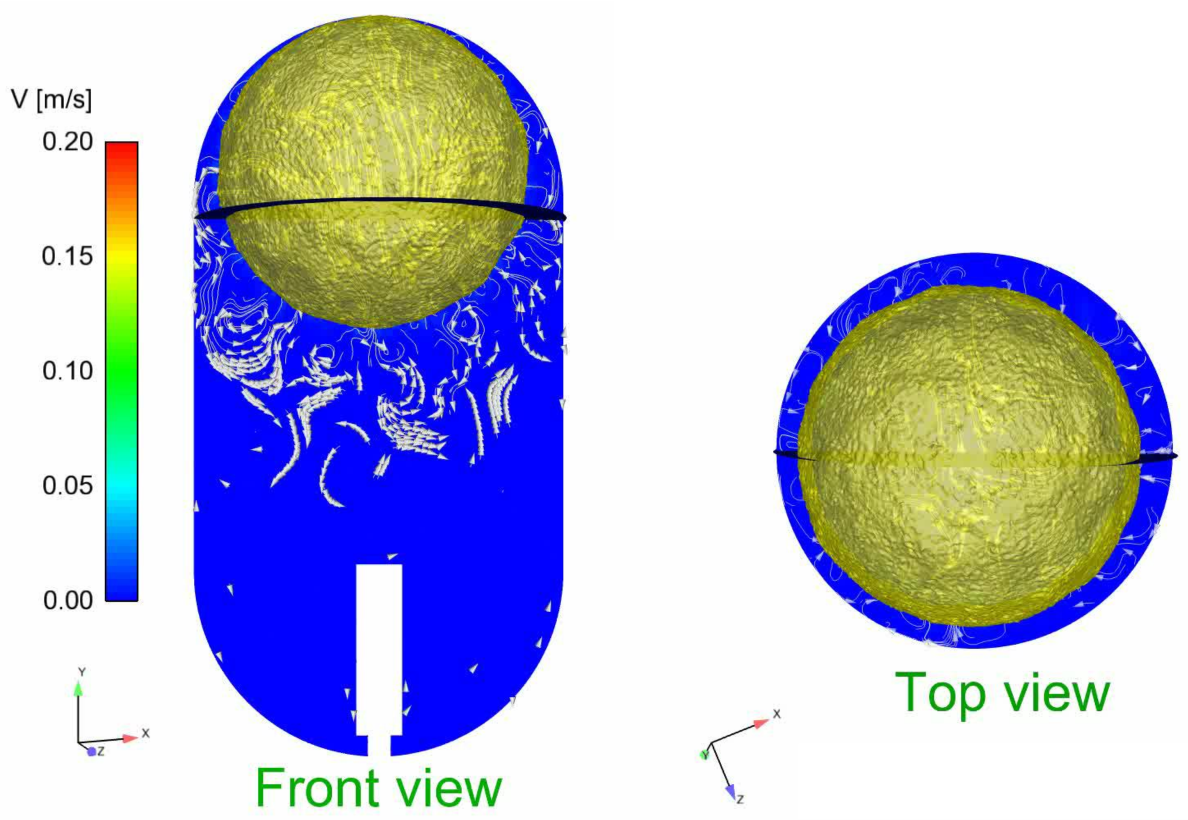
Jet Speed	Fill Level: 70%	Fill Level: 90%
4 cm/s		260
6 cm/s	9	
10 cm/s	24	254
25 cm/s	27	258

Results: Case 27 - 70% fill, 25 cm/s jet speed

LES



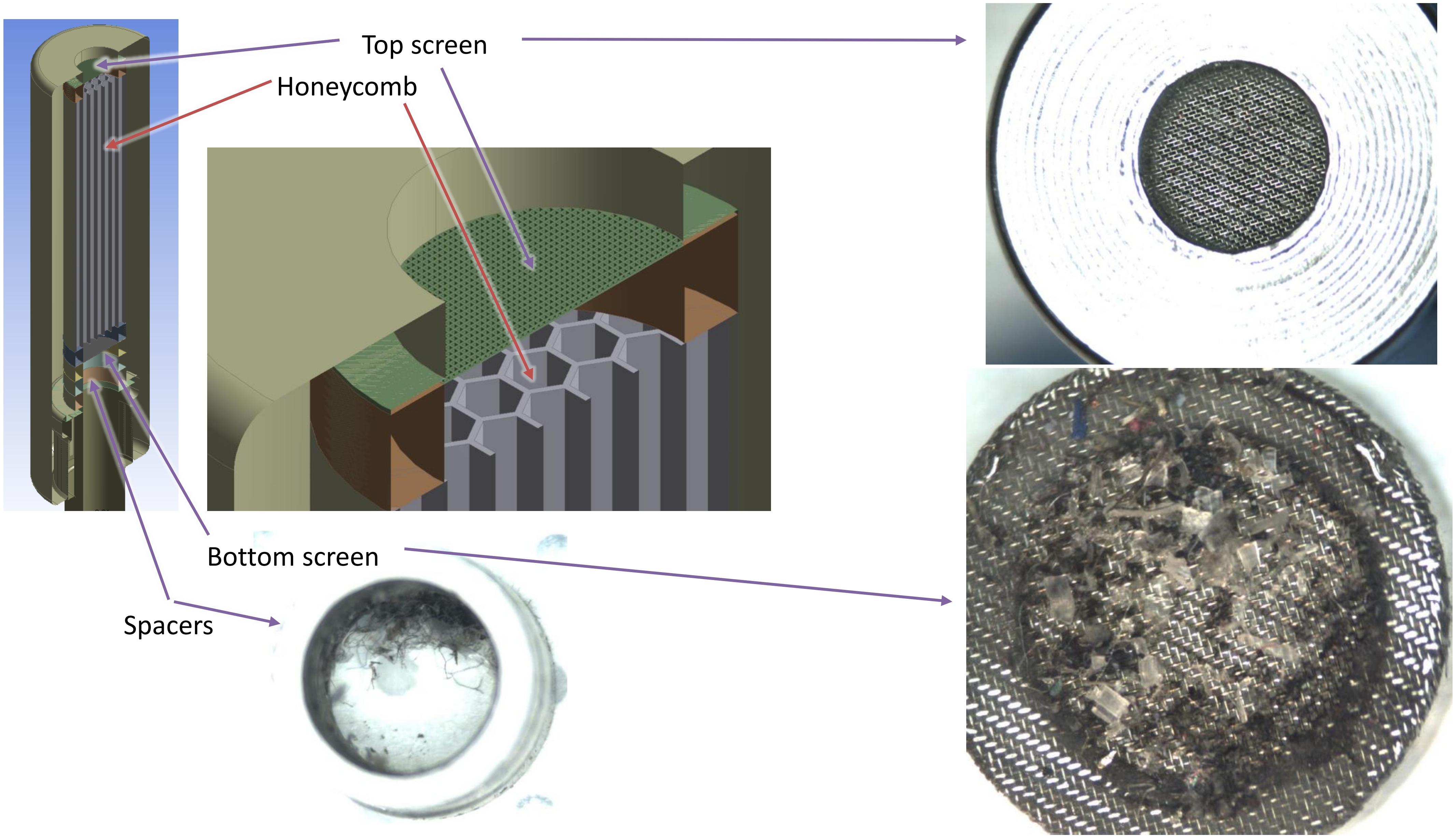
RANS



Results

Jet Speed	Fill Level: 70%	Fill Level: 90%
4 cm/s		260
6 cm/s	9	
10 cm/s	24	254
25 cm/s	27	258

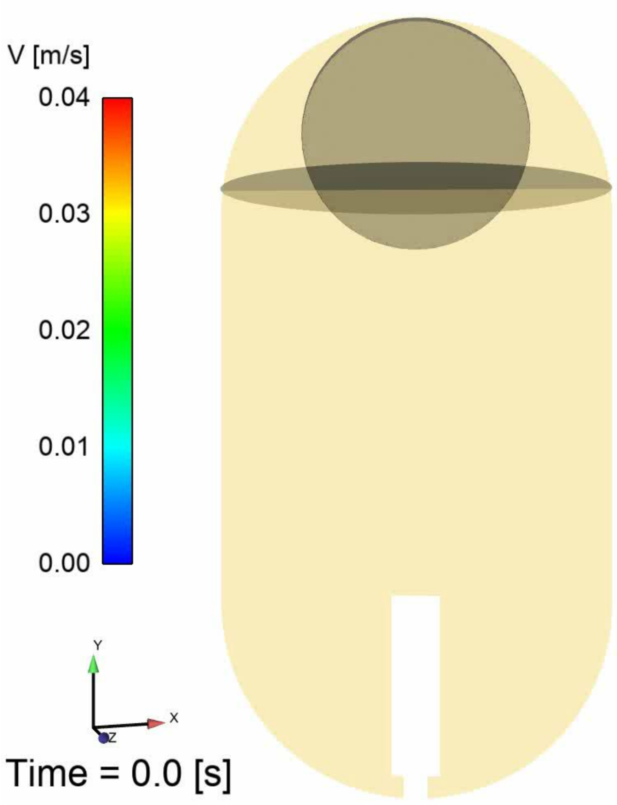
Results: ZBOT nozzle blockage

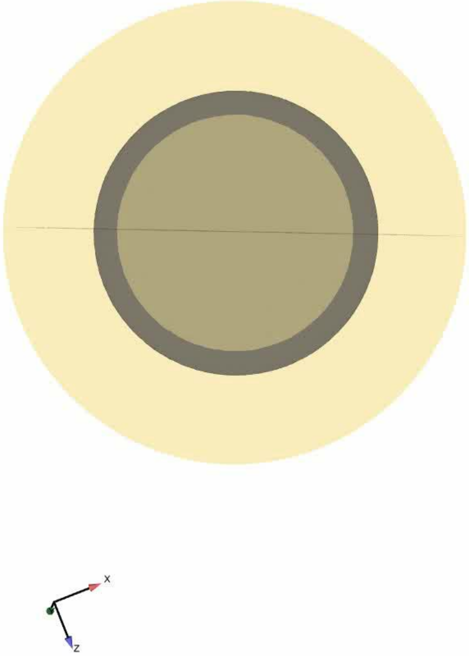


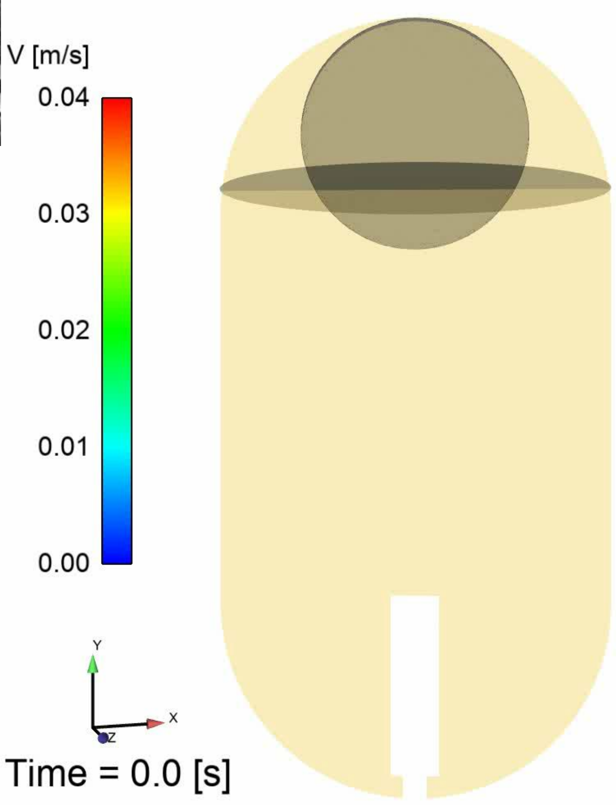
Results: Case 260 - 90% fill level, 4 cm/s jet speed

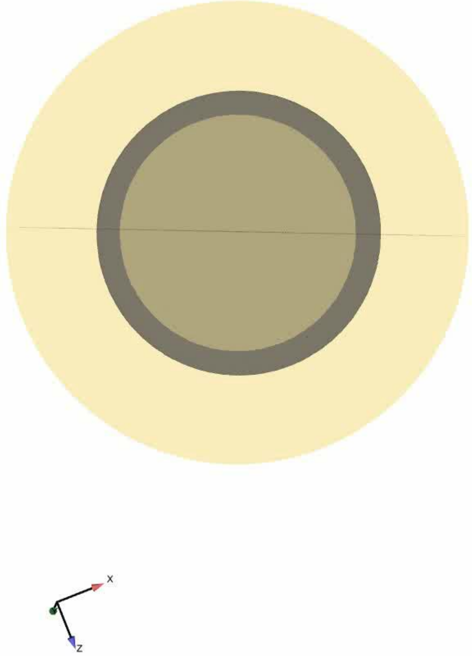
LES

RANS





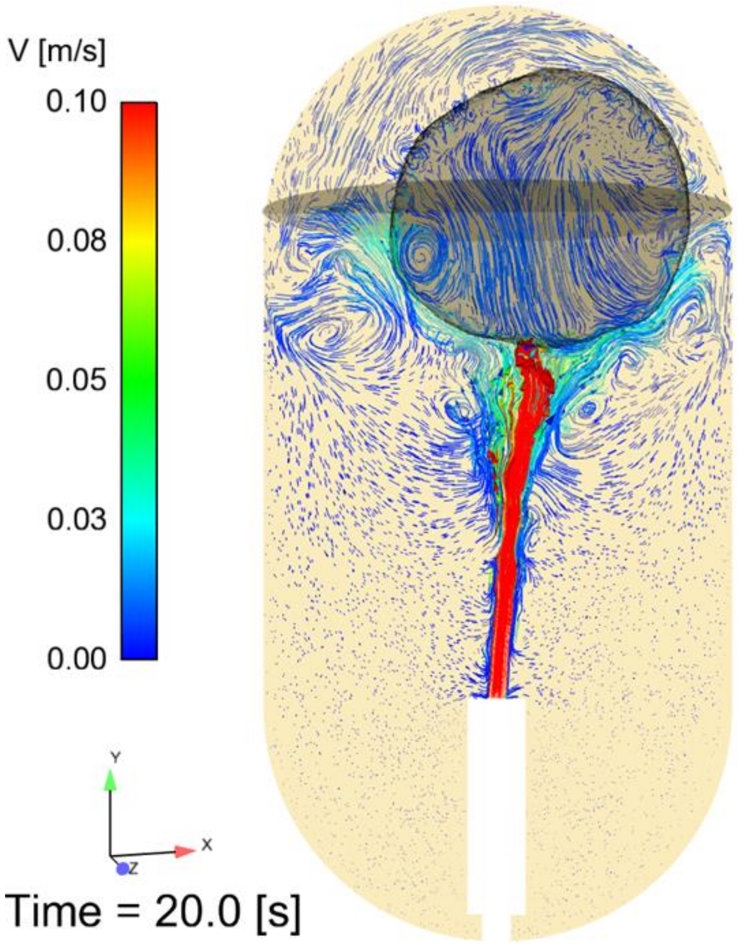




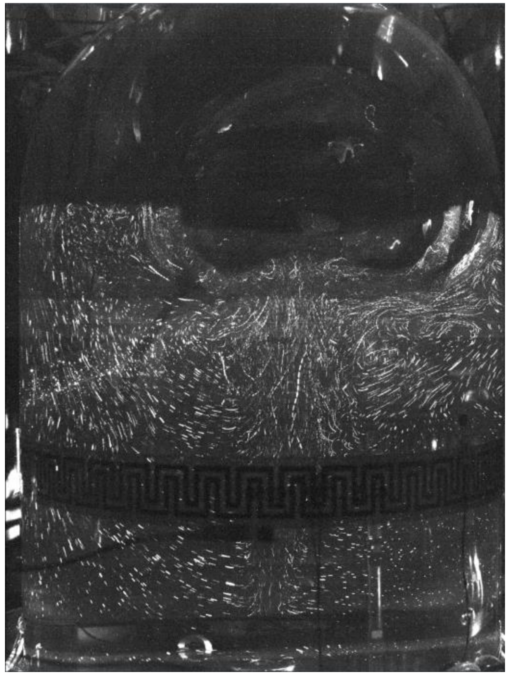
Results

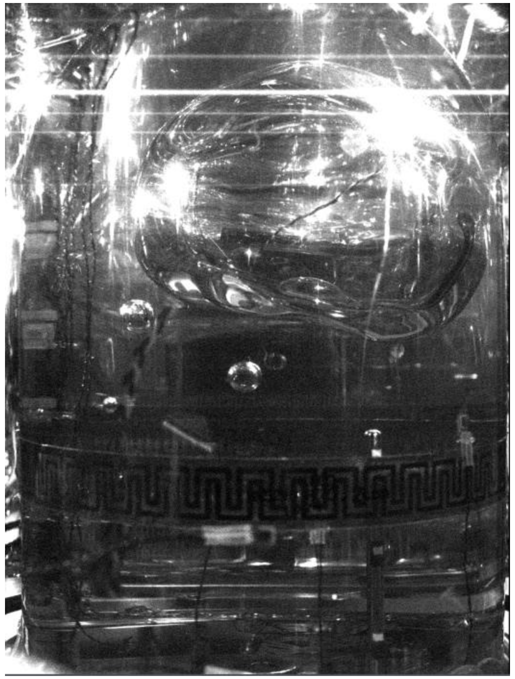
Jet Speed	Fill Level: 70%	Fill Level: 90%
4 cm/s		260
6 cm/s	9	
10 cm/s	24	254
25 cm/s	27	258

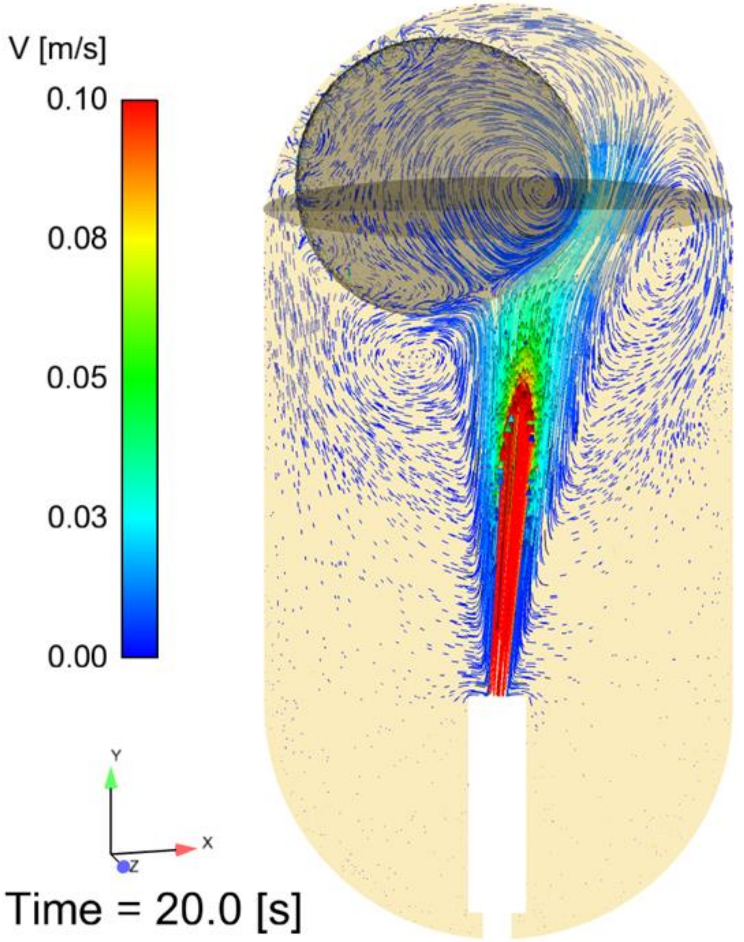
Results: Case 254 - 90% fill level, 10 cm/s jet speed
LES vs. RANS – Jet-Ullage Interaction @ 20 seconds of mixing



LES

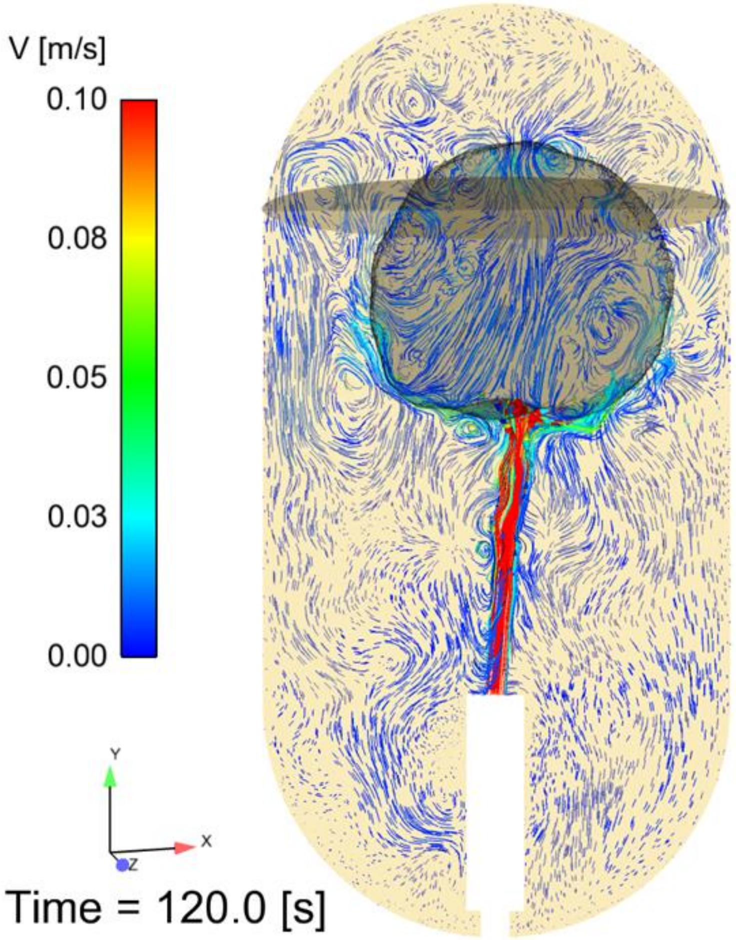


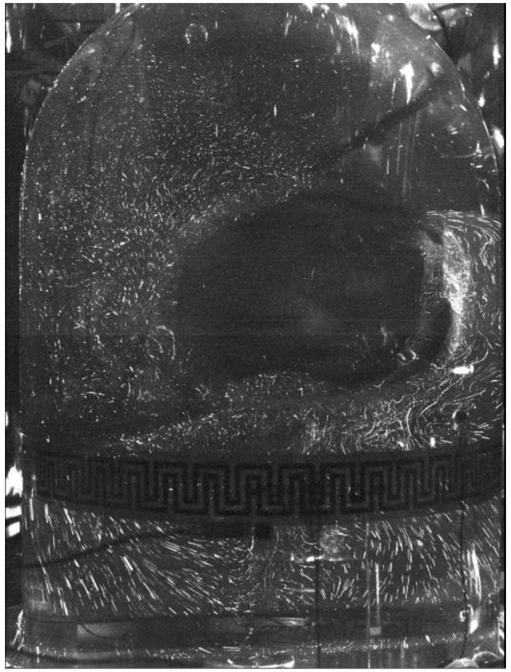


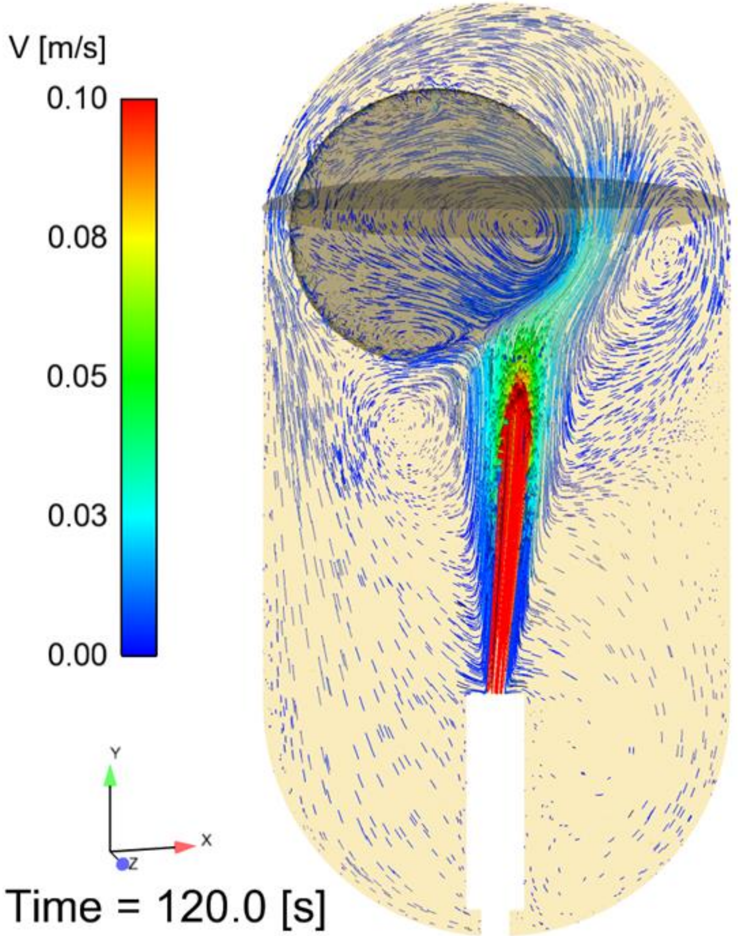


RANS

Results: Case 254 - 90% fill level, 10 cm/s jet speed
LES vs. RANS – Jet-Ullage Interaction @ 120 seconds of mixing



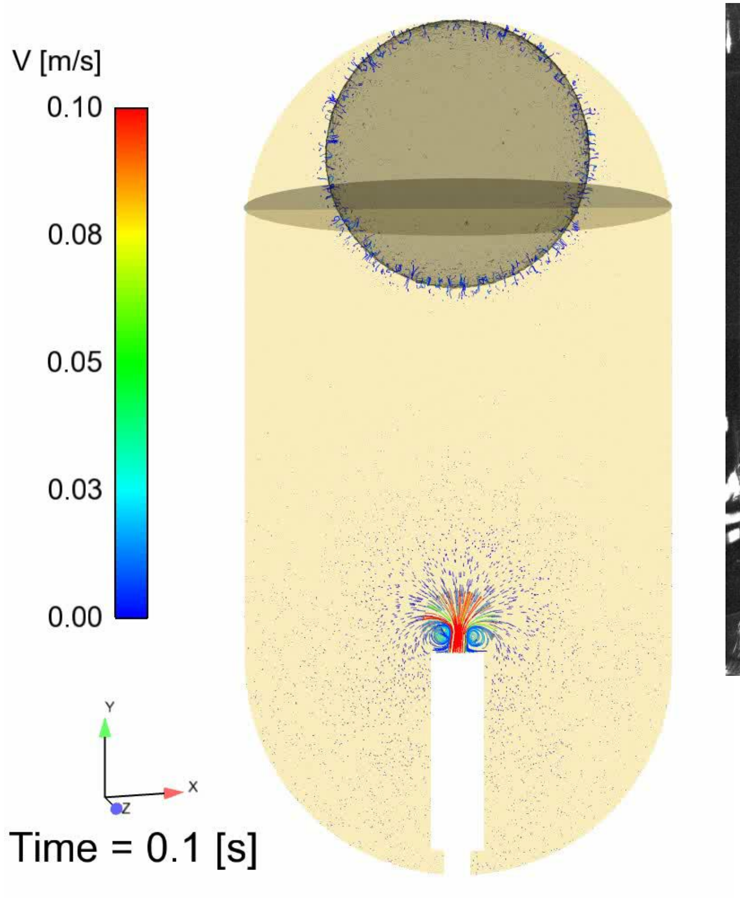


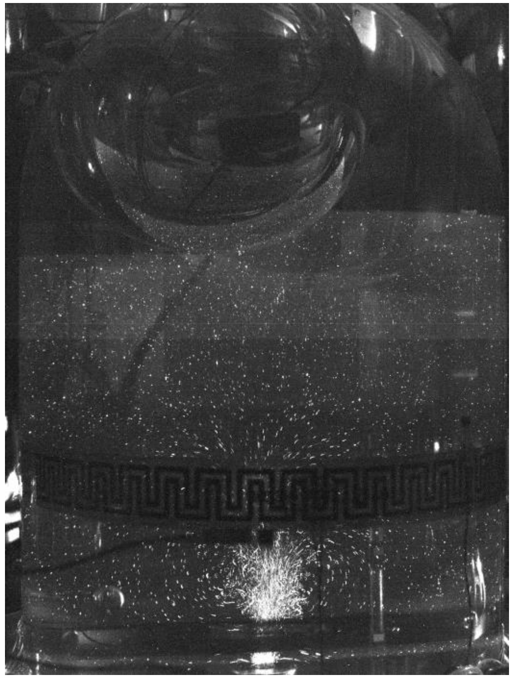


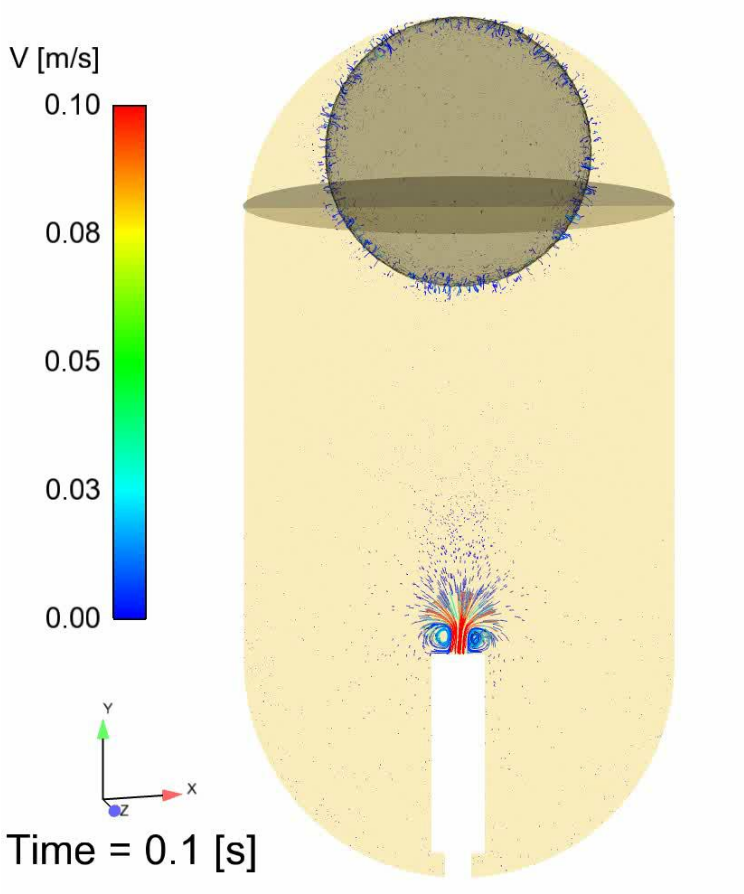
LES

RANS

Results: Case 254 - 90% fill level, 10 cm/s jet speed
LES vs. RANS vs. Experiment







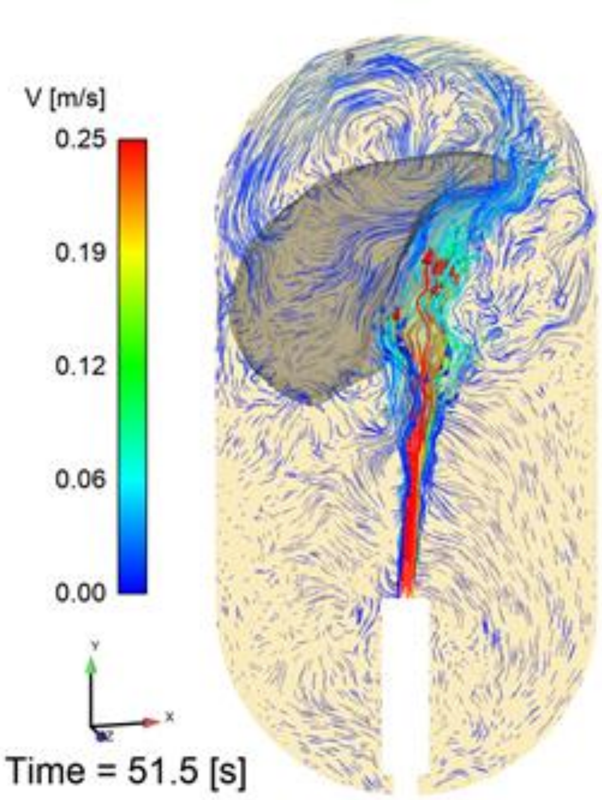
LES

RANS

Results

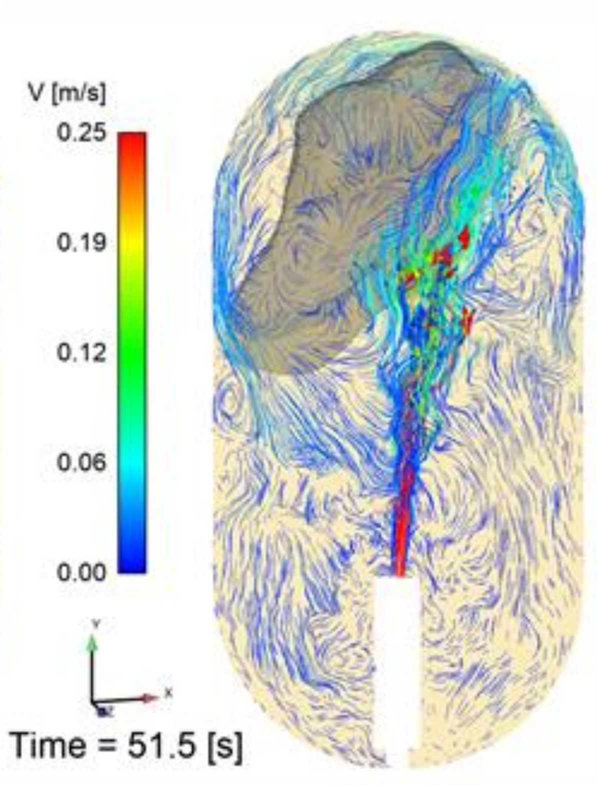
Jet Speed	Fill Level: 70%	Fill Level: 90%
4 cm/s		260
6 cm/s	9	
10 cm/s	24	254
25 cm/s	27	258

Results: Case 258 - 90% fill level, 25 cm/s jet speed
LES vs. RANS vs. Experiment



Vx1_35

LES



Vx2

LES

Conclusions

- CFD model was validated against the results of the ZBOT jet mixing experiments in microgravity for different liquid fill levels and jet speeds
- Performed parametric studies investigating effects of: 1) jet orientation, 2) value of jet angle, 3) value of residual gravity, 4) value of surface tension, 5) discretization scheme for volume fraction equation
- The LES model was able to accurately predict the ullage shape and position in all cases considered, with the best agreement in the cases with the medium jet speed (10 cm/s). The RANS model did not predict the dynamic behavior of the ullage movement and its deformation with the same fidelity as the LES model.
- The results of this investigation showed that the current storage tank CFD model implemented in the ANSYS Fluent CFD code is capable of successfully reproducing the main features of the jet-ullage interaction in microgravity for two different liquid fill levels in the tank and four different jet flow rates.
- The focus of the current study was on modeling the fluid flow and interface dynamics. Since modeling the thermal effects of the subcooled jet on the interfacial mass transfer is important, such cases will be considered in future work.

Acknowledgements

This work was supported by the NASA Space Life and Physical Sciences Research and Applications (SLPSRA) Division

and the NASA Space Technology Mission Directorate's Technology Demonstration Missions Program under the Evolvable Cryogenics Project.

Backup slides

Gravitational Acceleration

•Space Acceleration Measurement System-II (SAMS-II) measures accelerations caused by vehicle, crew and equipment disturbances. These vibratory/transient accelerations occur in the frequency range 0.01 to 300 Hertz.

•Microgravity Acceleration Measurement System (MAMS) measures vibratory and quasi-steady acceleration within the United States Laboratory Module on the International Space Station (ISS).

Gravitational Acceleration