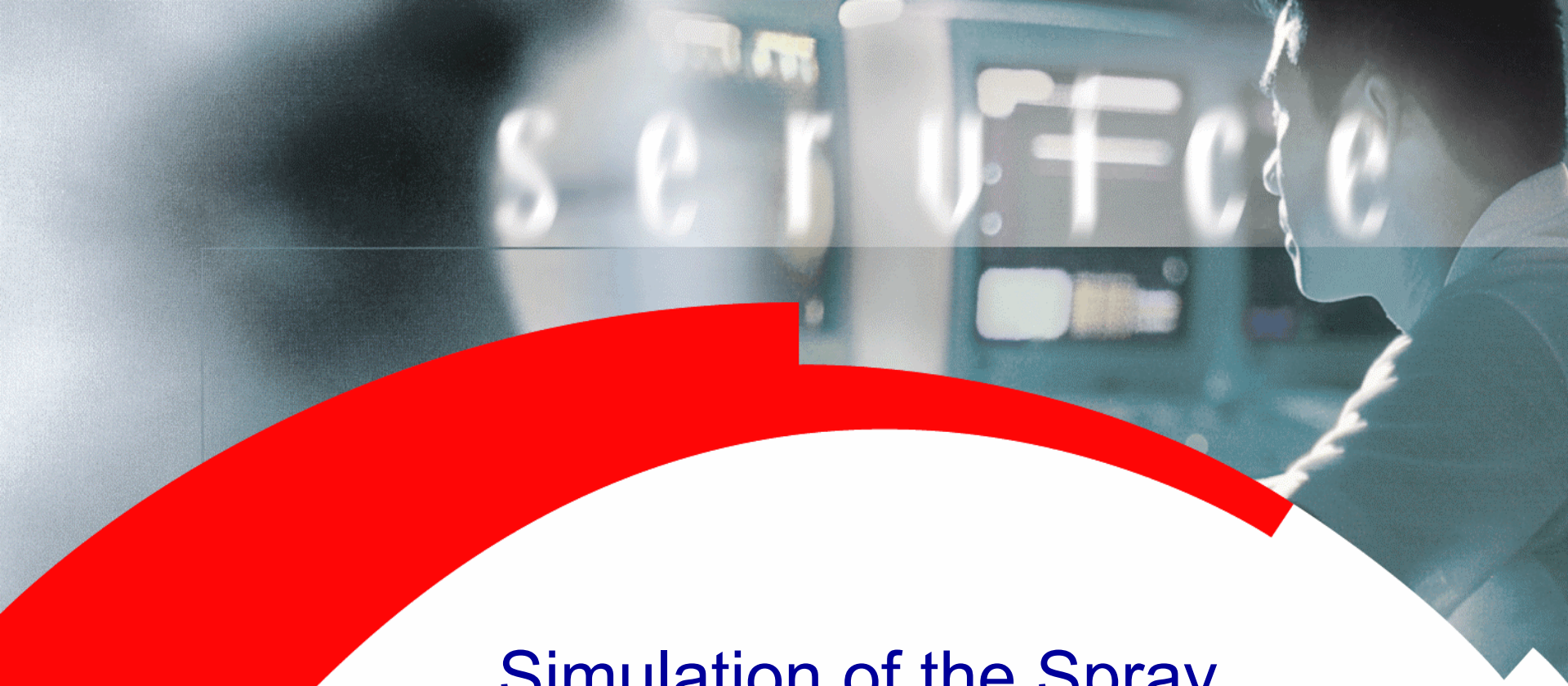


Simulation of the Spray Characteristics of Black Liquor

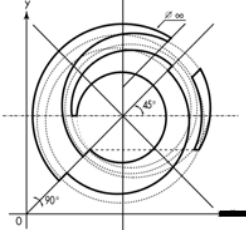
Colloquium on BL Combustion and Gasification

Denise Levesque

ALSTOM

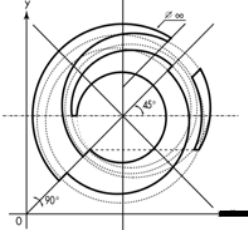
SIMULENT

May 2003



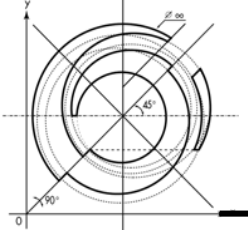
Co-Authors

- Mohammad Fard, Simulent Inc.
- Stuart Morrison, ALSTOM Canada
- Javad Mostaghimi, University of Toronto



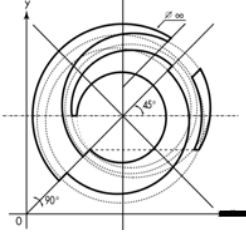
Agenda

- Project Goals
- Need for Code Development
- Code Development
- Code Validation
- Full Simulation
- Test Cases
- Summary



Long Term Goals

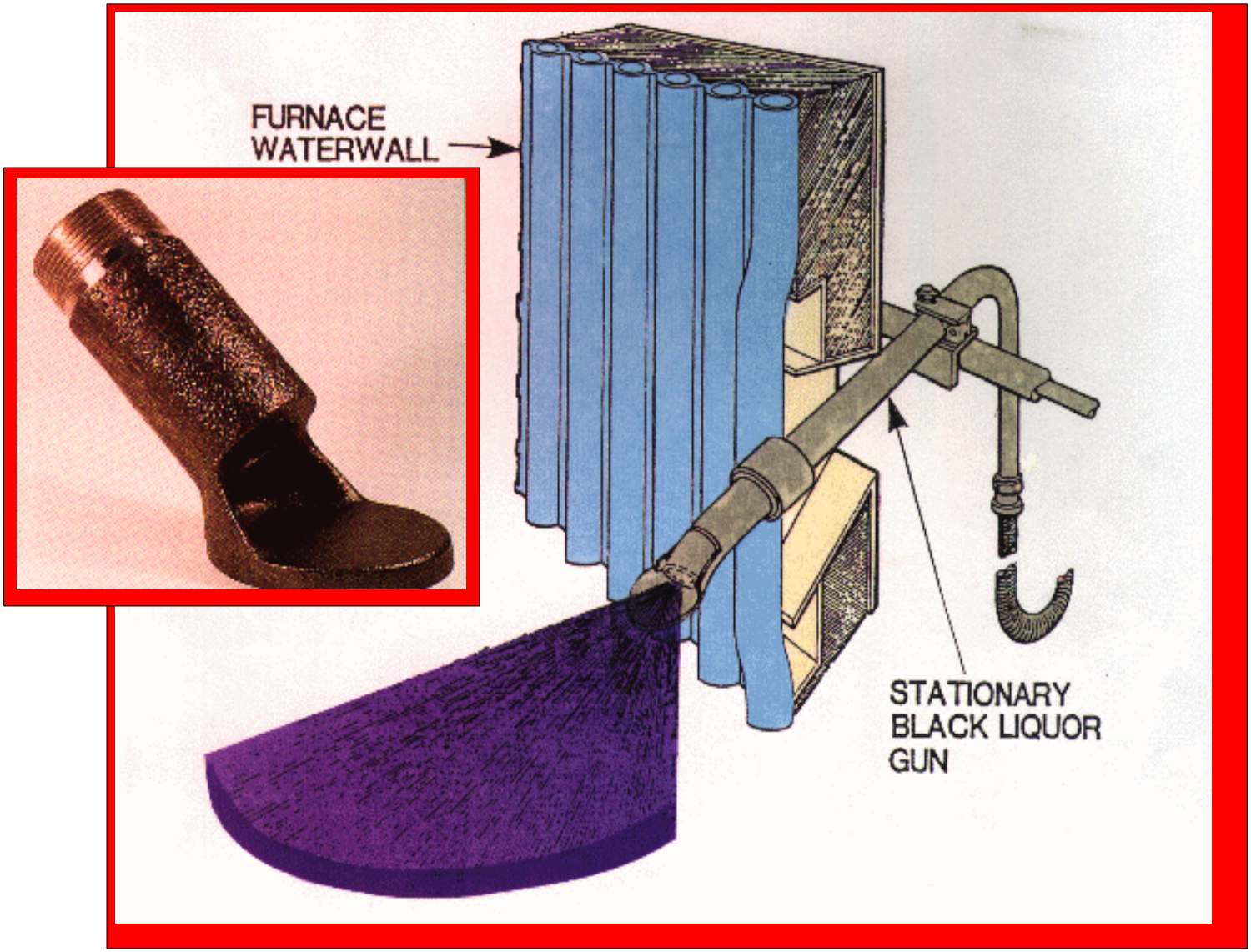
- Create a code which can be used to:
  - Optimise nozzle design
  - Predict droplet size for a particular operation
  - Provide input for CFD modeling

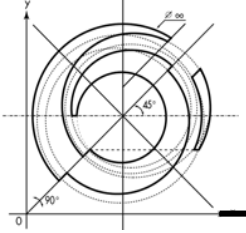


Objective of New Code

- Develop a code (computer program) which can properly simulate the liquid sheet formation and its breakup in a splash plate nozzle

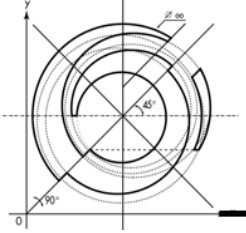
Objective of New Code





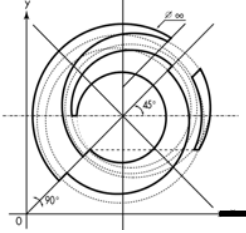
Need for Code Development

- Difficulty in testing spray characteristics in-situ
- Difficulty in reproducing firing conditions in the laboratory.
- Equations developed by Dombrowski and co-workers to predict droplet size are not general in nature.
- Improve spreadsheet which is currently used to predict droplet size based on boiler operating conditions.



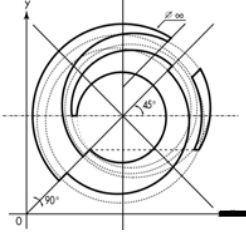
Code Development

- Work initiated to develop **BLSpray** in Sept 2000
- Numerical Methods:
  - Basic Assumptions
    - Laminar, Newtonian, incompressible flow
  - 3D Cartesian coordinate system, using a finite volume scheme
  - Full Navier-Stokes equations



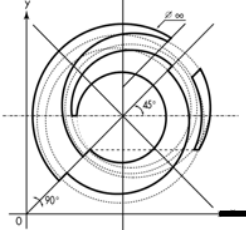
Code Capabilities

- Model any shape of solid object
- Handle a wide range of liquid properties
- Handle continuous fluid boundary conditions, inflow and outflow
- Provide liquid film thickness and its velocity distribution at any desired location and cross-section
- Plot results in the form of 3D images
- Include internal and external disturbances
- Simulate, with further development, other types of nozzles
- Can be coupled with CFD modeling software



Steps in Development of **BLSpray**

- Step 1:
  - Develop **BLSpray** to model normal impact of a liquid jet on a solid plate
- Step 2:
  - Develop **BLSpray** to accurately predict black liquor sheet thickness and velocity at the tip of the splash plate
- Step 3:
  - Develop **BLSpray** to enable the code to determine droplet size and distribution

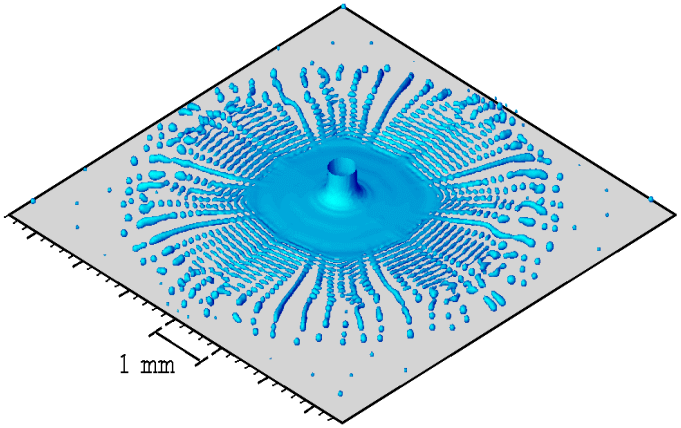


Initial Code Validation

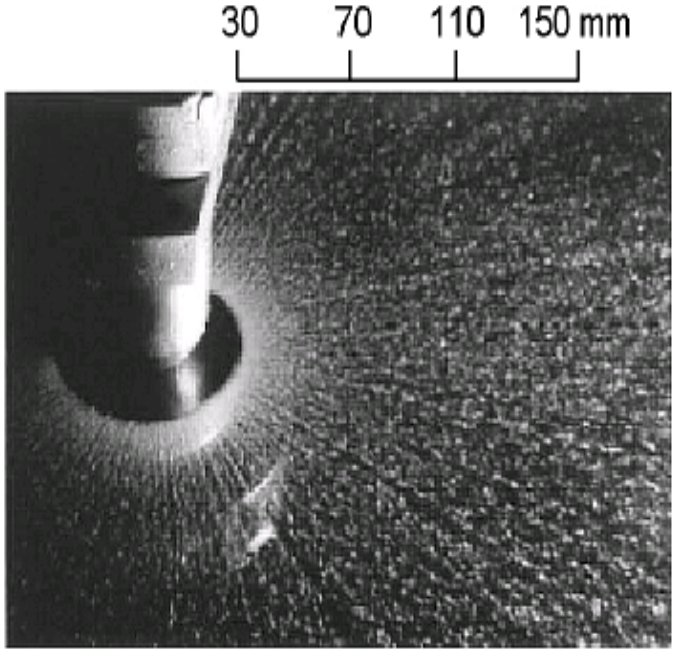
- Quantitative validation using Ashgriz et al.

Jet velocity m/s	Measured Mean Droplet Dia.	Simulation: Droplet Dia range	Simulation: Droplet Dia average
12	~ 160 μm	100-200 μm	150 μm
26.8	~ 80 μm	50-100 μm	80 μm

Initial Code Validation



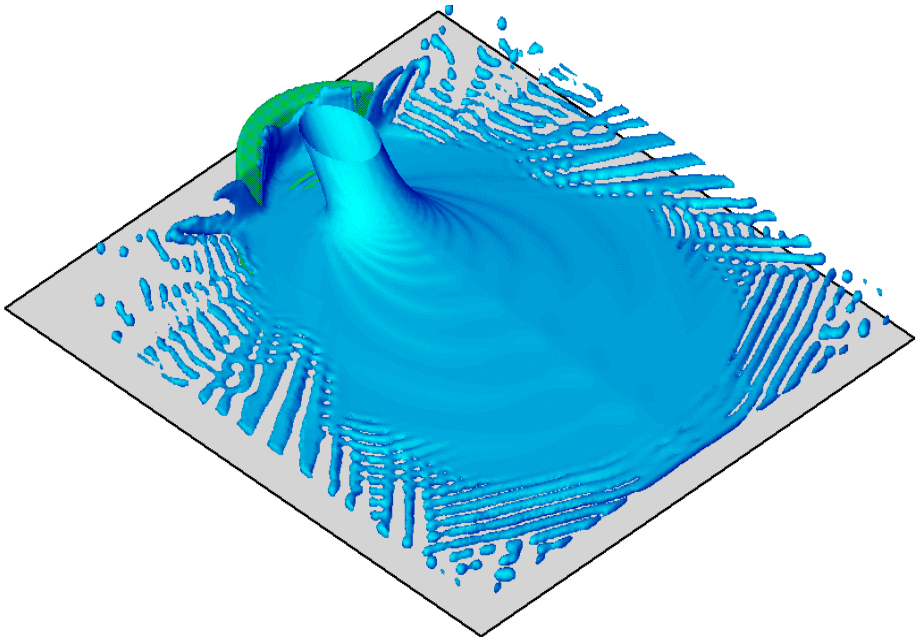
Numerical simulation

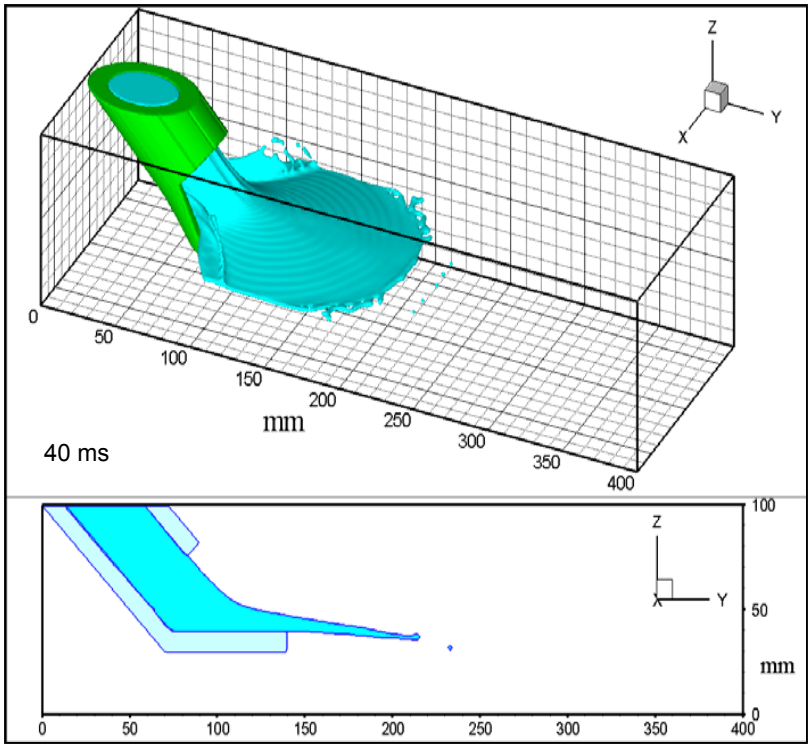


Azuma and Wakimoto
Int. Conference on Multiphase Flow, 2001

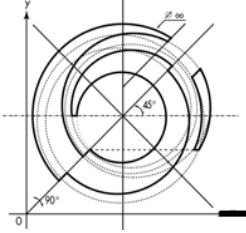
- Qualitative validation: liquid film and finger formation at high speed jet impact

BLSpray: Step 2





- Impingement of black liquor on a plate at an angle
- Progressed from a flat plate to a full nozzle body

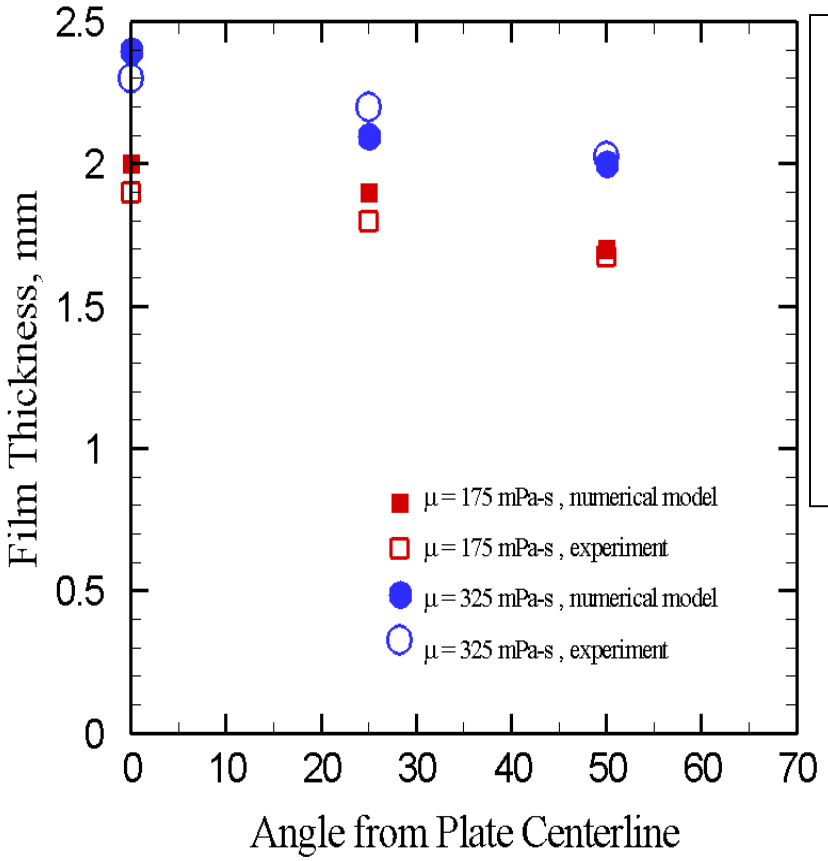


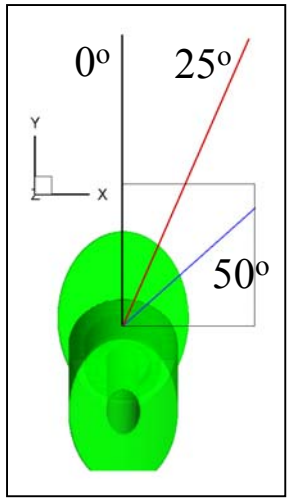
Step 2 Validation

- Corn syrup experiments by Obuskovic and Adams
- Validation of sheet thickness and velocity at the tip of the splash plate

Step 2 Validation

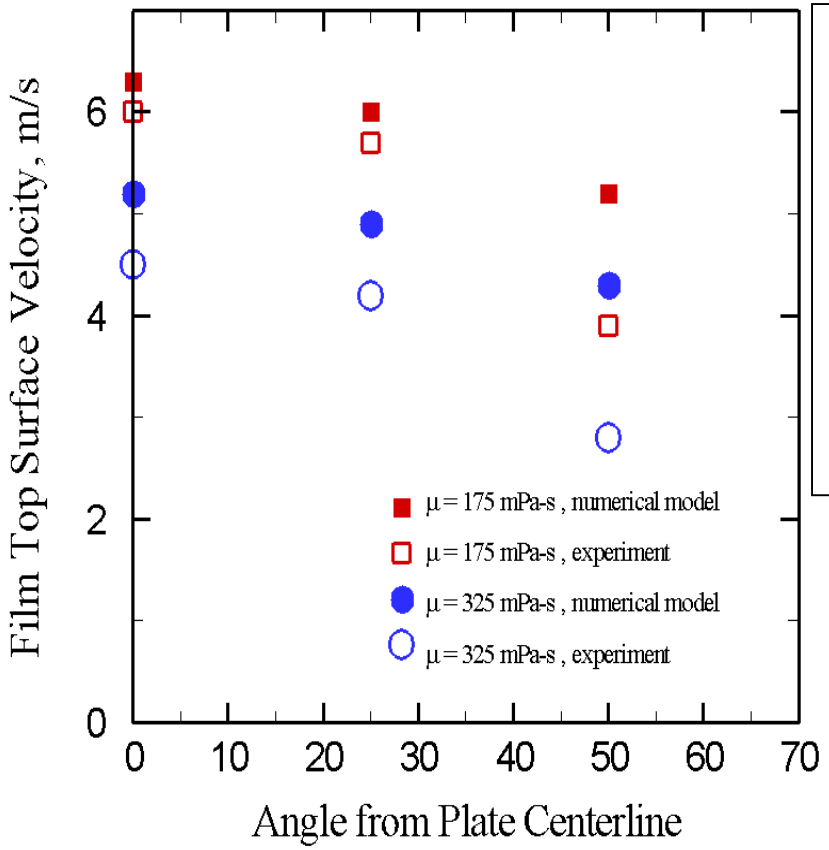
- Film Thickness
- **BLSpray** vs experimental results for two different viscosities

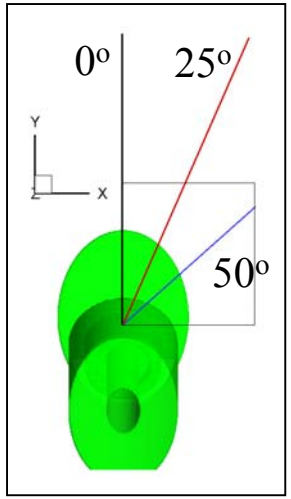


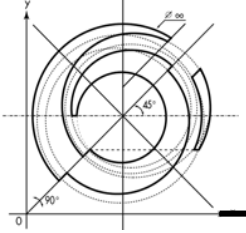


Step 2 Validation

- Film Top Surface Velocity
- **BLSpray** vs experimental results for two different viscosities





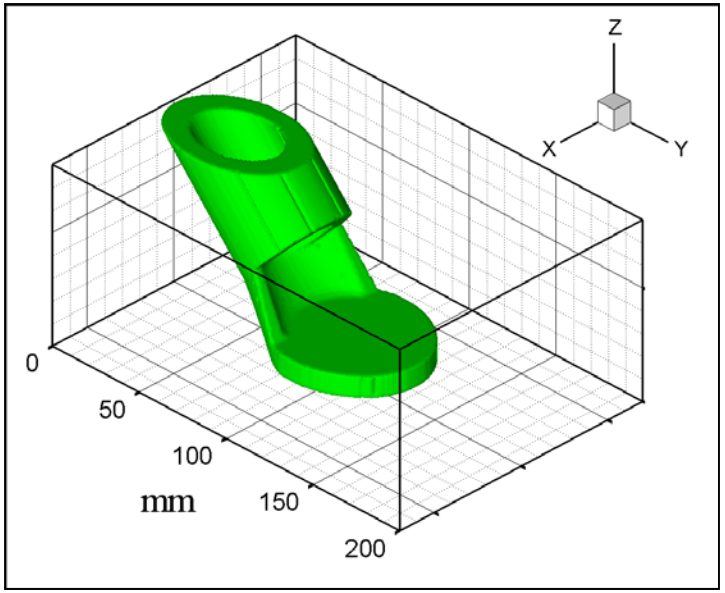


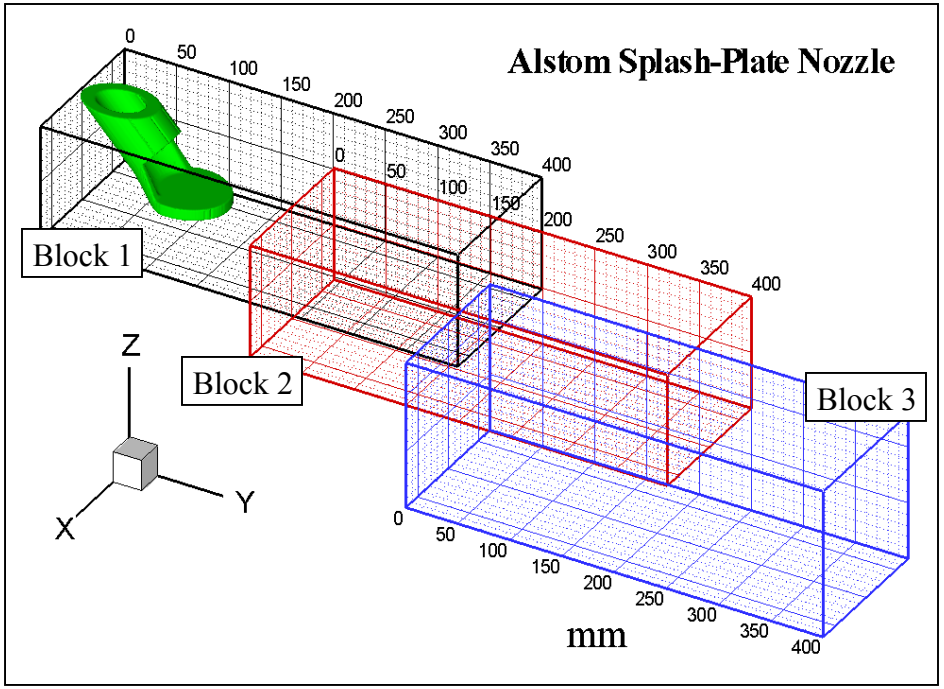
Full Simulation: Step 3

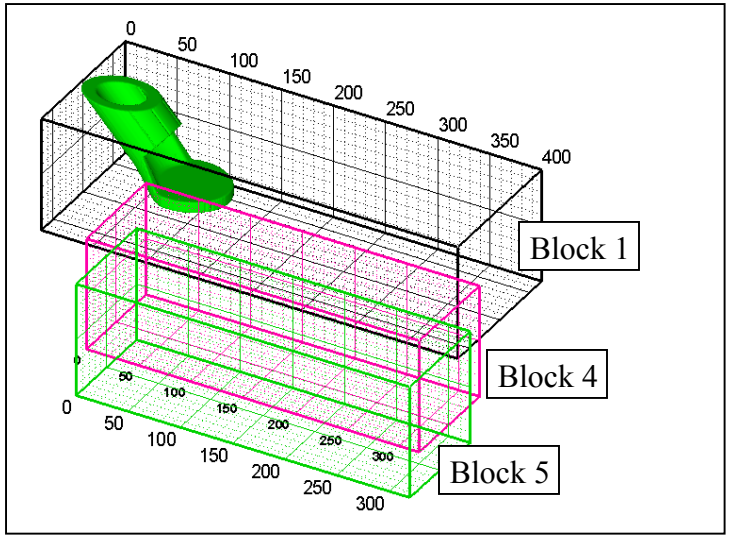
- Increased computational domain to capture breakup point
- Droplet size distribution obtained from the liquid volume fraction data calculated by the code

Full Simulation: Computational Domain

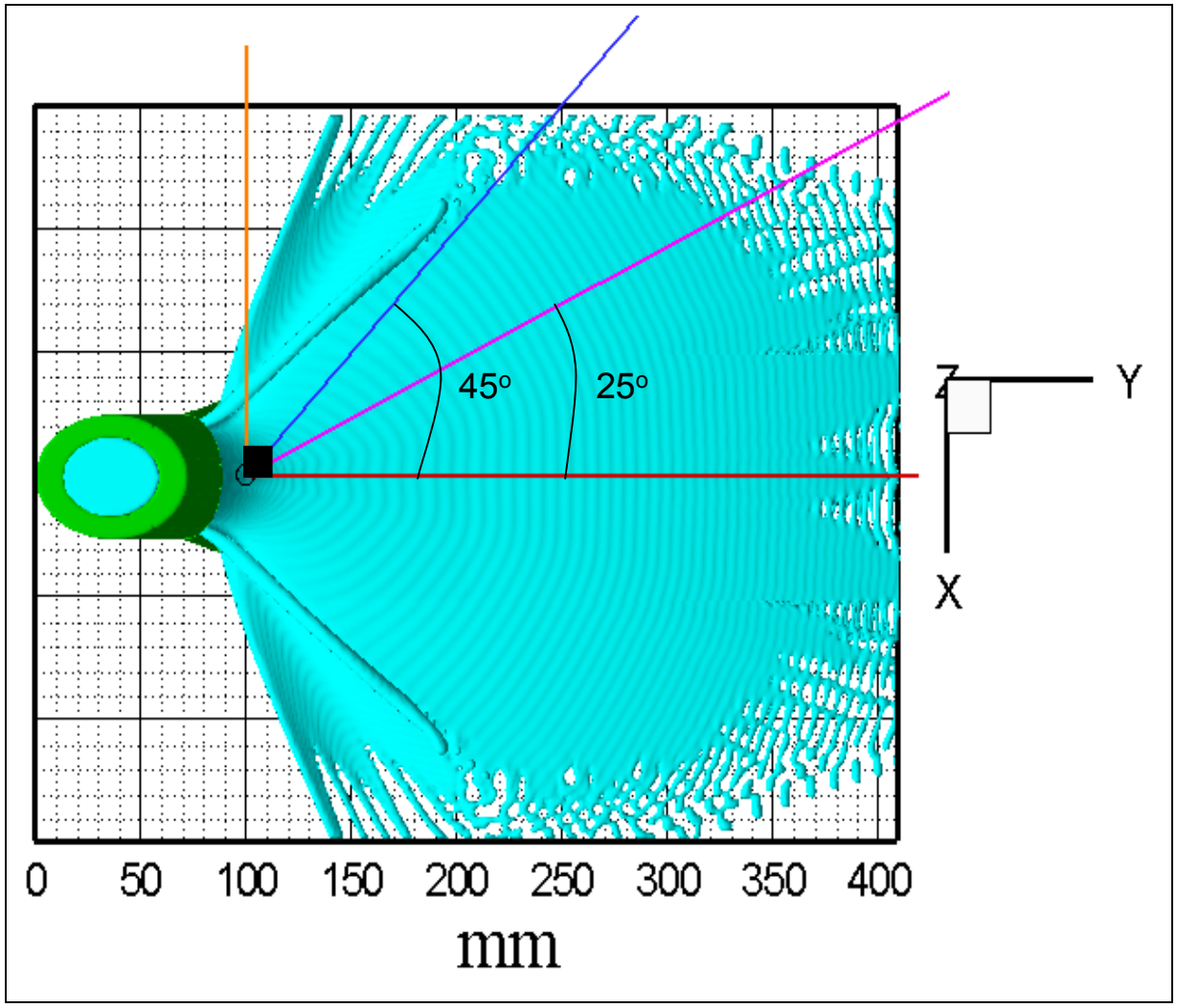
- The large domain is broken into smaller simulation blocks
- Simulation continues until droplet formation



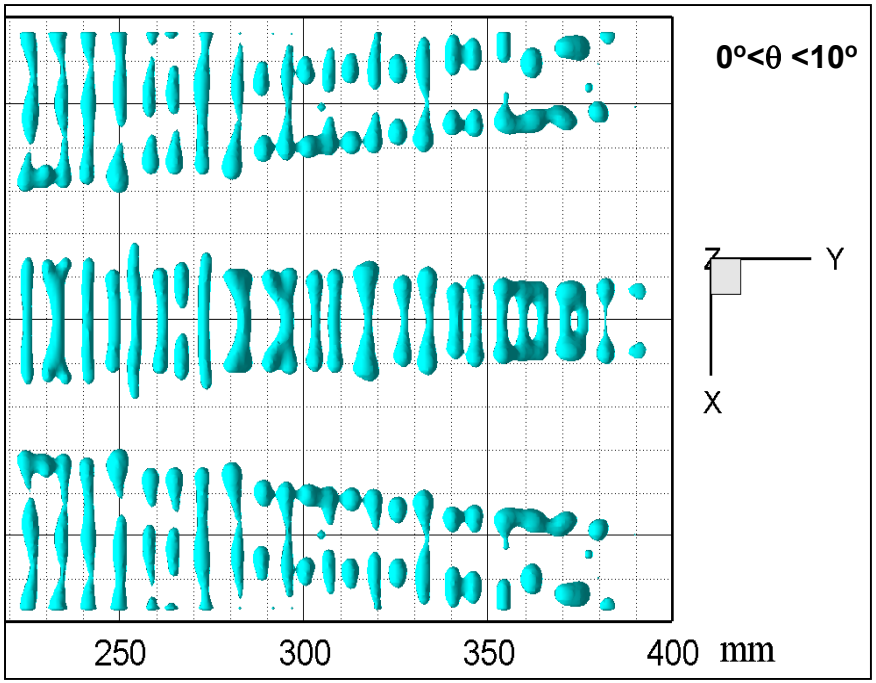


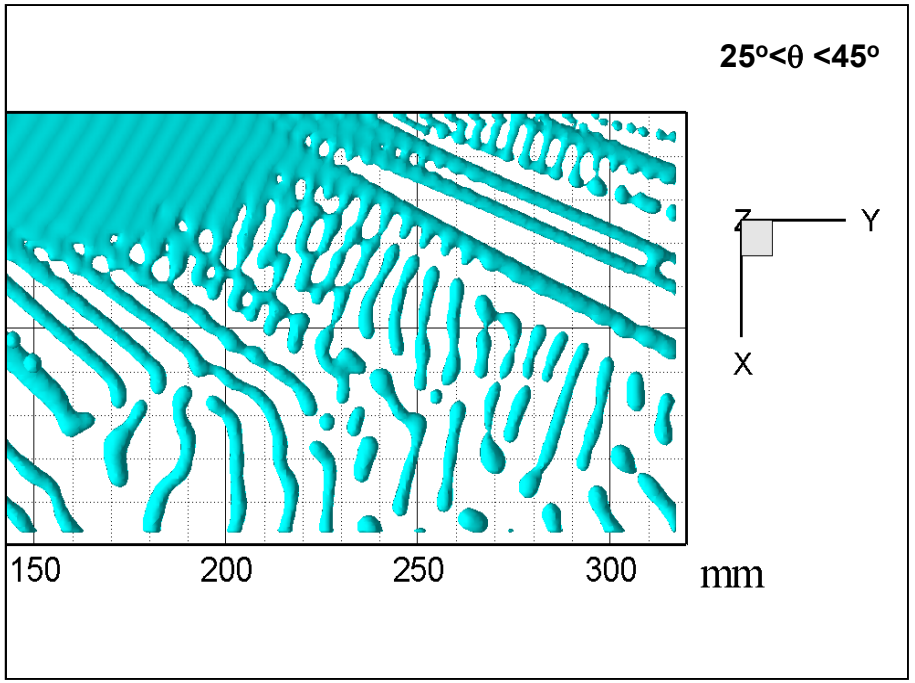


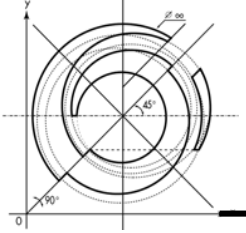
Images from Full Simulation



Images of Full Simulation

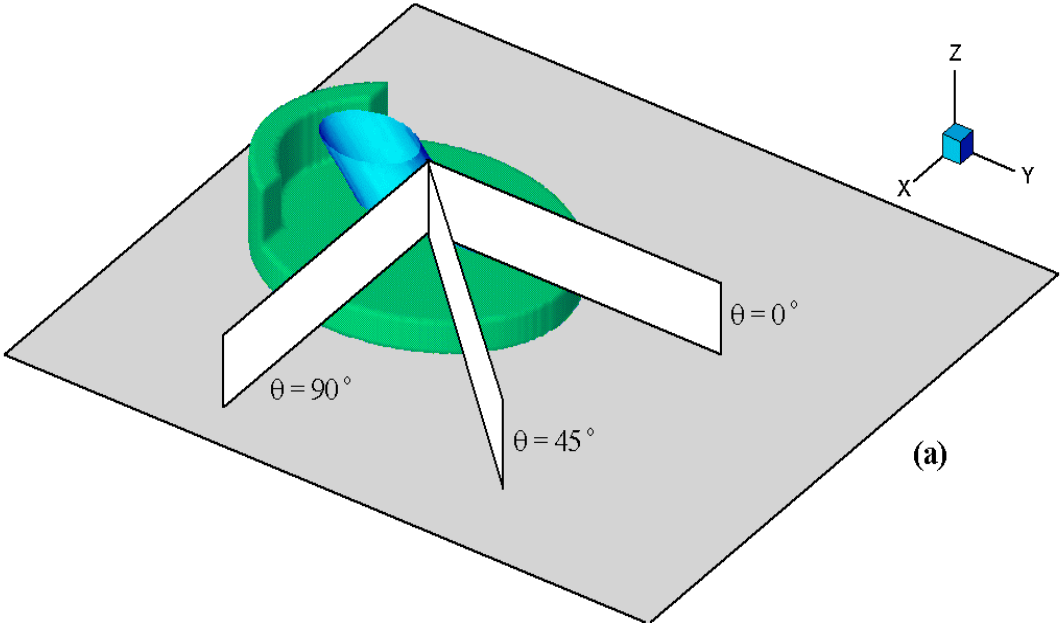


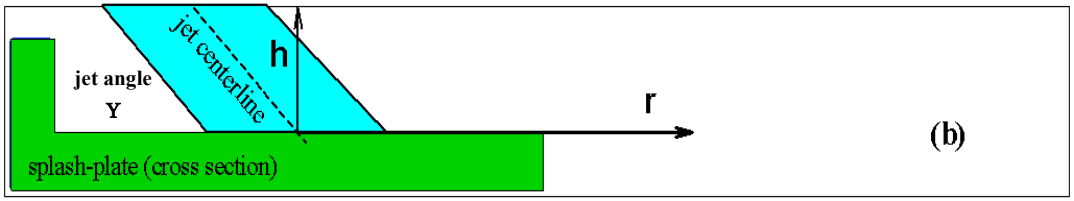


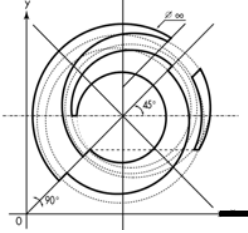


Test Cases

- One simulation using **BLSpray** gives all flow information in the entire domain of computation
- Results were analysed at three different cross-sections

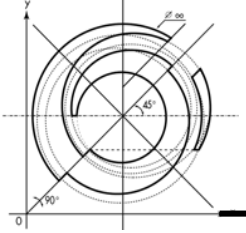






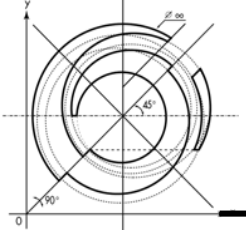
Test Cases: First Set

- Black liquor properties held constant
  - Viscosity 100 mPa·s
  - Surface Tension 60 mN/m
  - Density 1350 kg/m^3
- Varied splash plate conditions
  - Nozzle Diameter
  - Jet Velocity
  - Jet Angle
- Looking at effect on sheet characteristics



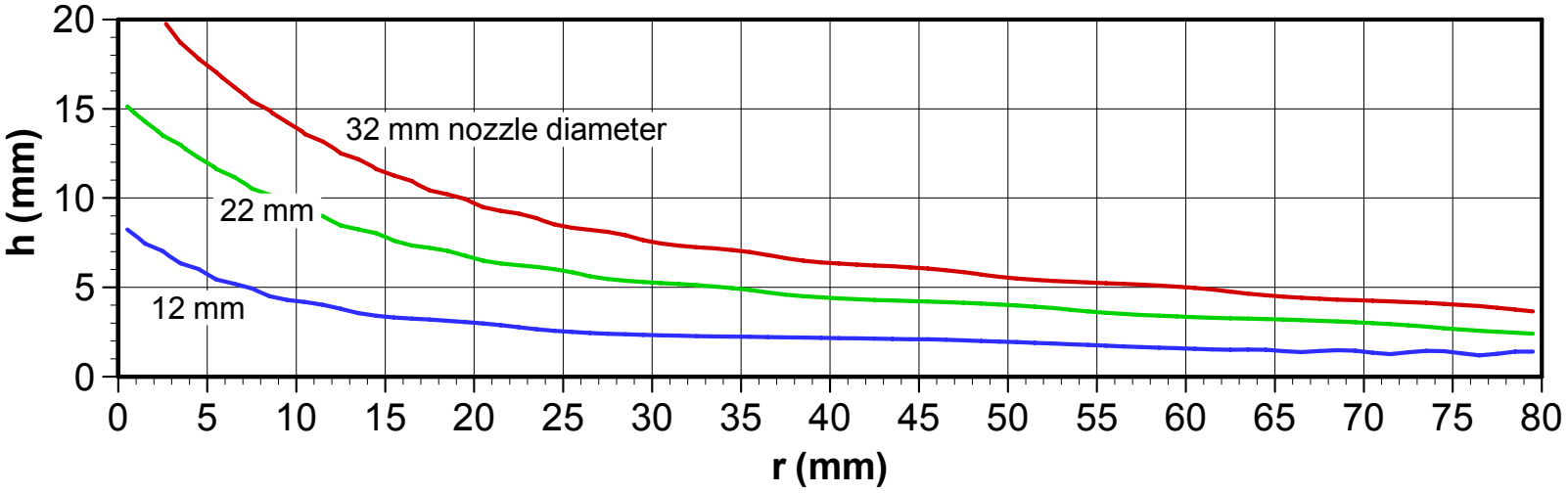
Nozzle Diameter

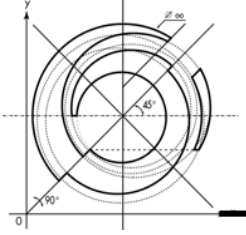
Nozzle Diameter (mm)	Jet Velocity (m/s)	Jet Angle (degrees)
12	10	45
22	10	45
32	10	45



Nozzle Diameter

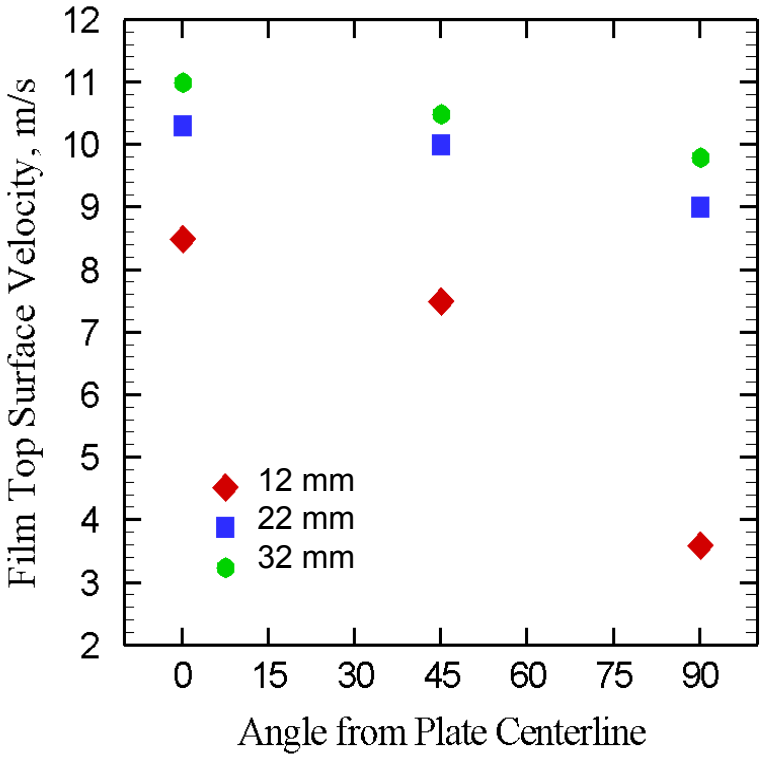
- As nozzle diameter increases
  - Film thickness increased
  - Sheet breaks up further from the plate
  - Radial distribution remained fairly constant

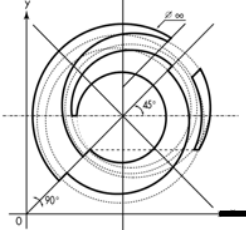




Nozzle Diameter

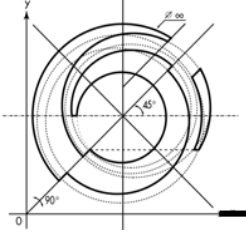
- Top surface velocity increased with increasing nozzle diameter



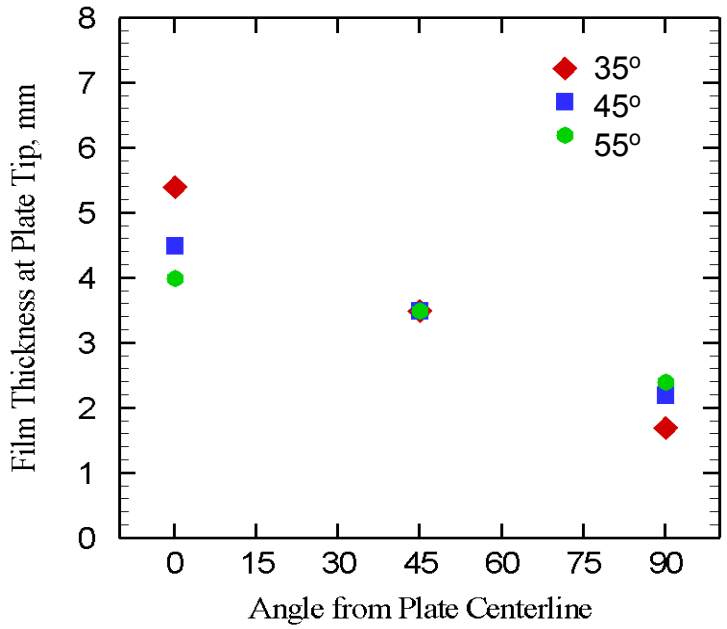


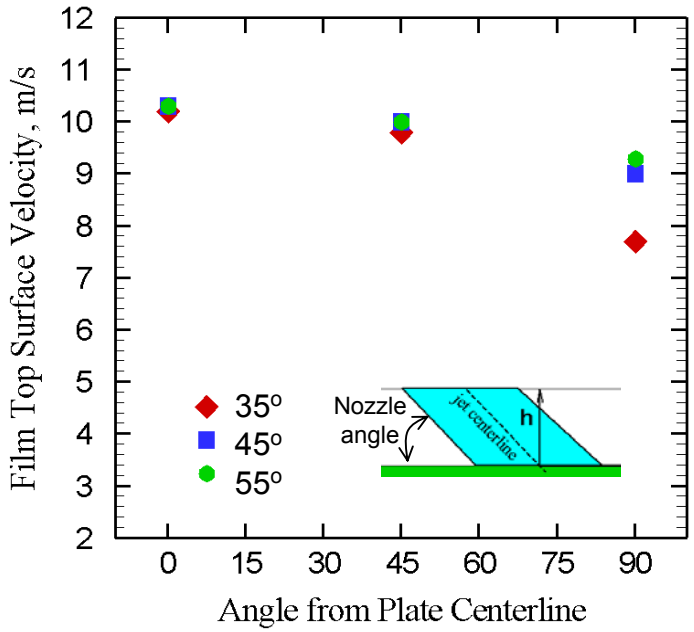
Jet Angle

Nozzle Diameter (mm)	Jet Velocity (m/s)	Jet Angle (degrees)
22	10	35
22	10	45
22	10	55

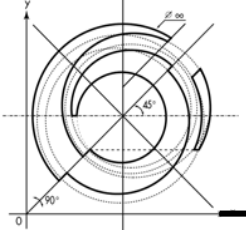


Jet Angle



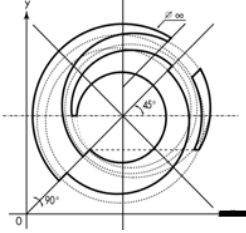


- As jet angle increases:
  - more atomisation towards side of splash plate, creates more uniform thickness distribution
  - atomisation occurs closer to plate at plane of symmetry
  - little effect on top surface velocity

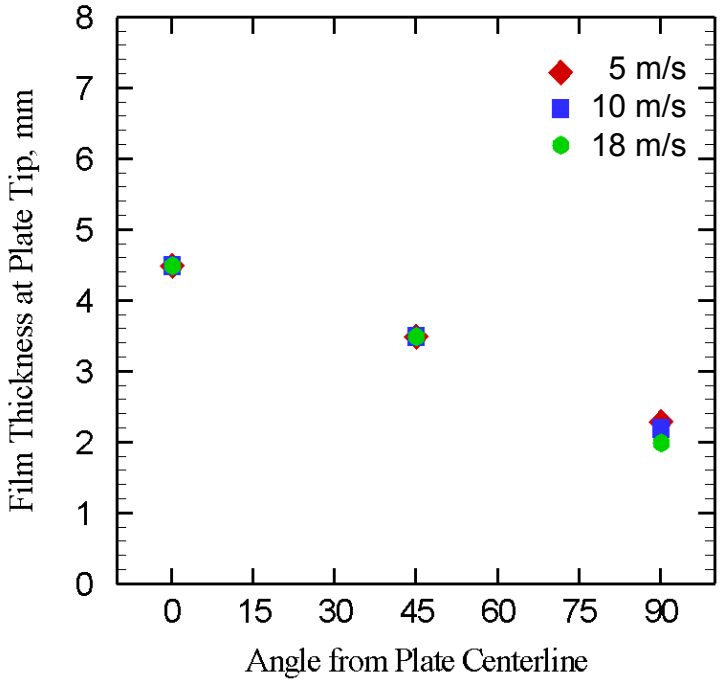


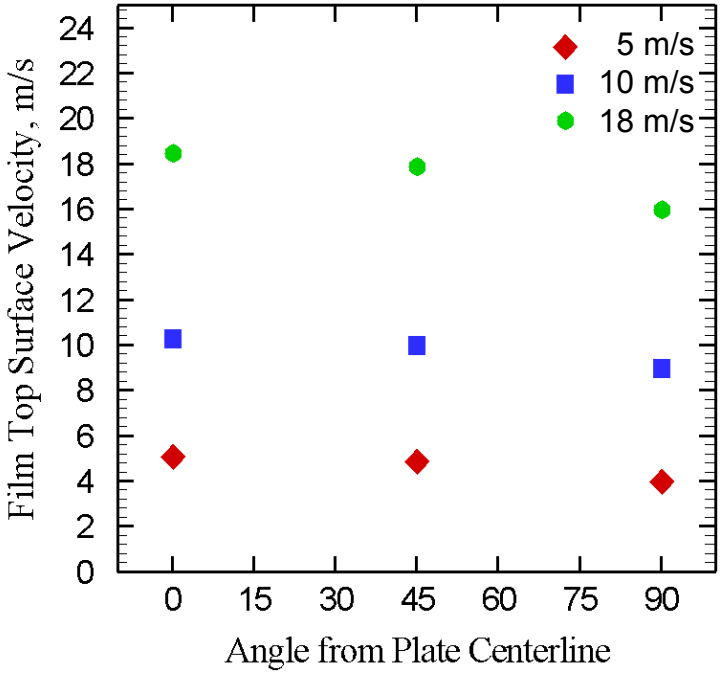
Jet Velocity

Nozzle Diameter (mm)	Jet Velocity (m/s)	Jet Angle (degrees)
22	5	45
22	10	45
22	18	45

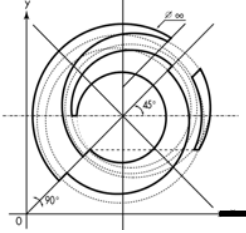


Jet Velocity



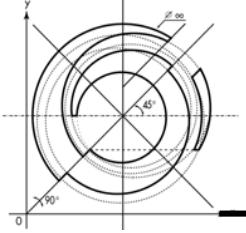


- As jet velocity increases
  - there is no effect on sheet thickness or radial distribution
  - velocity distribution increases proportionally

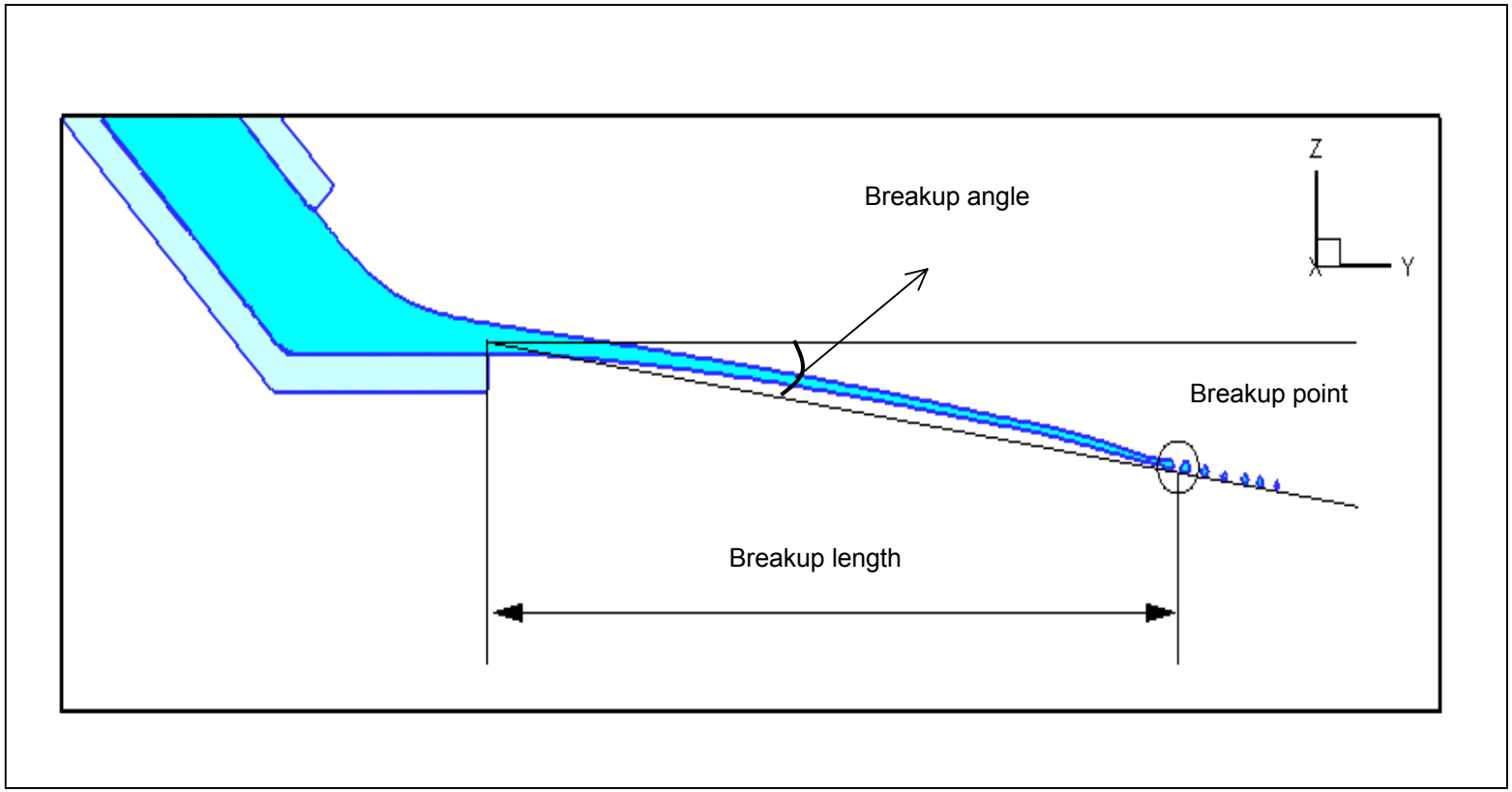


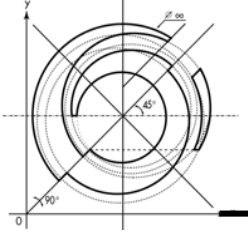
Test Cases: Second Set

- Splash plate configuration held constant
  - Nozzle Diameter 32 mm
  - Jet Angle 45 degrees
- Varied key properties affecting droplet size
  - Viscosity
  - Jet Velocity
  - Surface Tension
- Looking at effect on droplet size. Only 0 to 10º from plane of symmetry was analysed.



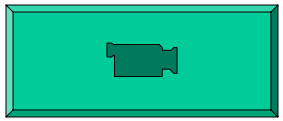
Test Cases: Second Set



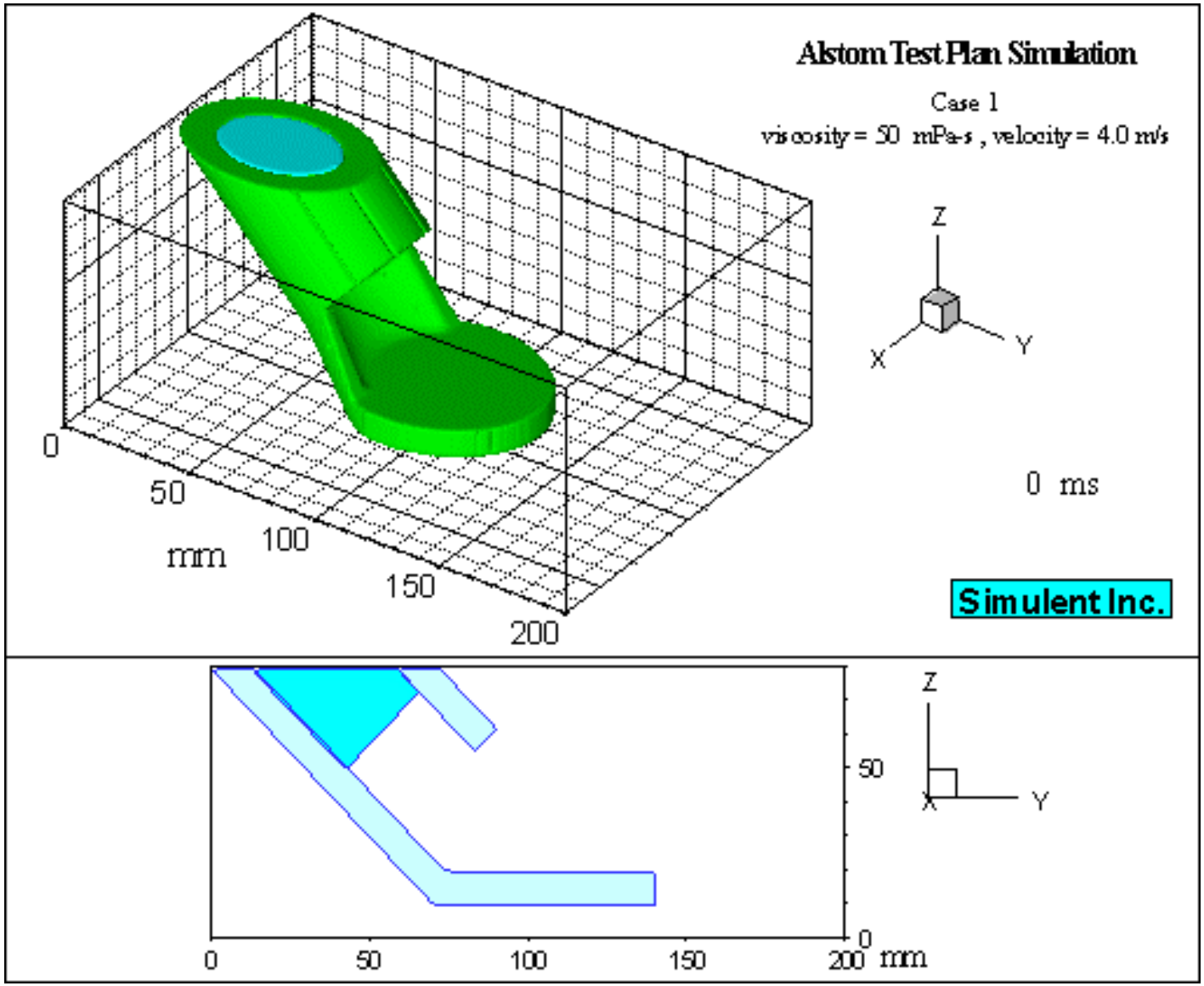


Low Black Liquor Viscosity: Case 1

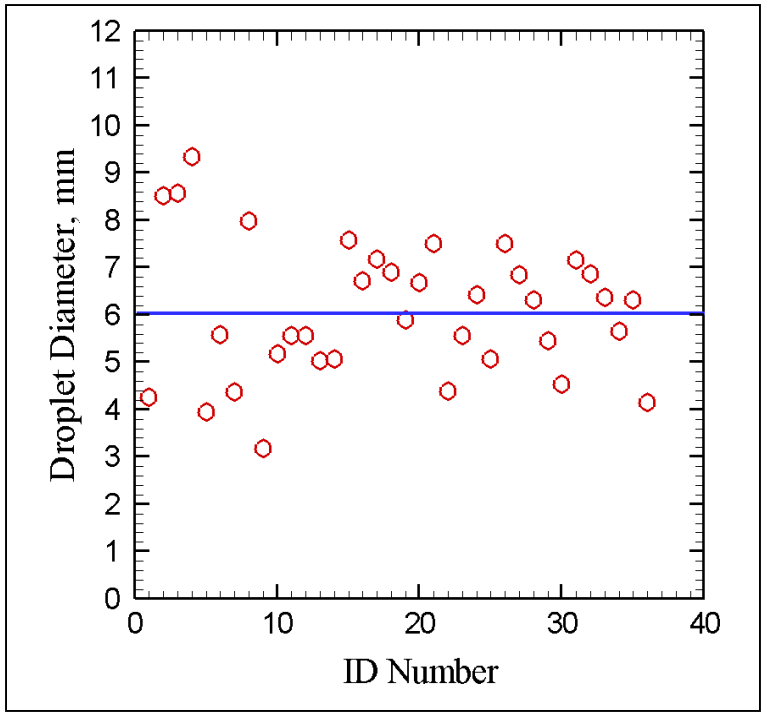
- Viscosity 50 mPa·s
- Jet Velocity 4 m/s
- Surface Tension 60 mN/m
- Density 1350 kg/m^3

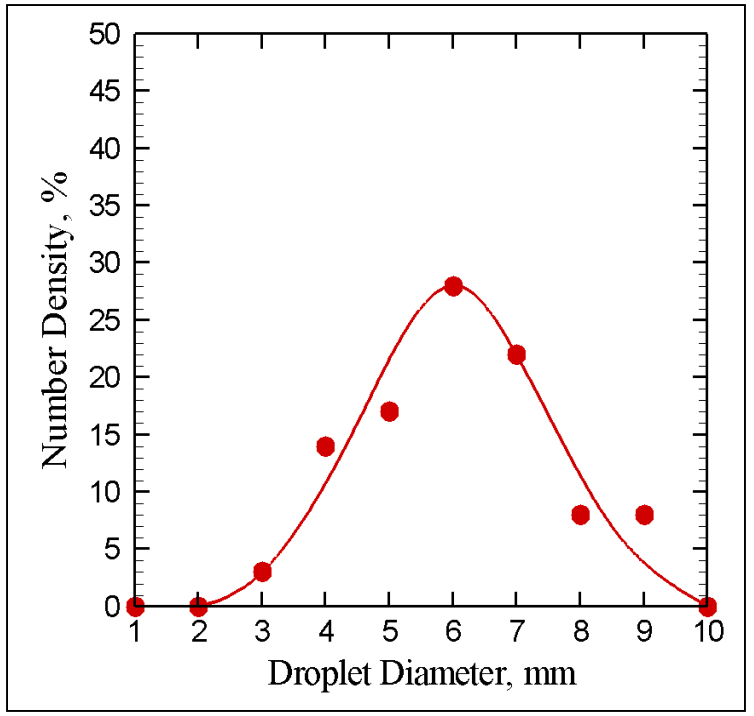


Low Black Liquor Viscosity: Case 1

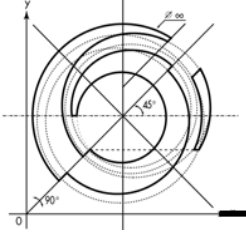


Low Black Liquor Viscosity: Case 1



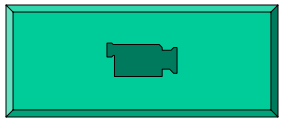


- Average Droplet Diameter 6.08 mm
- Breakup Length 270 mm
- Breakup Angle 8.4 degrees

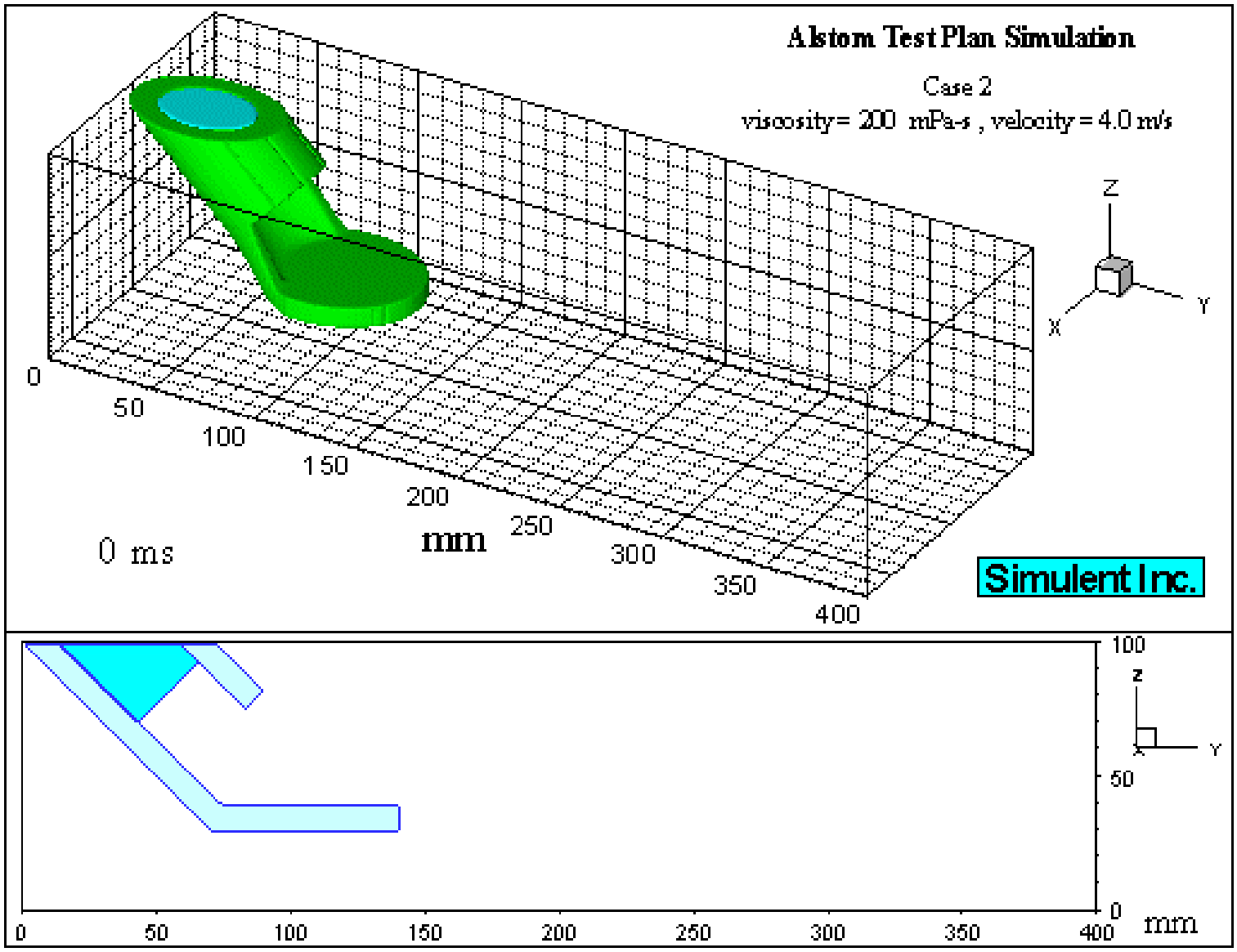


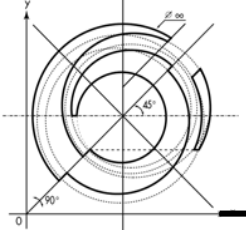
Typical Splash Plate Conditions: Case 2

- Viscosity 200 mPa·s
- Jet Velocity 4 m/s
- Surface Tension 60 mN/m
- Density 1350 kg/m^3

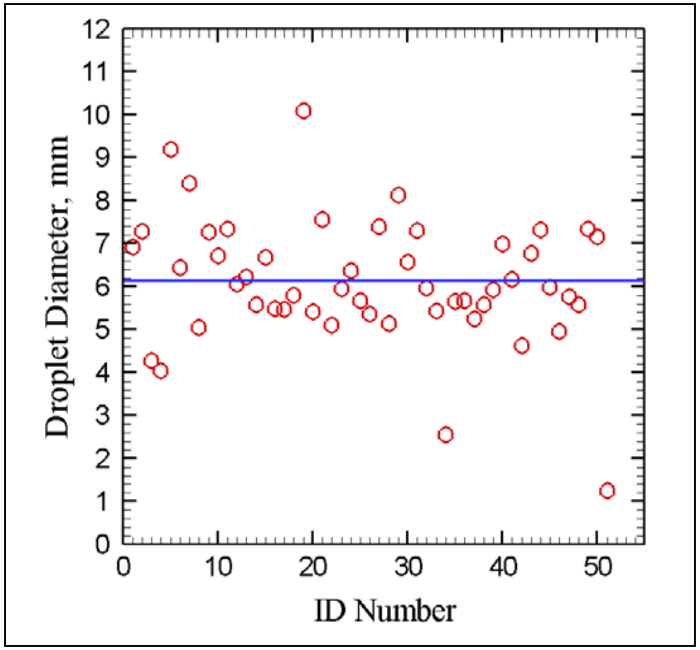


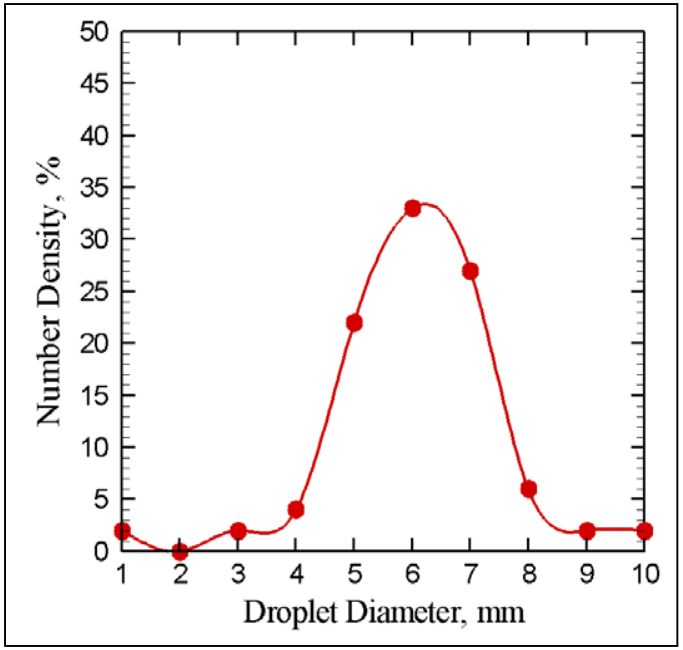
Typical Splash Plate Conditions: Case 2



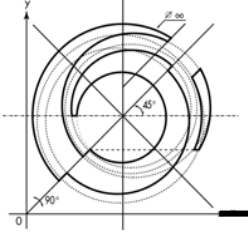


Typical Splash Plate Conditions: Case 2



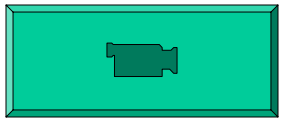


- Average Droplet Diameter 6.16 mm
- Breakup Length 270 mm
- Breakup Angle 9.5 degrees

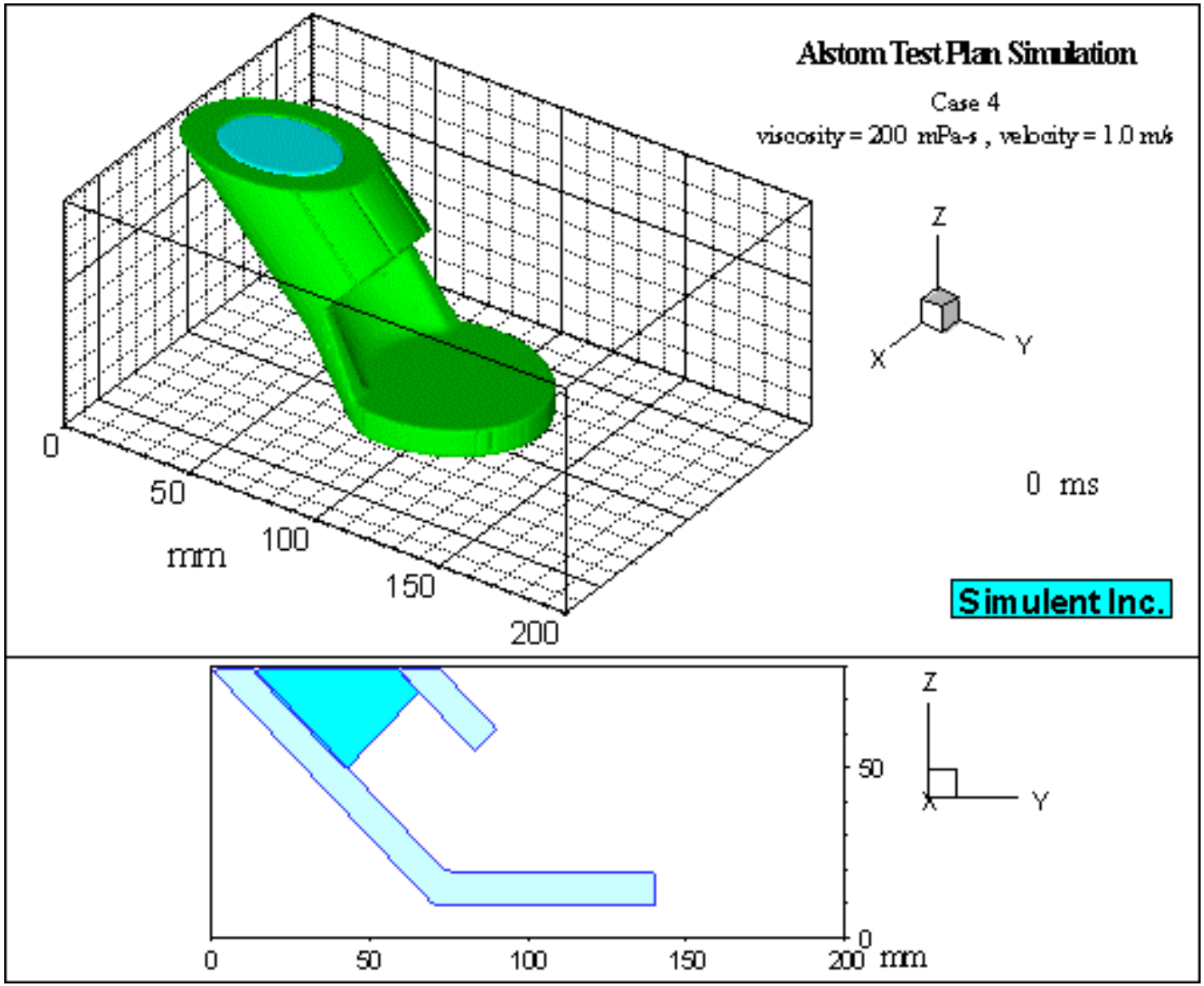


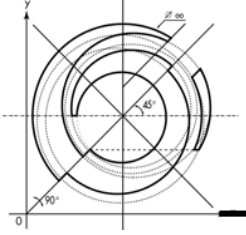
Low Jet Velocity: Case 4

- Viscosity 200 mPa·s
- Jet Velocity 1 m/s
- Surface Tension 60 mN/m
- Density 1350 kg/m^3

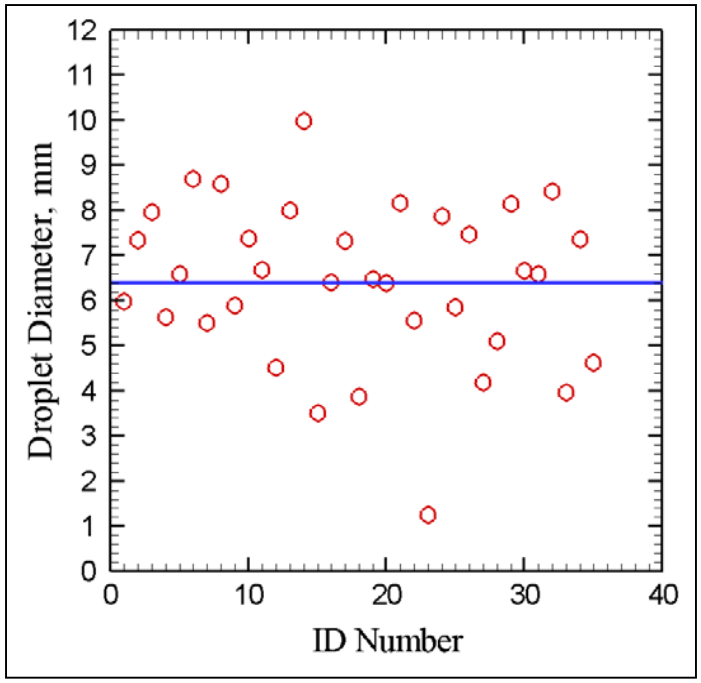


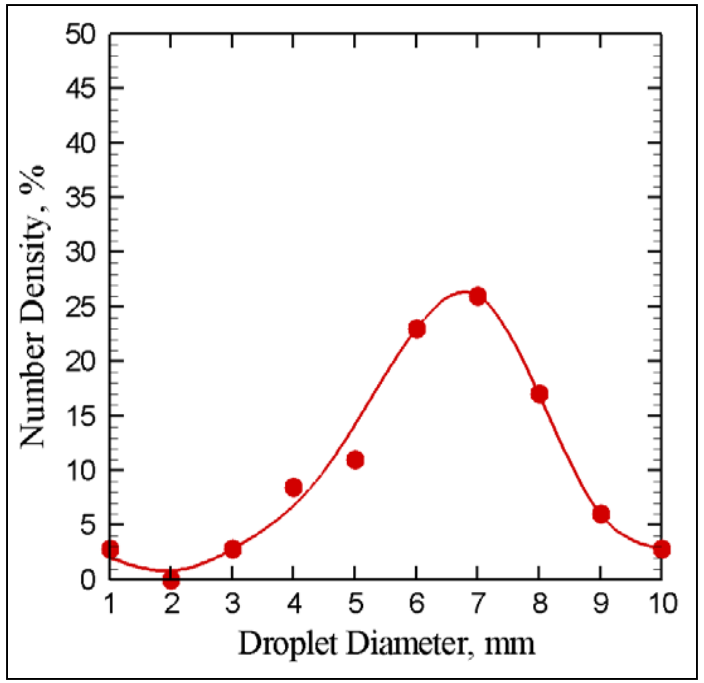
Low Jet Velocity: Case 4



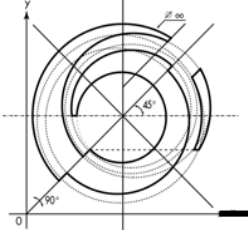


Low Jet Velocity: Case 4



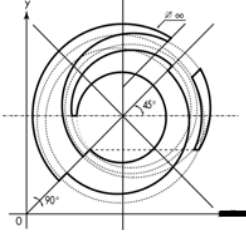


- Average Droplet Diameter 6.39 mm
- Breakup Length 120 mm
- Breakup Angle 36.9 degrees



Summary of Test Case Results: Second Set

Case #	Visc (mPa·s)	Nozzle Velocity (m/s)	Surface Tension (mN/m)	Droplet Size (mm)	Breakup Length (mm)	Breakup Angle (degrees)
1	50	4	60	6.08	270	8.4
2	200	4	60	6.16	270	9.5
3	700	4	60	6.58	320	10.6
4	200	1	60	6.39	120	36.9
5	200	10	60	4.49	270	3.8
6	200	4	30	5.48	270	9.5
7	200	4	90	7.6	280	10.1



Summary

- Preliminary **BLSpray** has been developed and validated
- Current **BLSpray** can be used to:
  - optimise current nozzle designs
  - test new nozzle designs
  - understand effects of varying black liquor properties
- Work is continuing to improve the code to include in-situ influences such as vapourisation, vertical velocity

Actual Spray