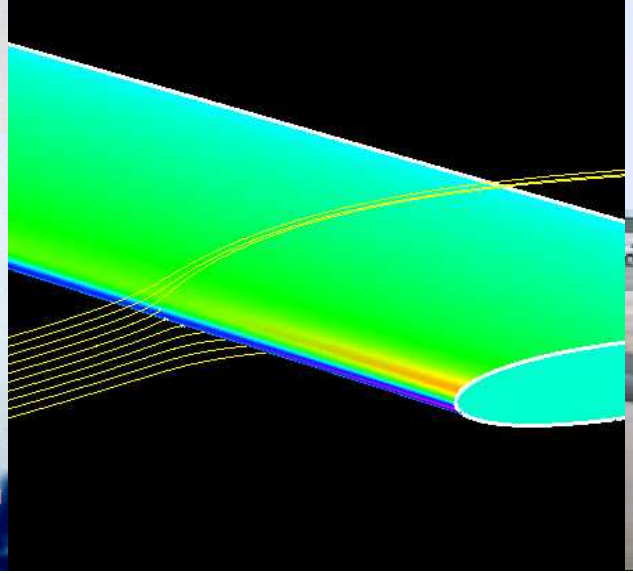

SLD Modelling in the UK

Roger W Gent

Technical Manager - Rotorcraft, Noise & Acoustics

Consultant - Aircraft Icing

Presentation for the NASA/ONERA 'CFD methods for SLD Simulation' workshop, Phoenix, 19-20 October 2006

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Contents

- Brief history of research in the UK
- Droplet splash modelling
- Icing code developments
- Future activities

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Brief History of SLD Research in the UK

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Introduction – UK SLD Research History

- Super-cooled Large Droplet, SLD, interest following Roselawn, ATR, crash
- SLD icing problem subsequently investigated at QinetiQ (DERA) from 1998
- Funded by UK civil government (Department of Trade and Industry)
- Conducted SLD icing wind tunnel test:-
  - GKN-ACT Artington 1998 - Initial investigation + Ice shapes for code validation
- Also modified 2D icing code (1998); drag law, gravity and (basic) splash
- Poor prediction of ice shape - much larger than measured!
- ***Reason attributed to inability to model splash mass loss***
- GKN-TS (ACT) Luton 2000 icing wind tunnel test
  - Splash investigation with BAES using high power laser imaging technique
  - ***Confirmed SLD splash***

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Laser imagery of SLD droplet Splash

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Introduction – UK SLD Research History (2)

- QinetiQ awarded 3-year fundamental research contract in FY01, split approximately equally between experiment and analysis (theory)
- *Aim: Develop splash mass loss algorithm for use in icing codes*
- Funded by DTI under Civil Aircraft R&D (CARAD) programme
- Scope of work extended by collaboration with NASA Glenn (Droplet imaging)
- Joint tunnel test conducted in May 2002 in ACT Luton Icing Research Wind Tunnel
- Initial algorithm formulated
  - Catch efficiency reduced due to splash - tendency to predict rime ice!
  - Empirical droplet re-impingement/re-attachment (small droplets) model added
  - ***Improvement in ice shape/mass for cylinders,poor agreement for aerofoils!***

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Other UK SLD Icing Modelling Research Activities

- University College London

  - Theoretical study of droplet splash into a wall/water film
  - Used 2D Volume of Fluid (VOF) method

- Cranfield University

  - Extended UCL 2D VOF to include thermal effects / iced surface
  - Droplet splash experimental programme (vertical wind tunnel)
    - Funded by UK CAA

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Other UK SLD Icing Modelling Research Activities

- University College London
  - *2D VOF method; droplet splash into a wall/water film*
  - Academic funding (EPSRC), QinetiQ as Industrial Sponsor
  - First phase completed in 2004
    - Assumed problem was inviscid, isothermal, and treated in 2D
    - No air effects included (splash in a vacuum)
    - Extended to include splash in air effects ; shear velocity
    - Splash of non-spherical droplet
    - Initial look at viscosity, and surface roughness
  - Second phase started Sept. 2006
    - Extension to 3D, roughness and air effects

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Other UK SLD Icing Modelling Research Activities

- Cranfield University
  - *Extended UCL 2D VOF to include thermal effects / iced surface*
  - Academic funding, GKN-TS as Industrial sponsor
  - Completed Spring 2006 (Phd Thesis)
  - *Predicted most splash mass loss is from fluid layer – not the droplet*

  - *CAA funded vertical wind tunnel, droplet splash measurement*
  - Using NASA imaging equipment / joint trial
  - Data processed for use in generating/validating algorithms
  - Work completed in 2005.

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Water droplet impact into a liquid Layer

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Droplet Impact and Aircraft Icing

Dr Richard Purvis

University of East Anglia

Prof Frank Smith

University College London

Sponsor: QinetiQ

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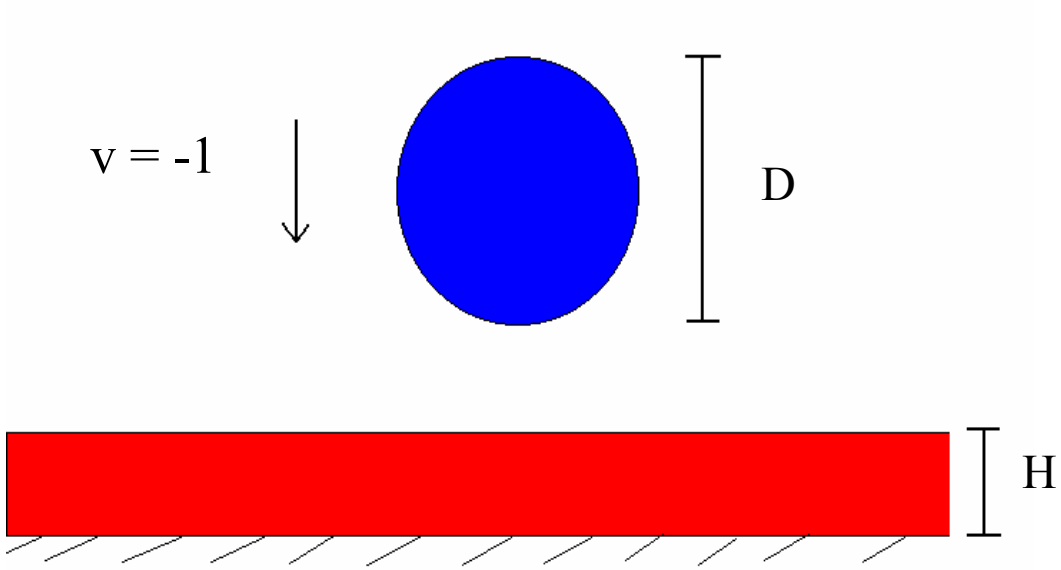
The problem

- Two Dimensional
- Inviscid (Re~$10^{5)}$
- No gravity (Fr~10^{8})
- Incompressible
- No air
- Undisturbed water layer
- No ice roughness



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Volume of fluid method

- The VOF method tracks the free-surface by introducing a function **F** such that, in each grid cell, **F** has the value of the fraction of that cell which is filled with fluid.
- The interface is then reconstructed using straight lines in each grid cell.
- This can then be evolved using the local velocity field.

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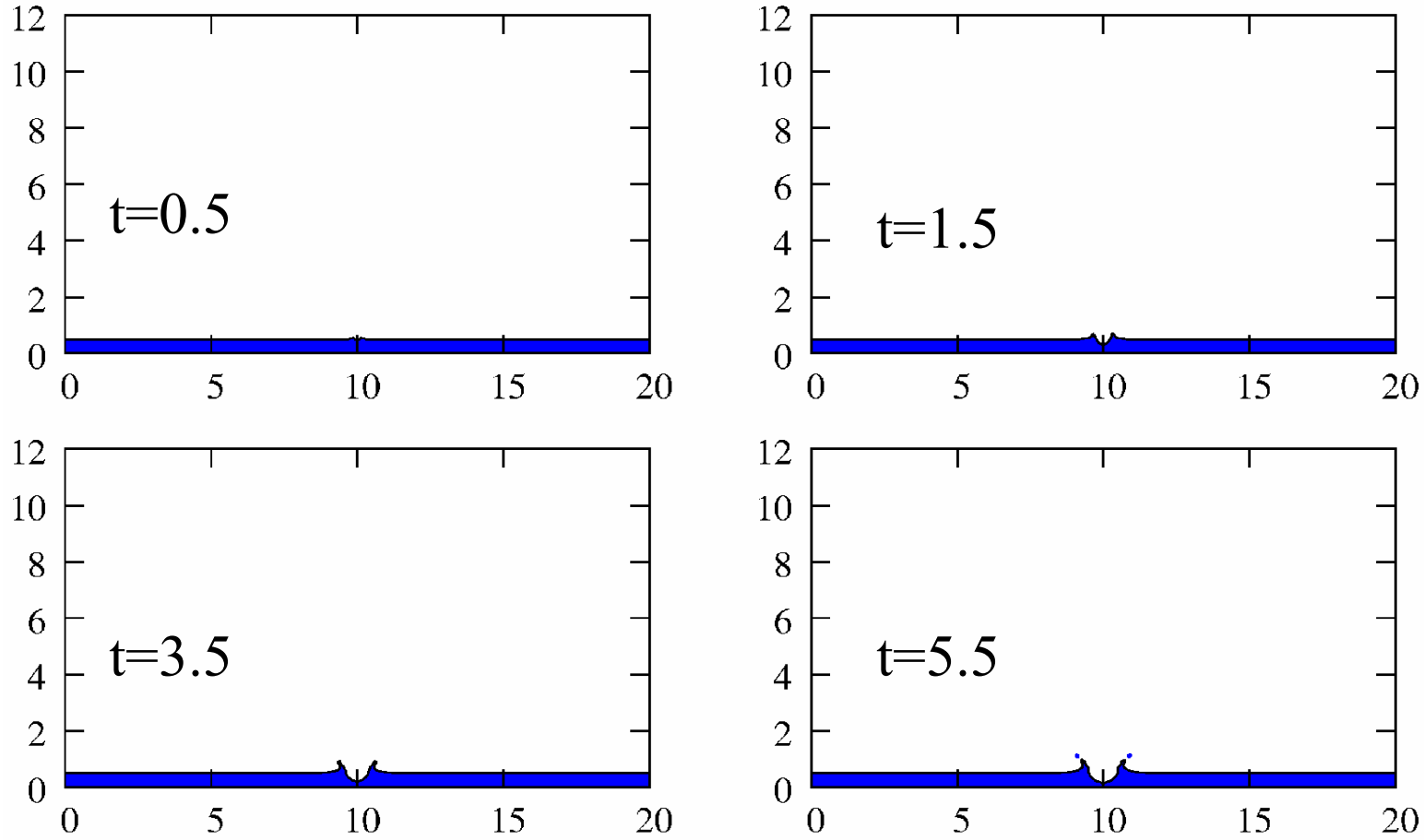
Numerical Results – D/H=1/2



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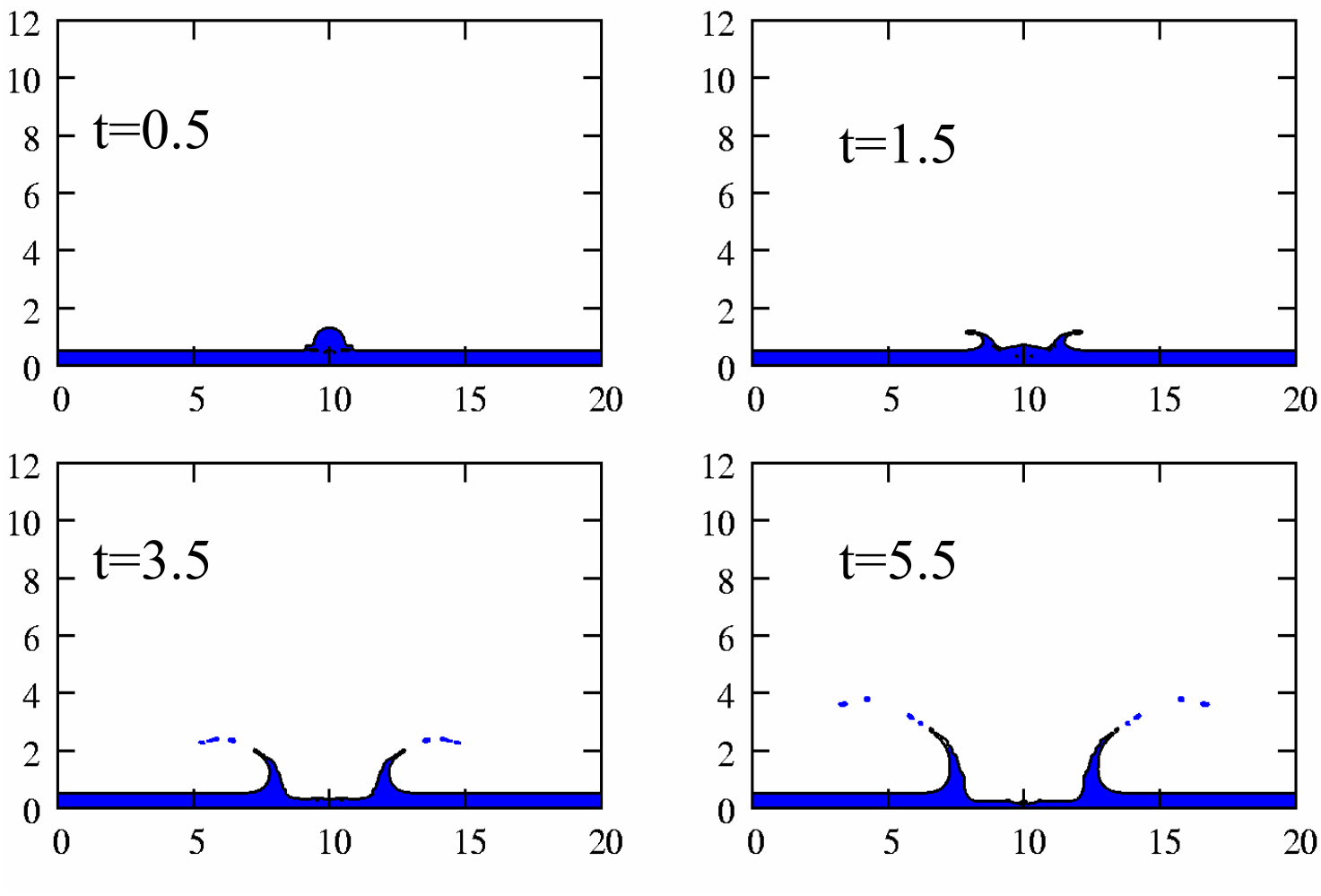
Numerical Results – D/H=2



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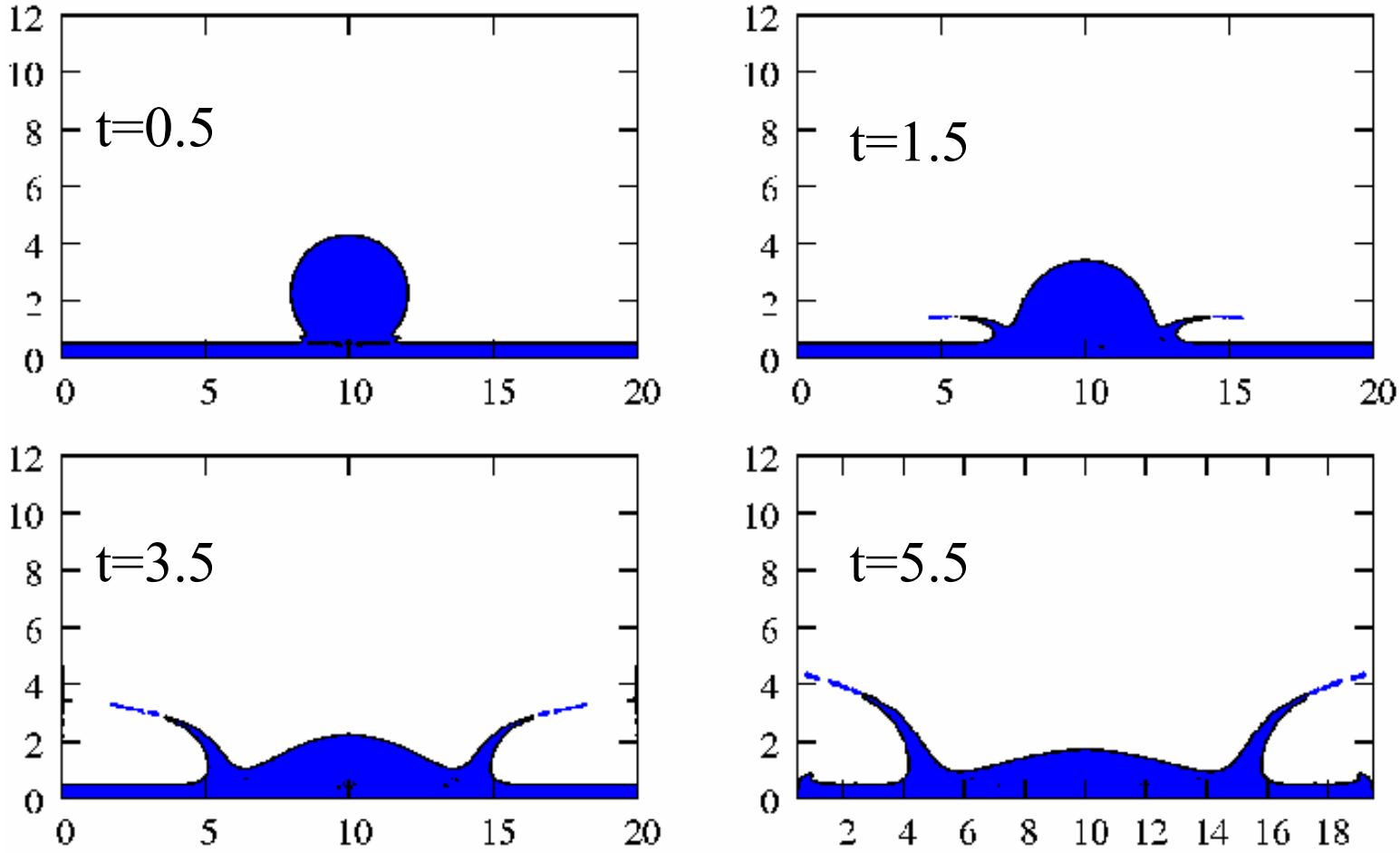
Numerical Results – D/H=8



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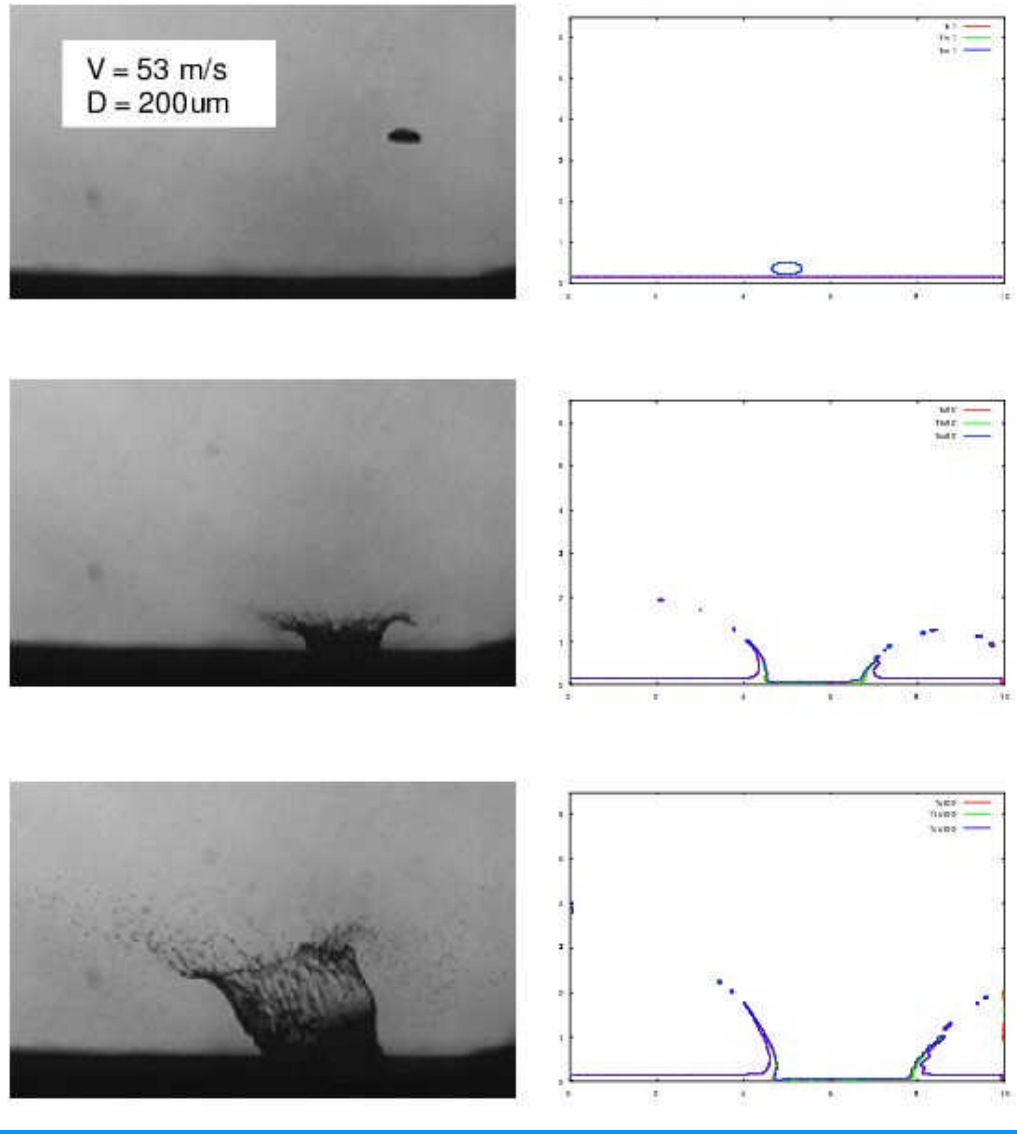
Comparison with experiments

- Good agreement early in impact
- Not so good as corona develops



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Extension to include Air effects

- VOF method extended to include air effects
- This involves
  - Pre-impact Air cushioning
    - Large droplets ‘flatten’ just prior to impact
  - Droplet distortion in accelerating flow

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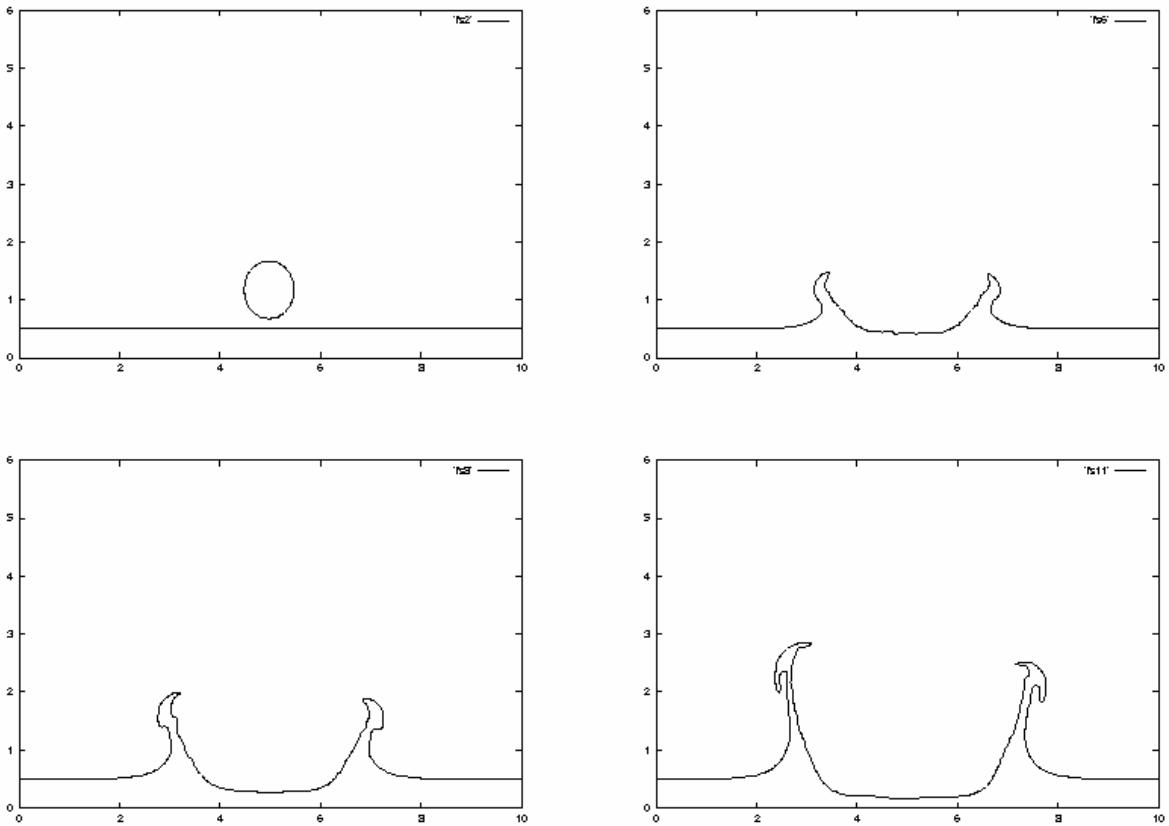
Numerical Results – D/H=2, with shear flow

Shear Flow=
10% of droplet velocity



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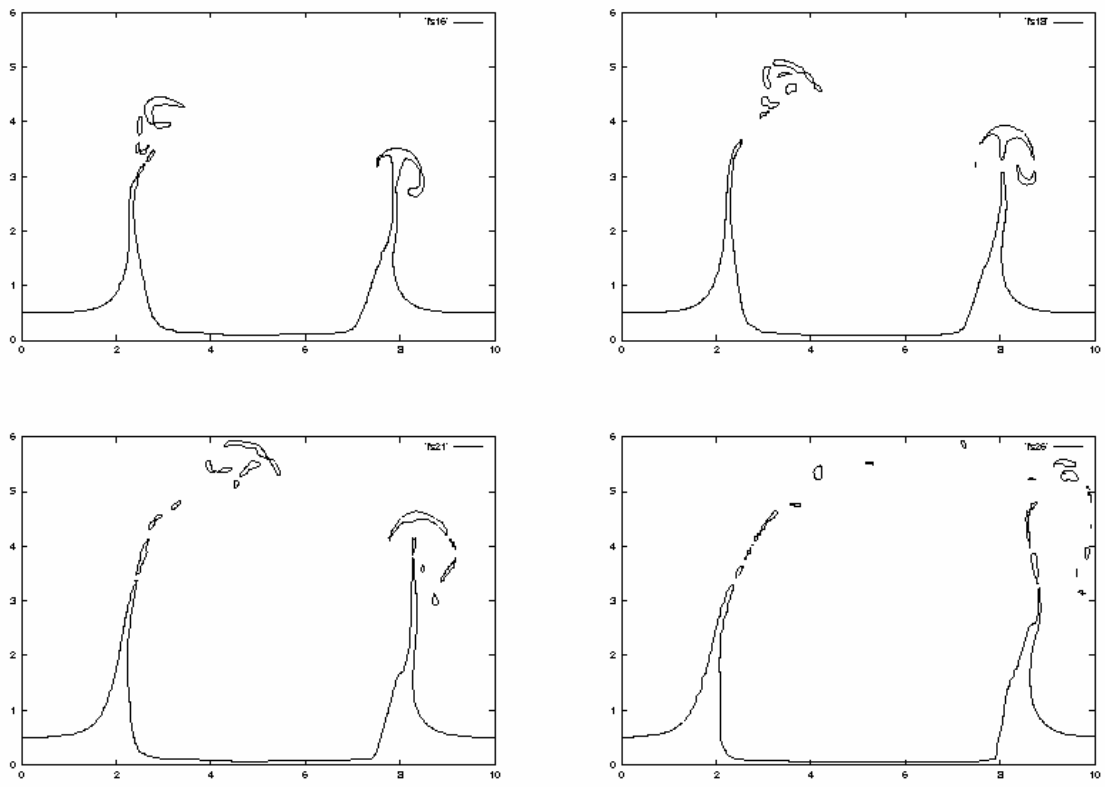
Numerical Results – D/H=2; with shear flow



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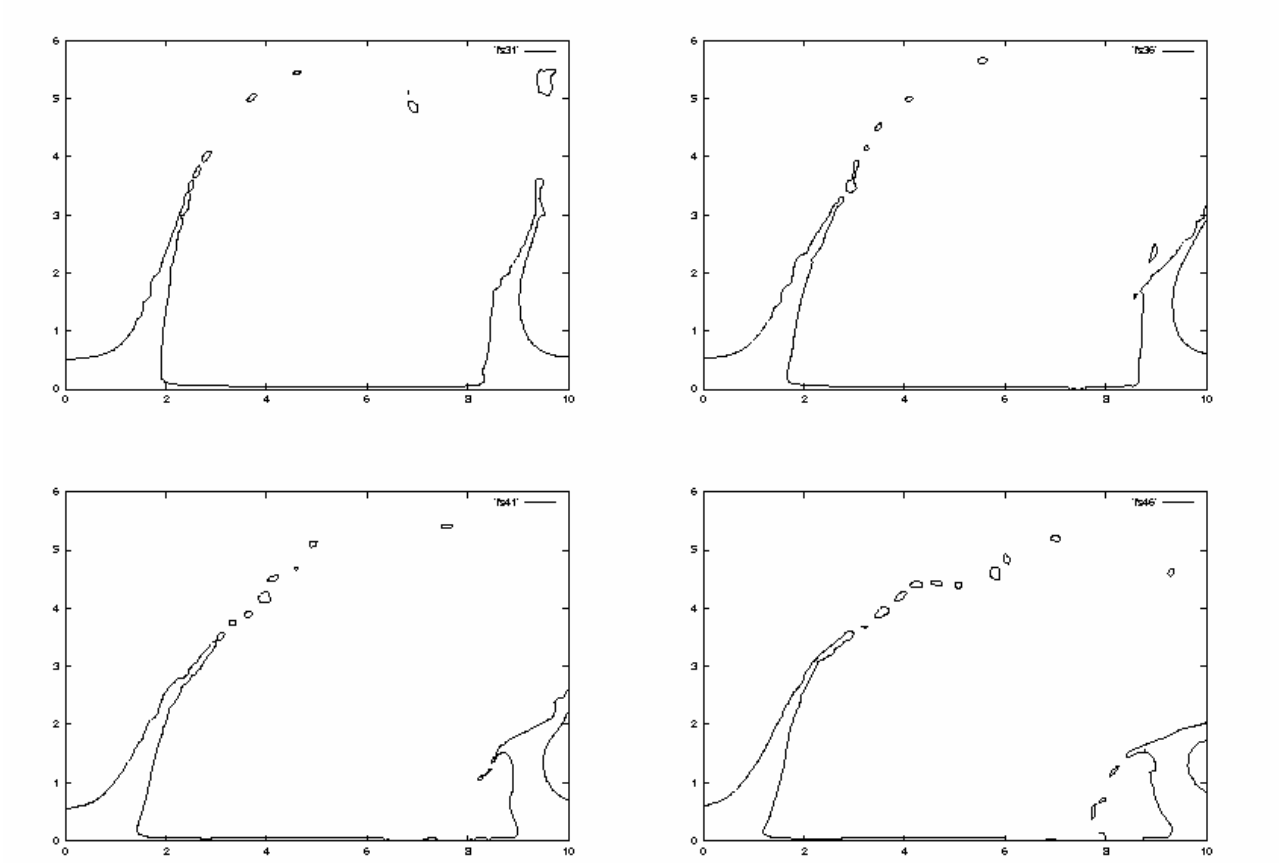
Numerical Results – D/H=2; with shear flow



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Thermal effects and impact on iced surface

Manuel Quero and David Hammond
Cranfield University

Collaborators: Richard Purvis (University of East Anglia) and
Frank Smith (University College, London)

Sponsor: GKN Aerospace

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Objectives

- To compare experiments and modelling
- Study of the heat transfer between SLD and water film during splash
- Outline of Solidification model

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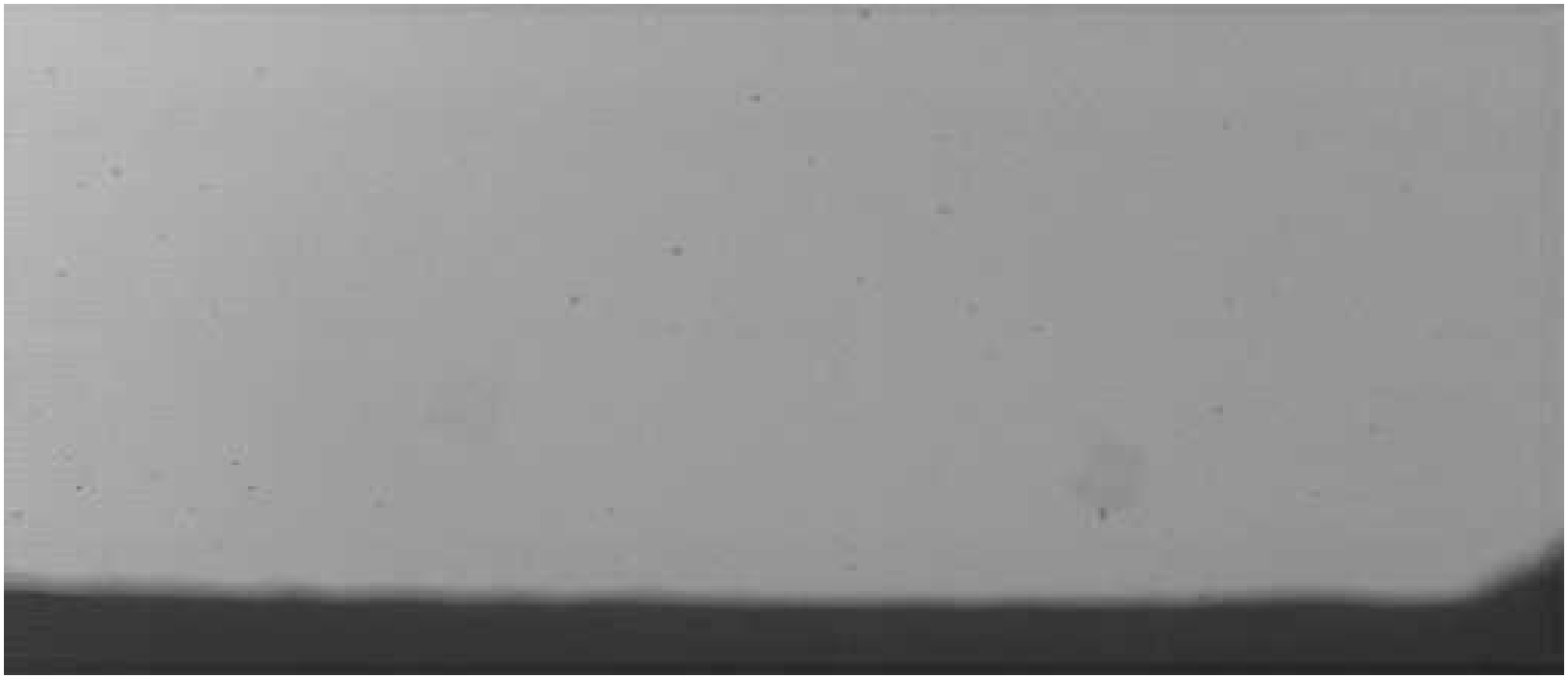

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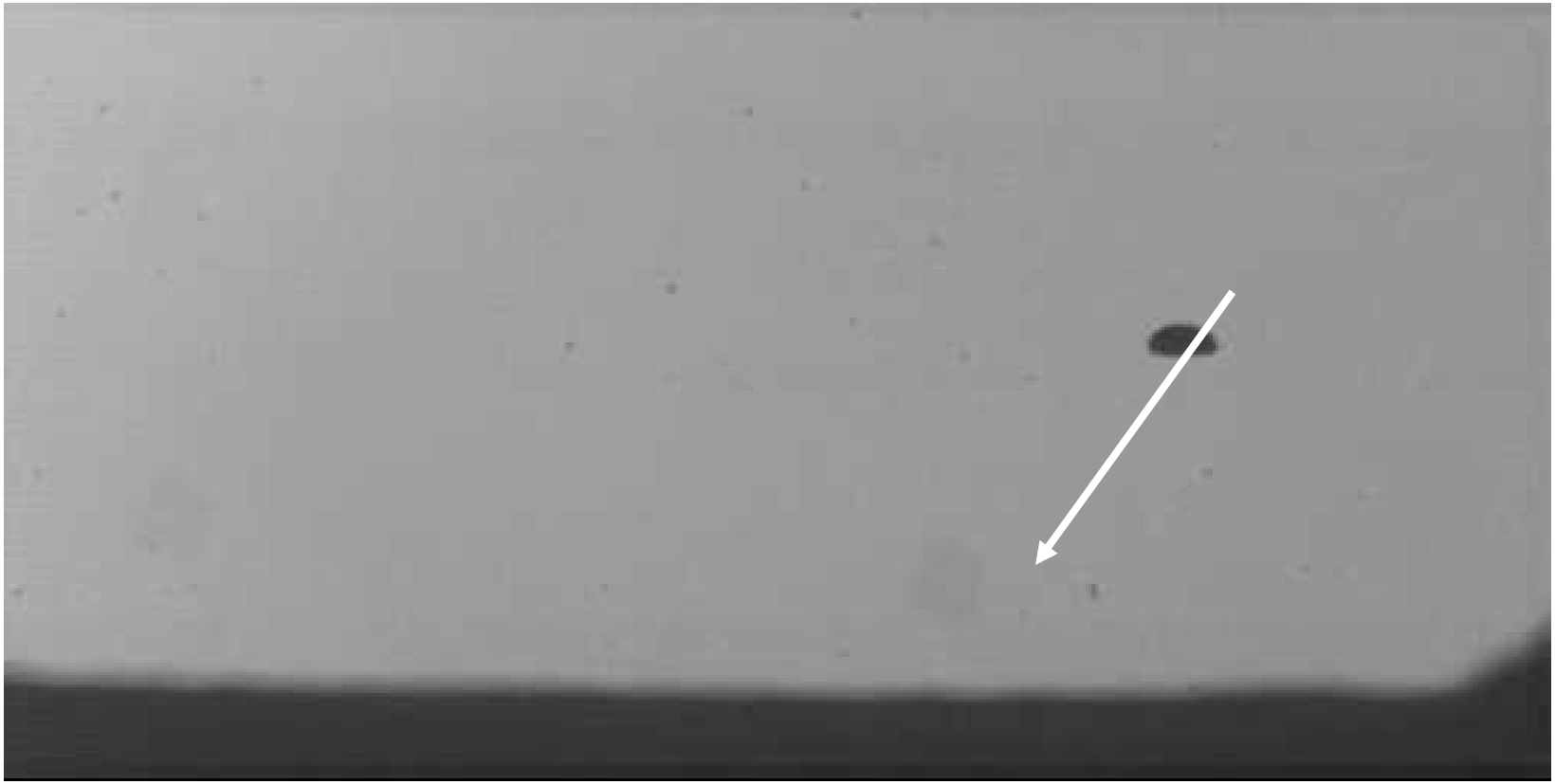

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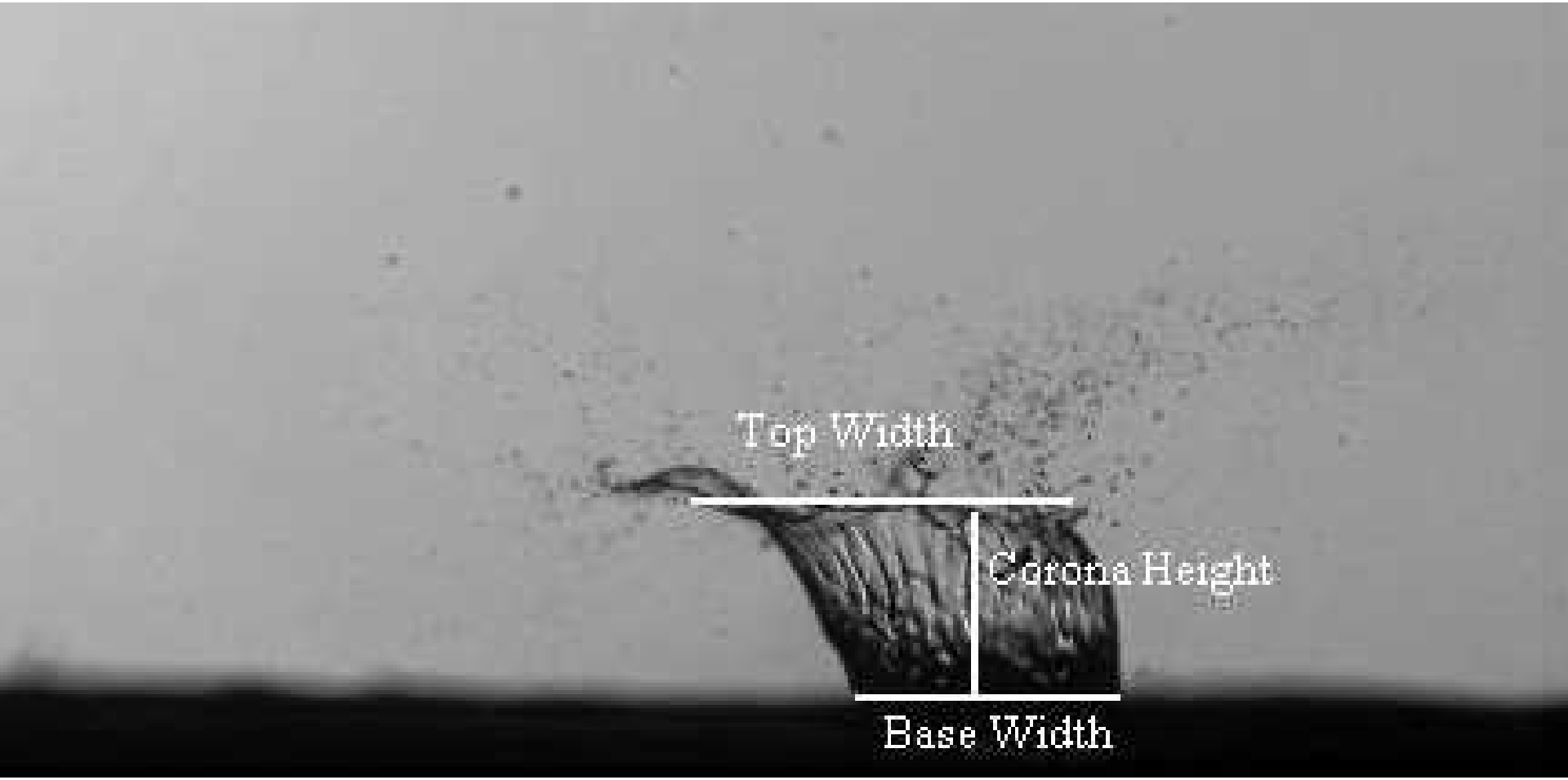

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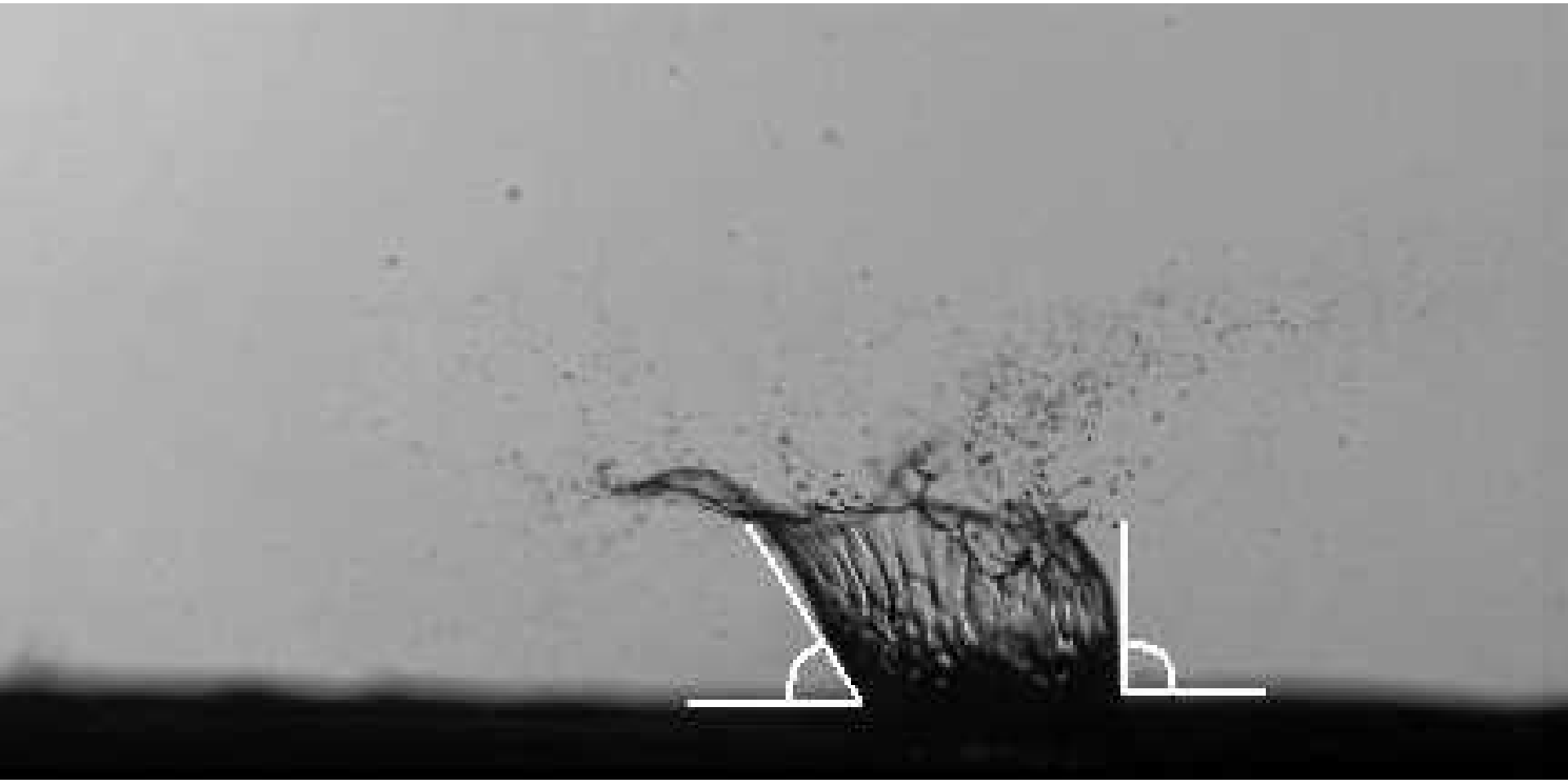

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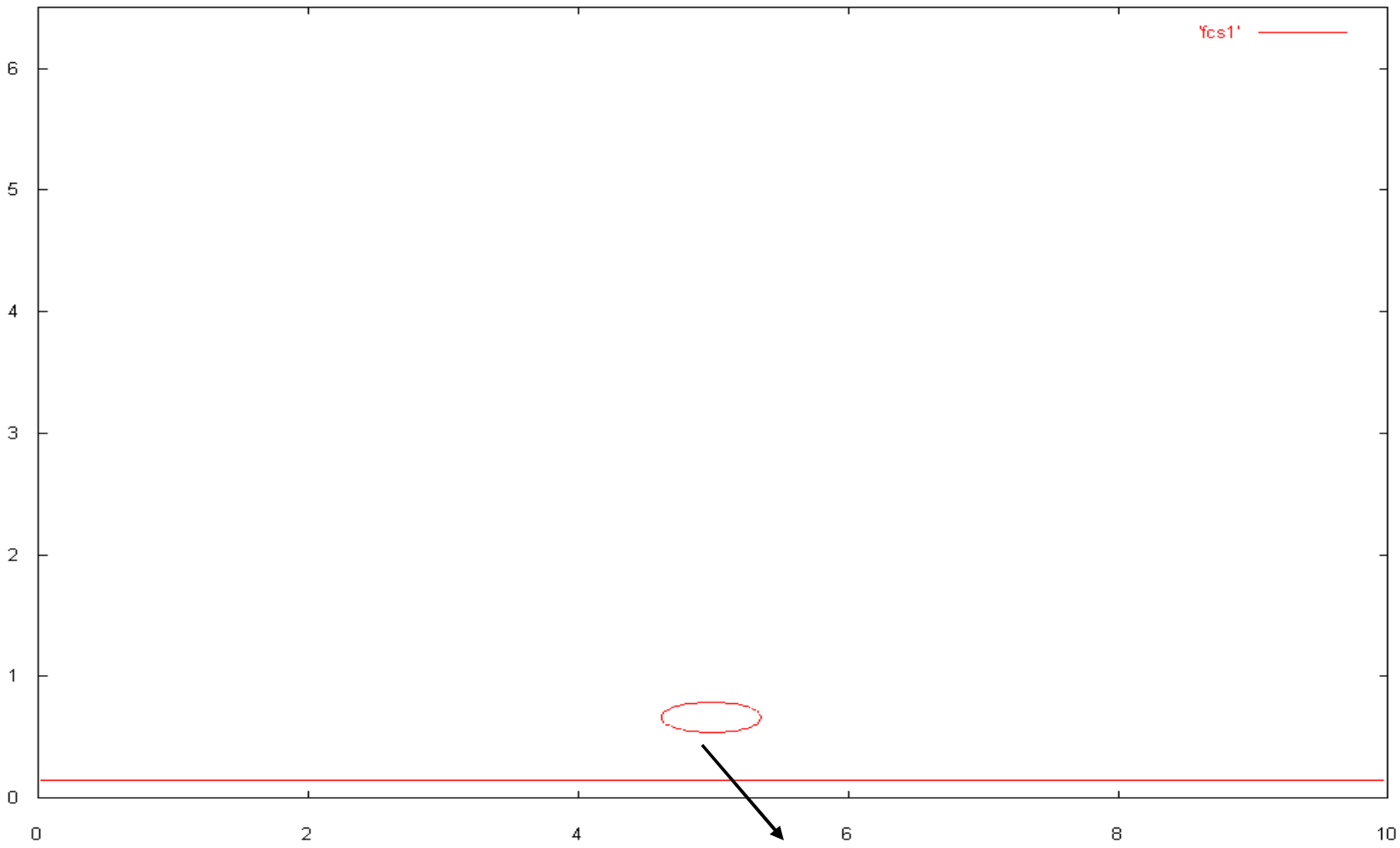

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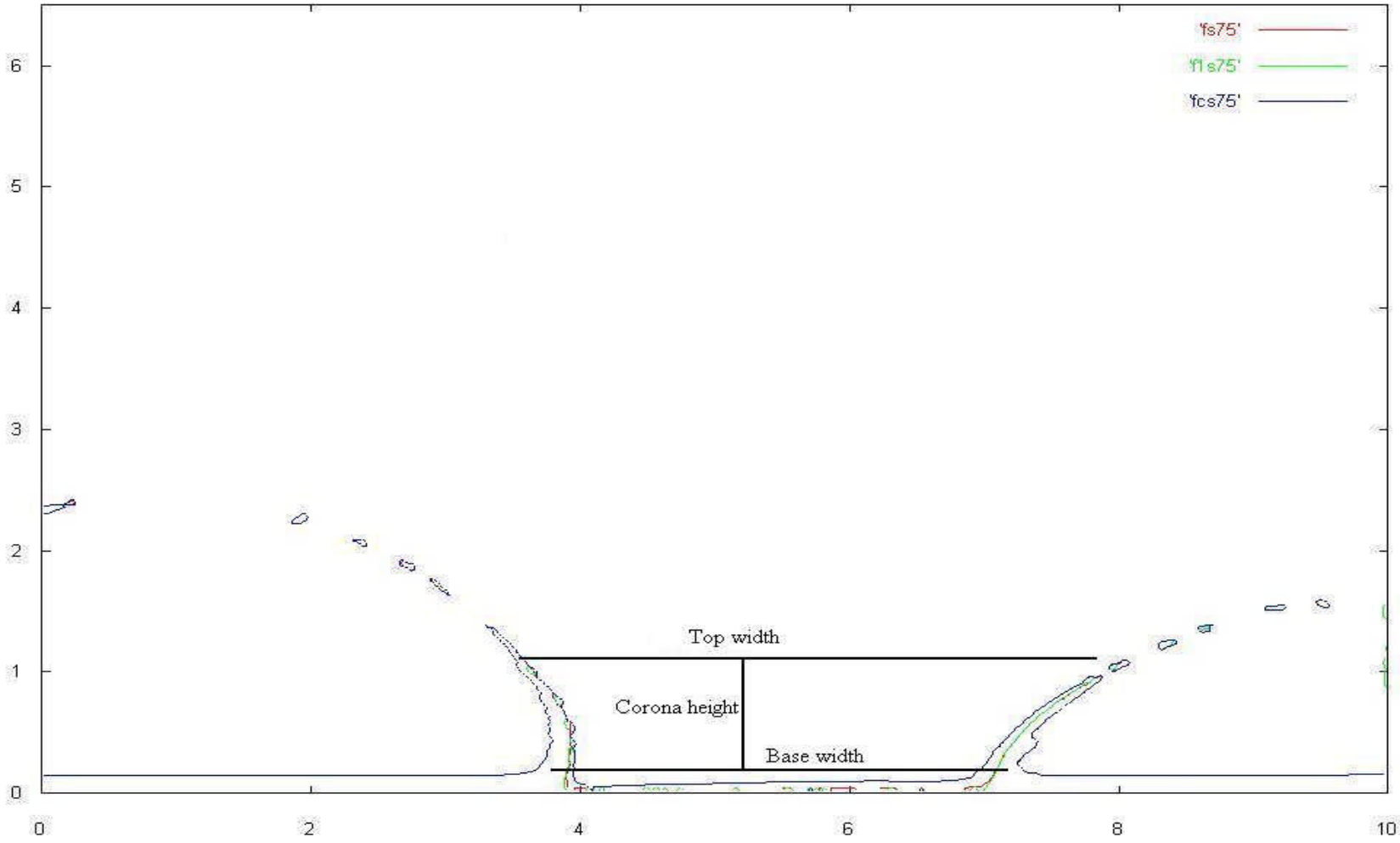

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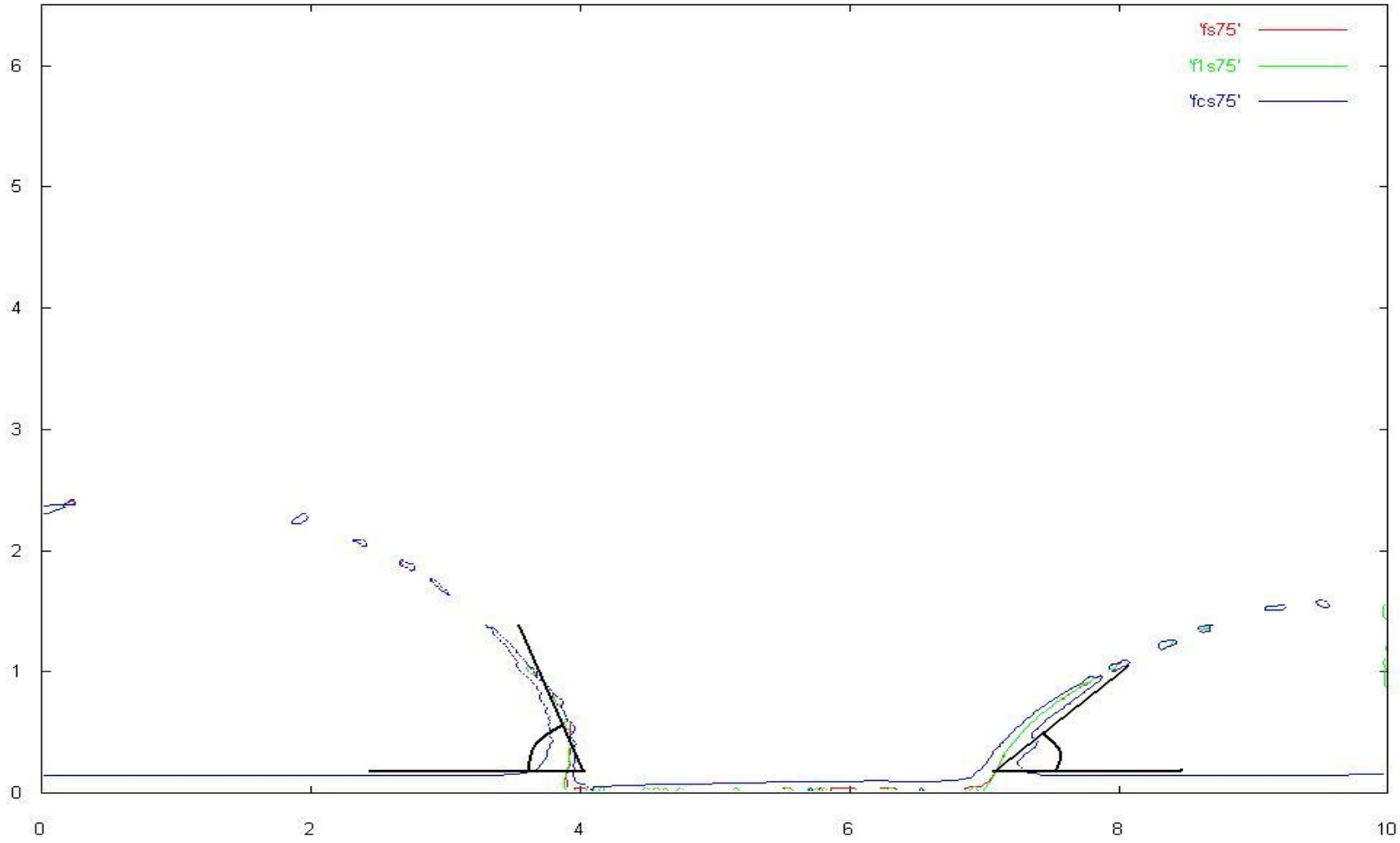

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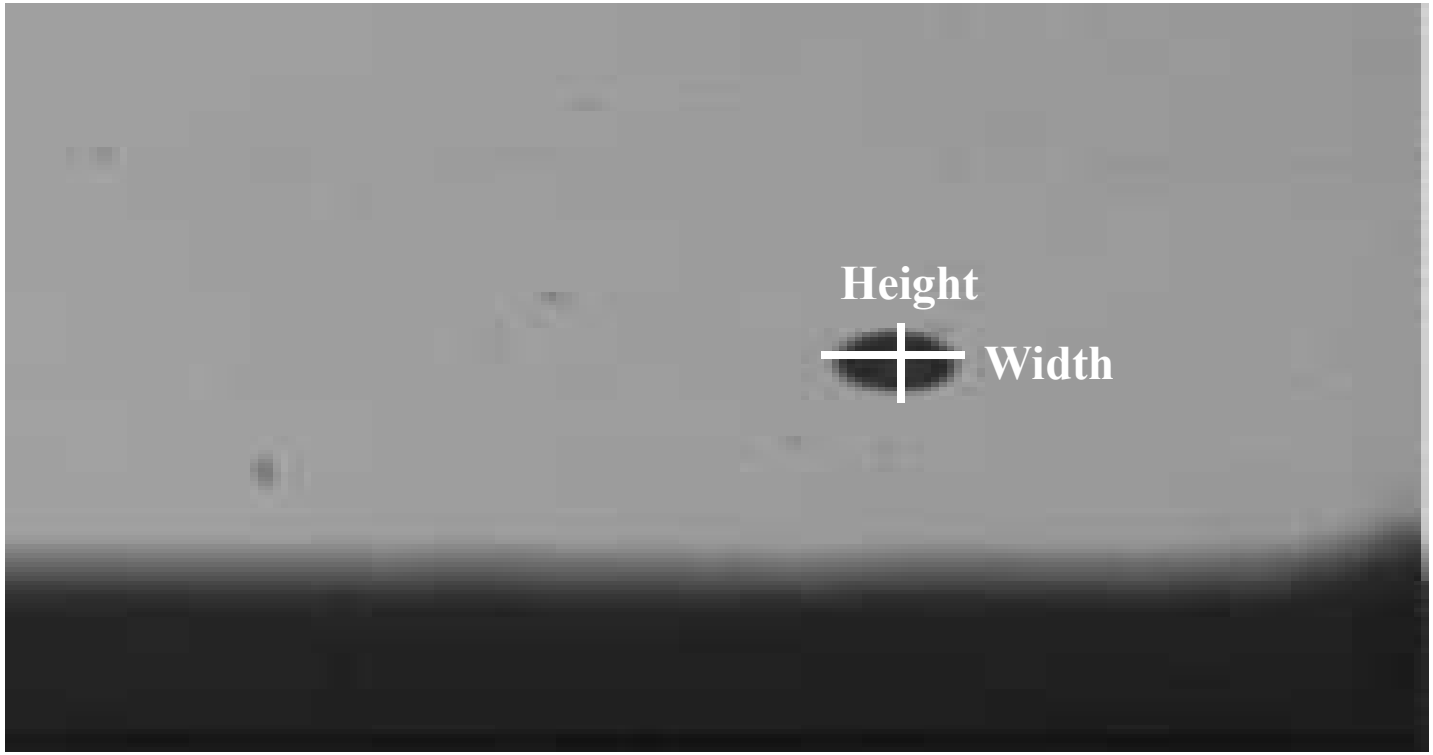

$$VED = \sqrt[3]{W^2 H}$$

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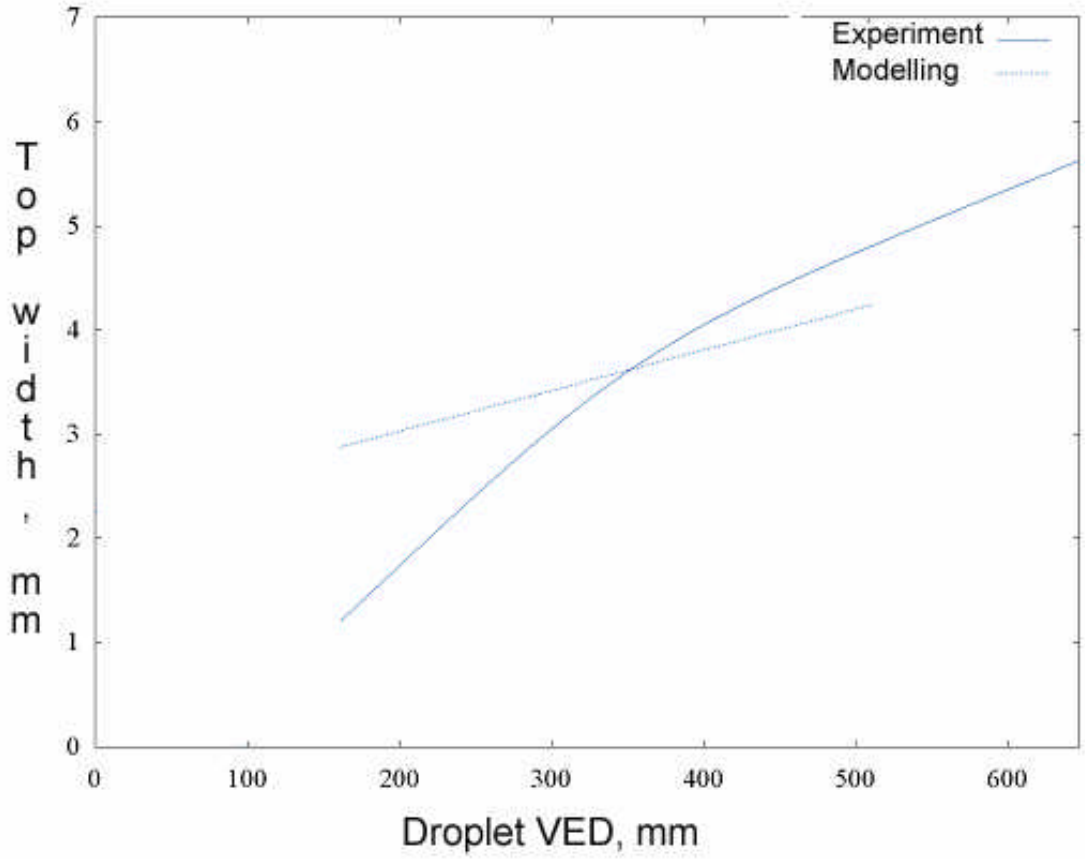
Comparisons



Corona Top Width

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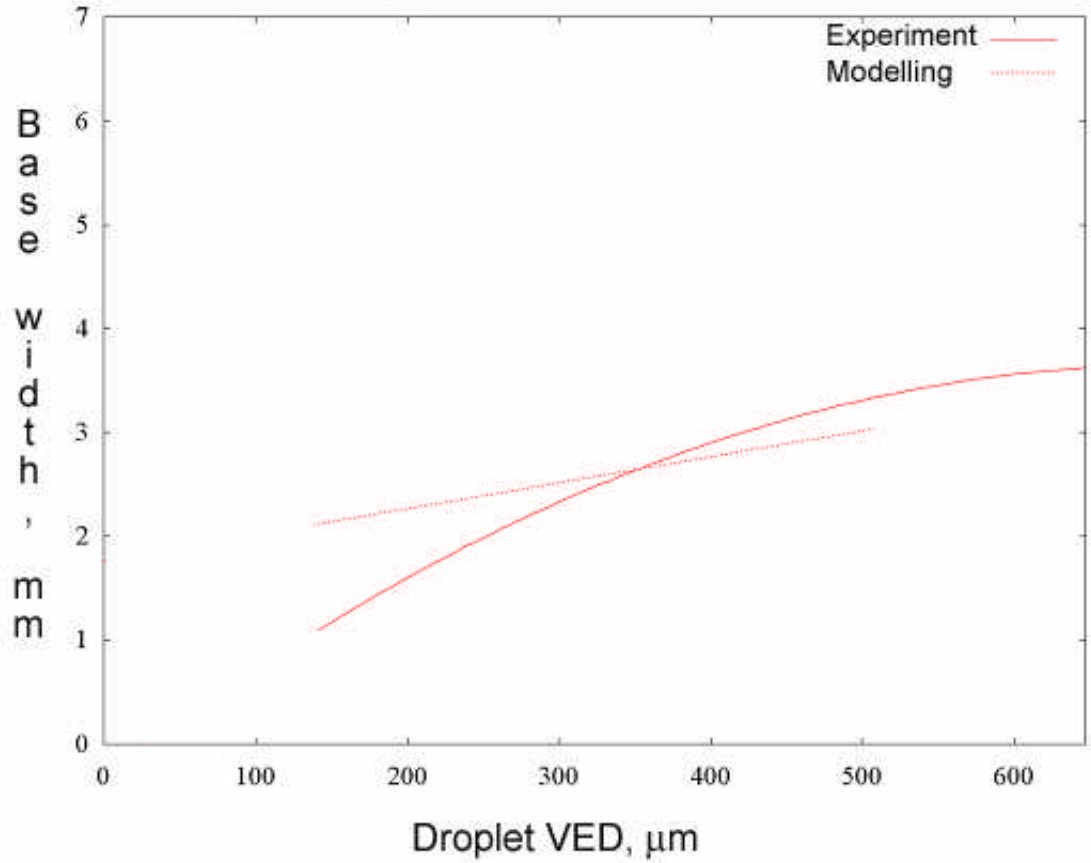
Comparisons



Corona Base width

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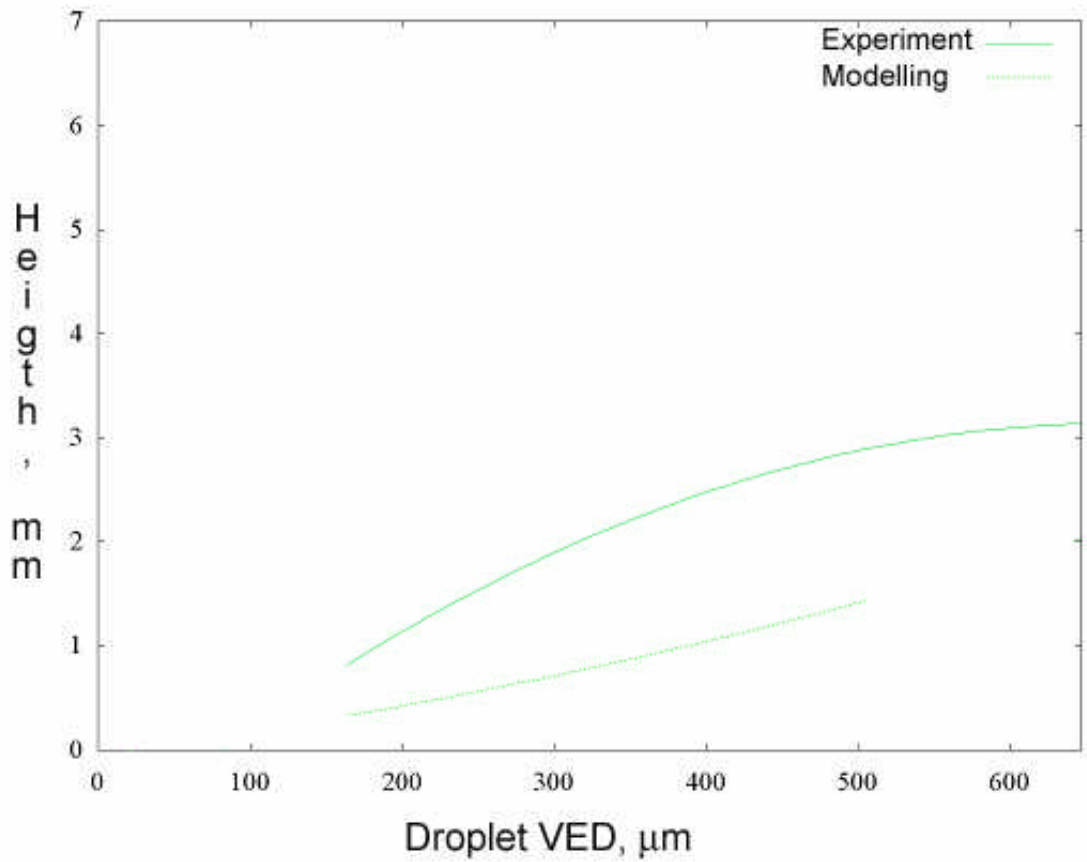
Comparisons



Corona Height

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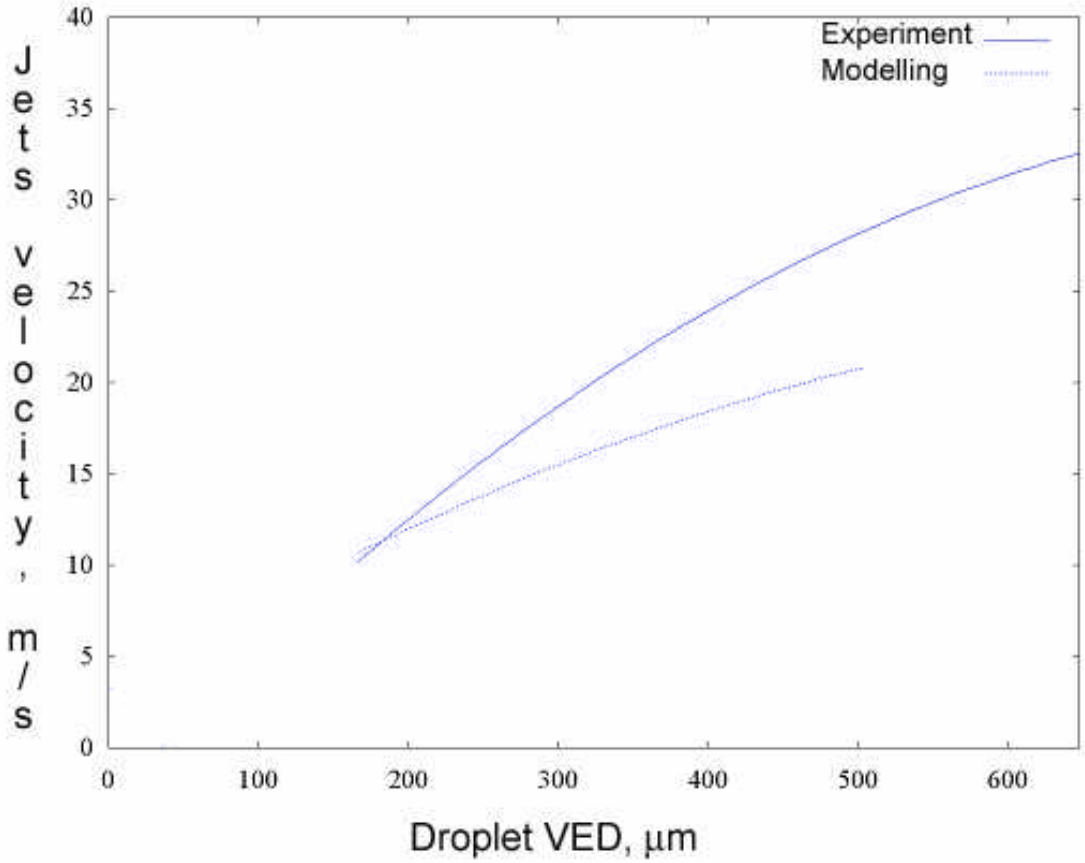
Comparisons



Jets velocity

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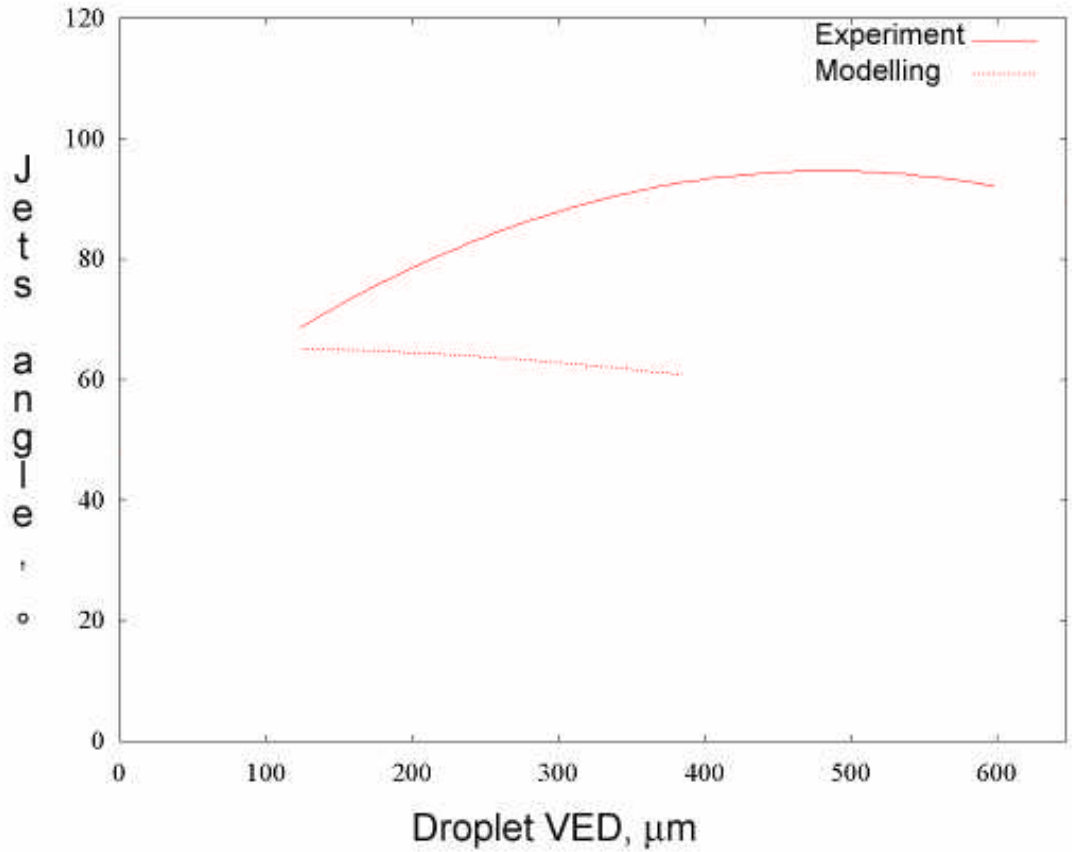
Comparisons



Big angle

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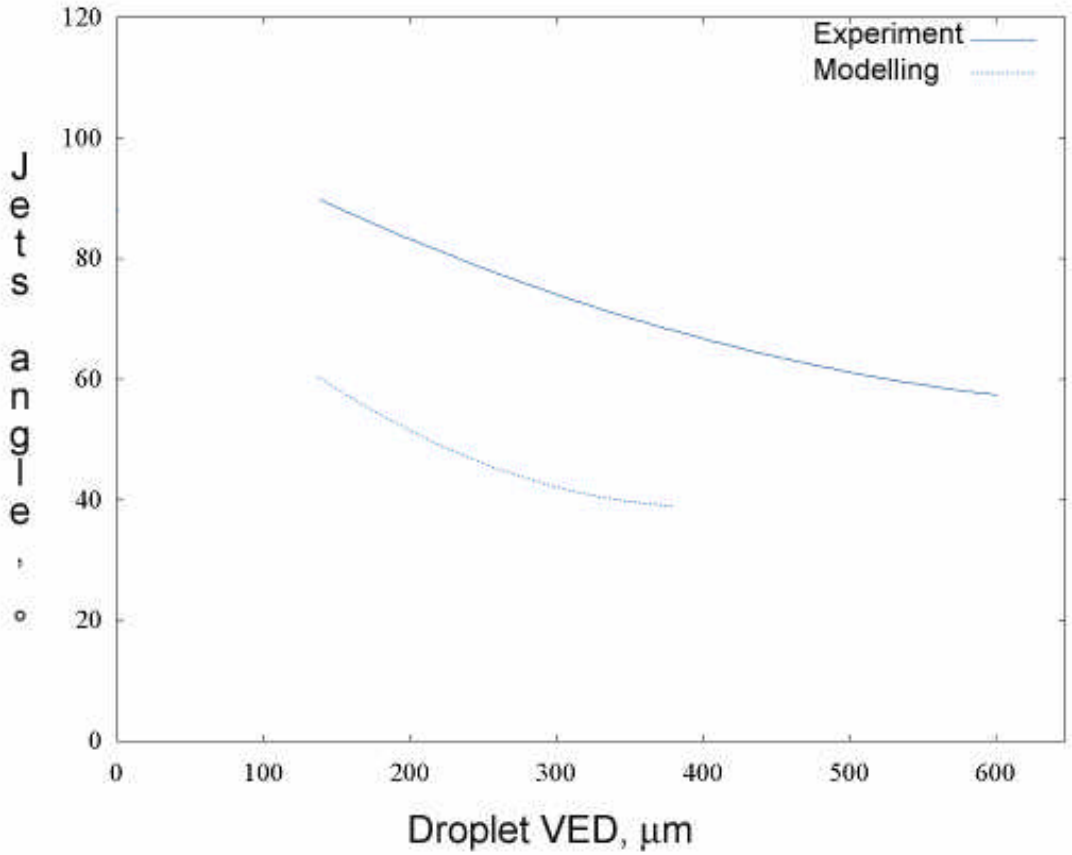
Comparisons



Small angle

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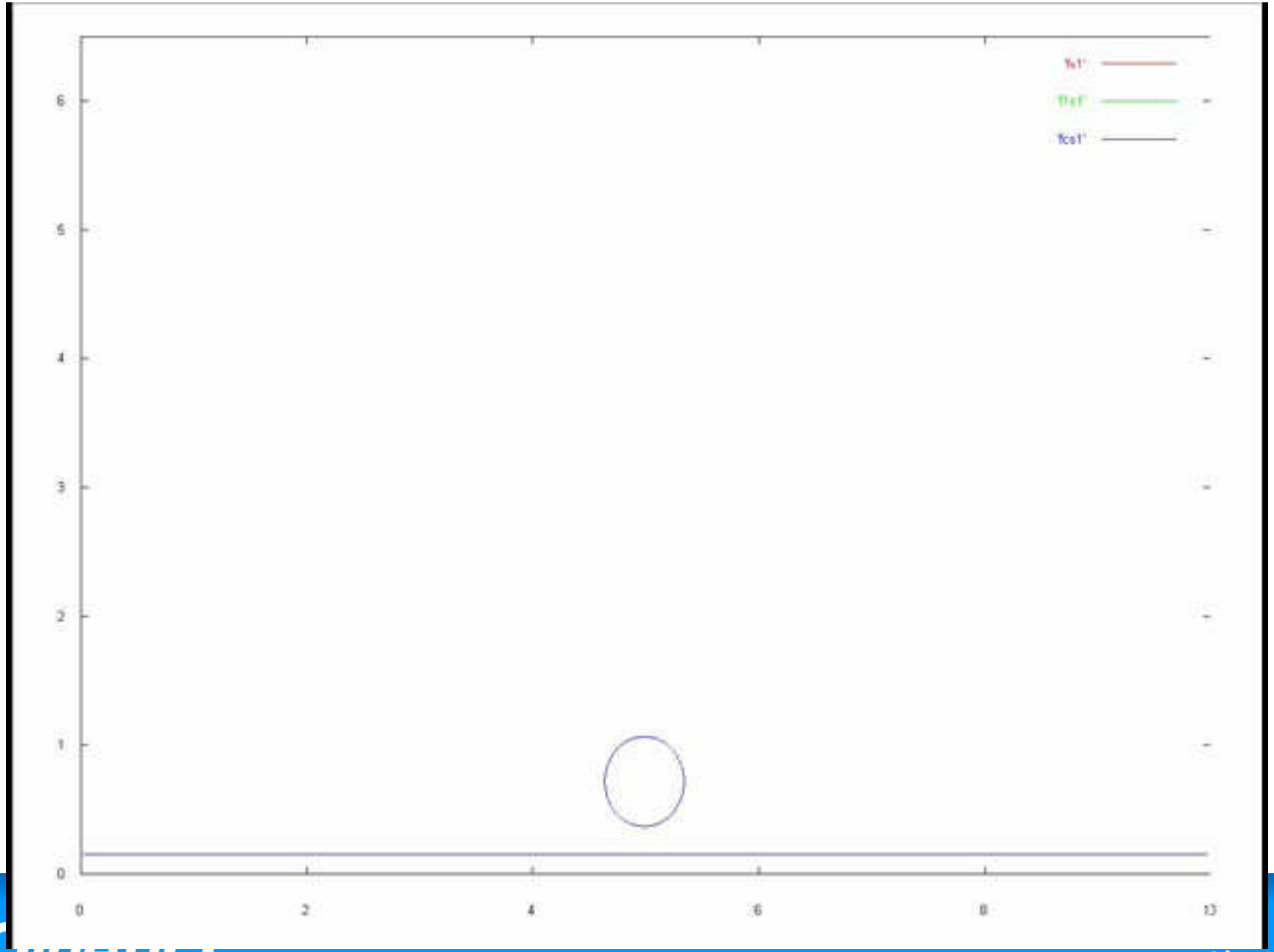

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Freezing model

- To consider ice roughness at the bottom of the domain
- To calculate the heat transfer between the ice and the water film
- Include ice layer growth

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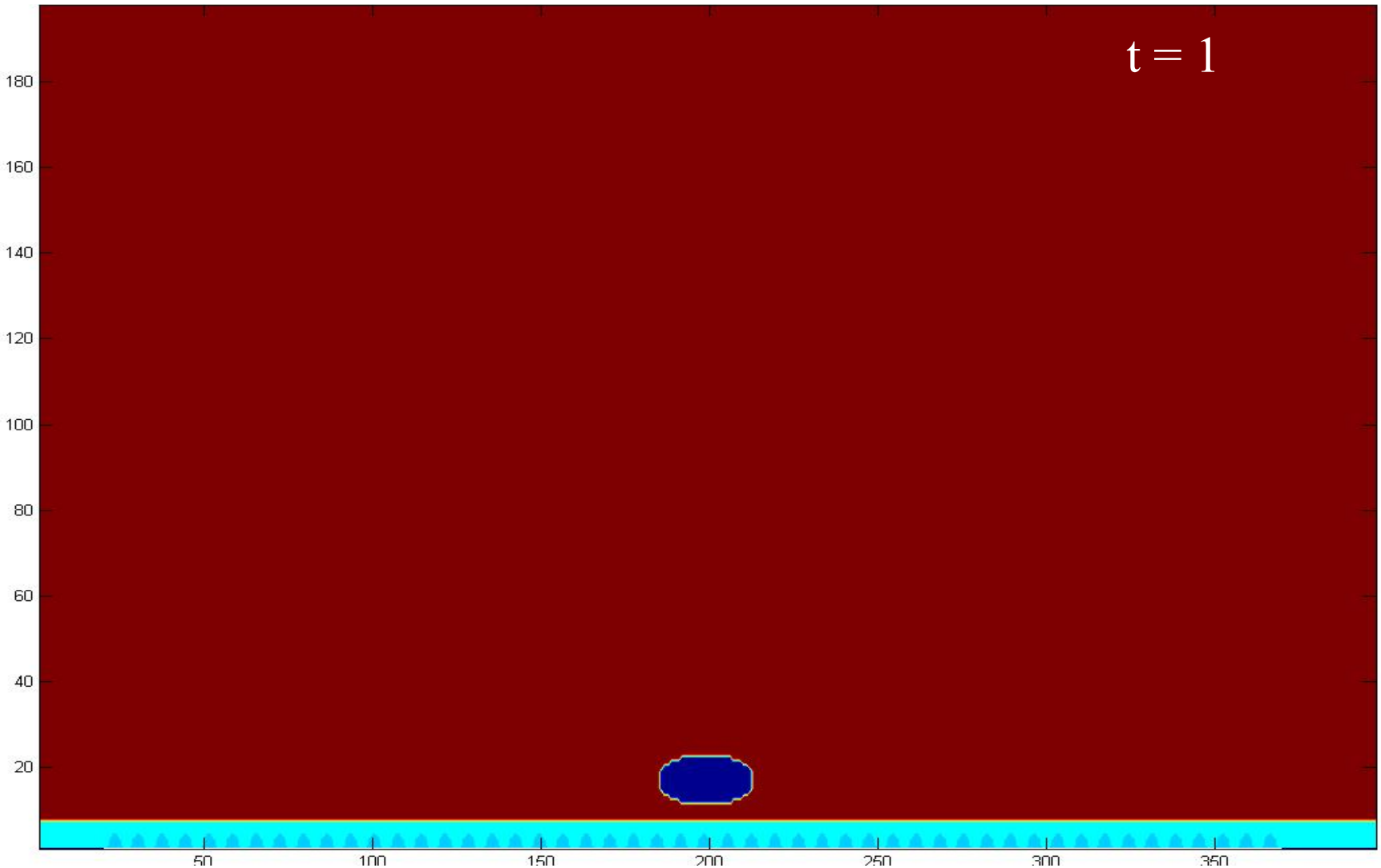

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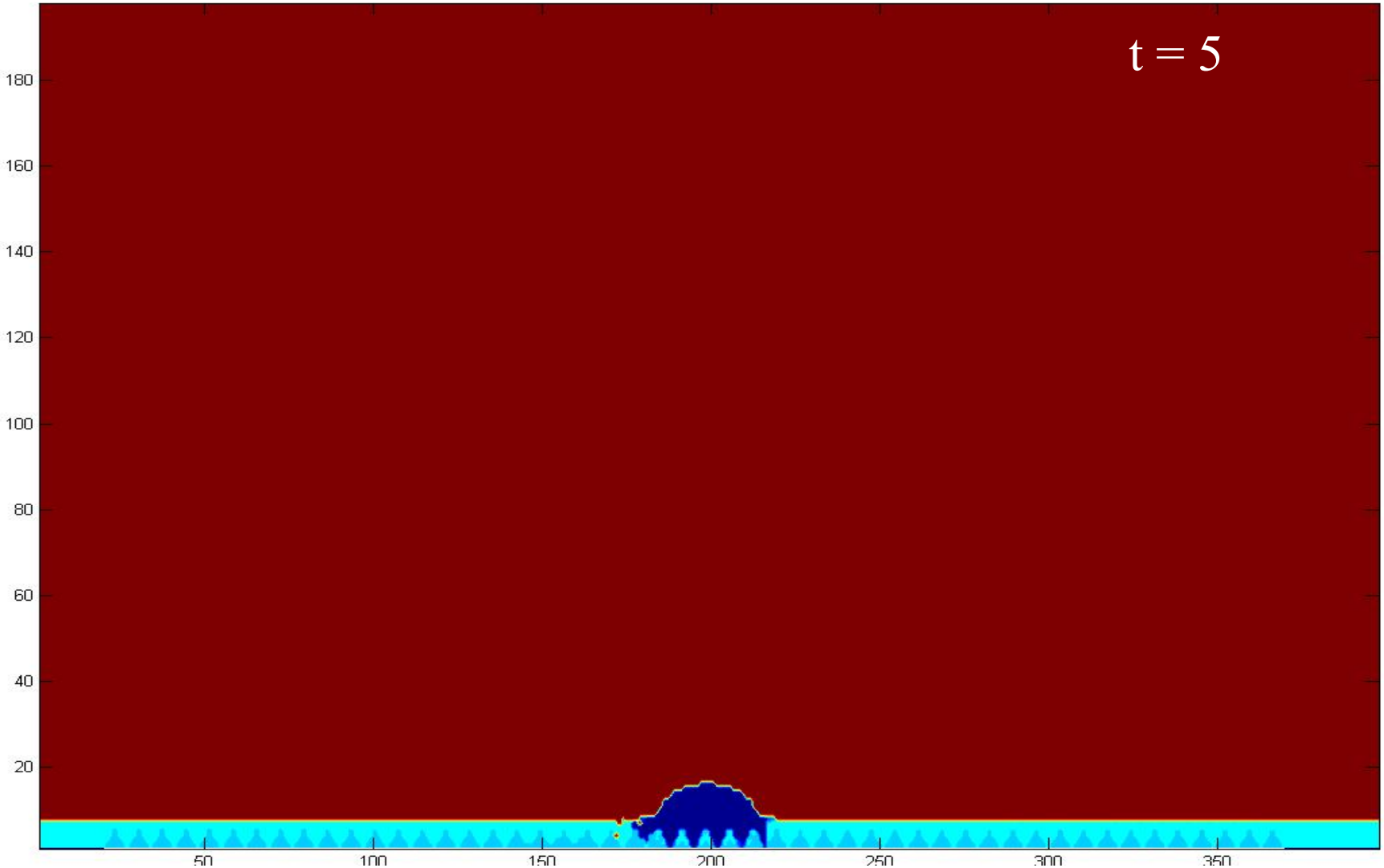

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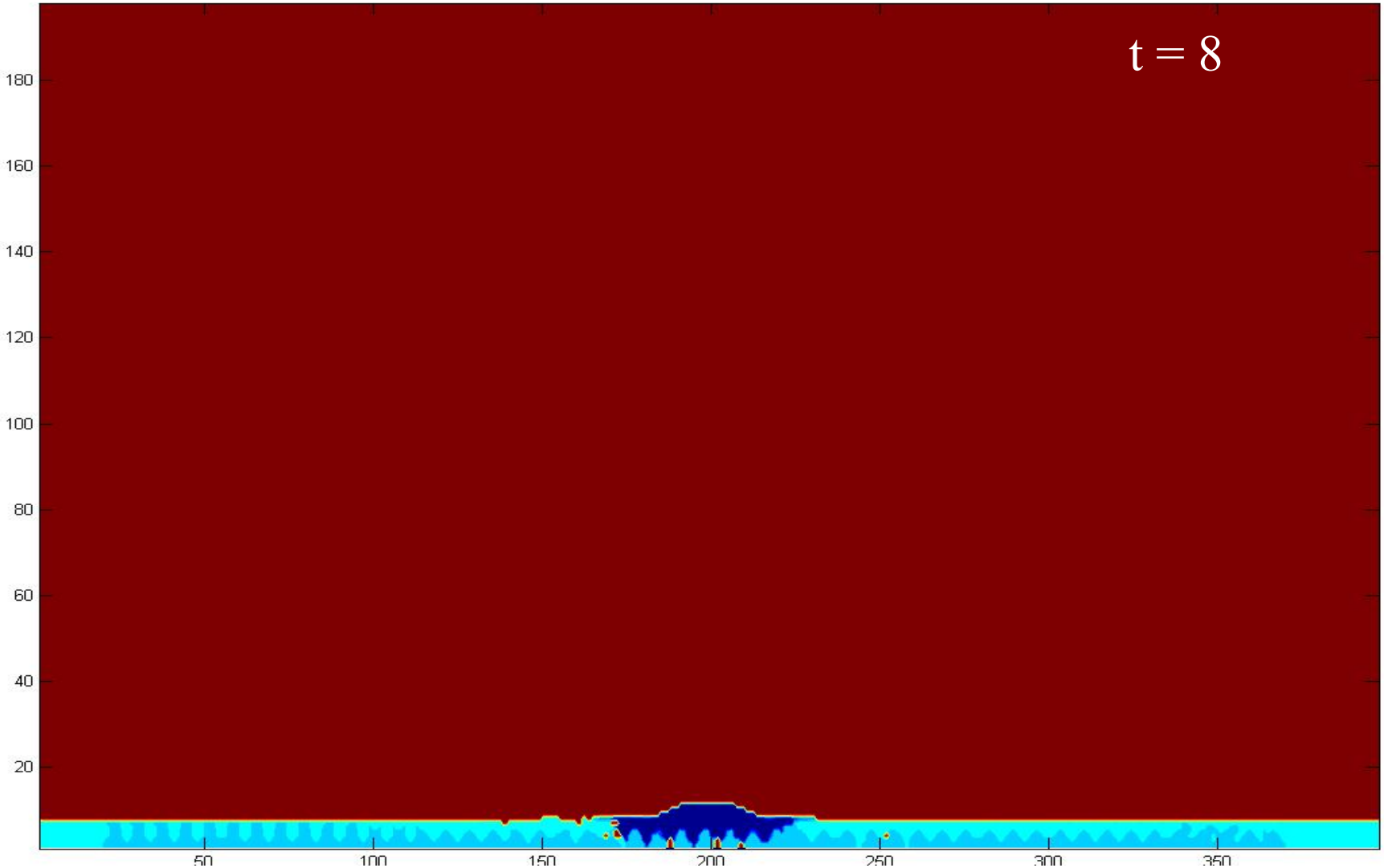

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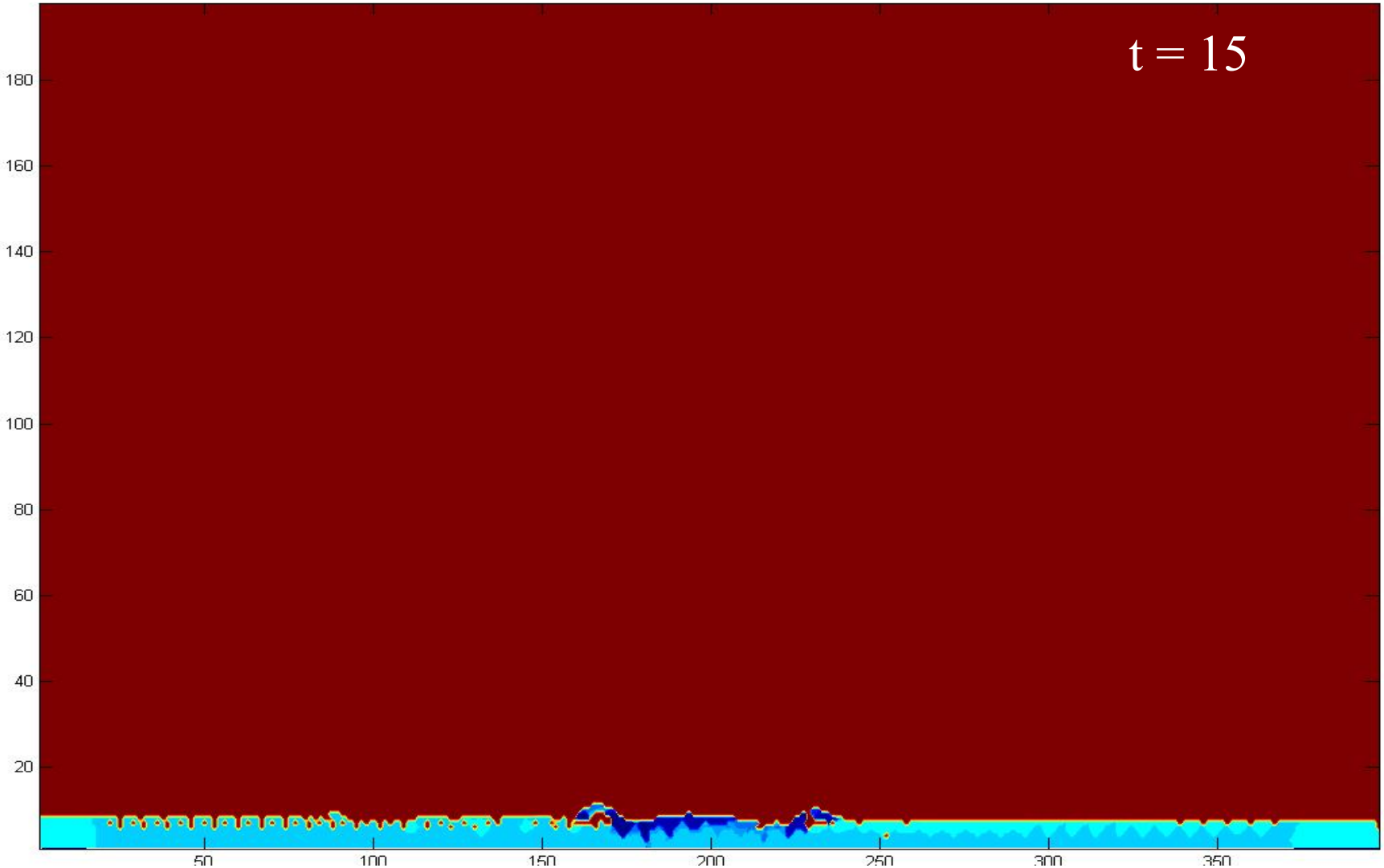

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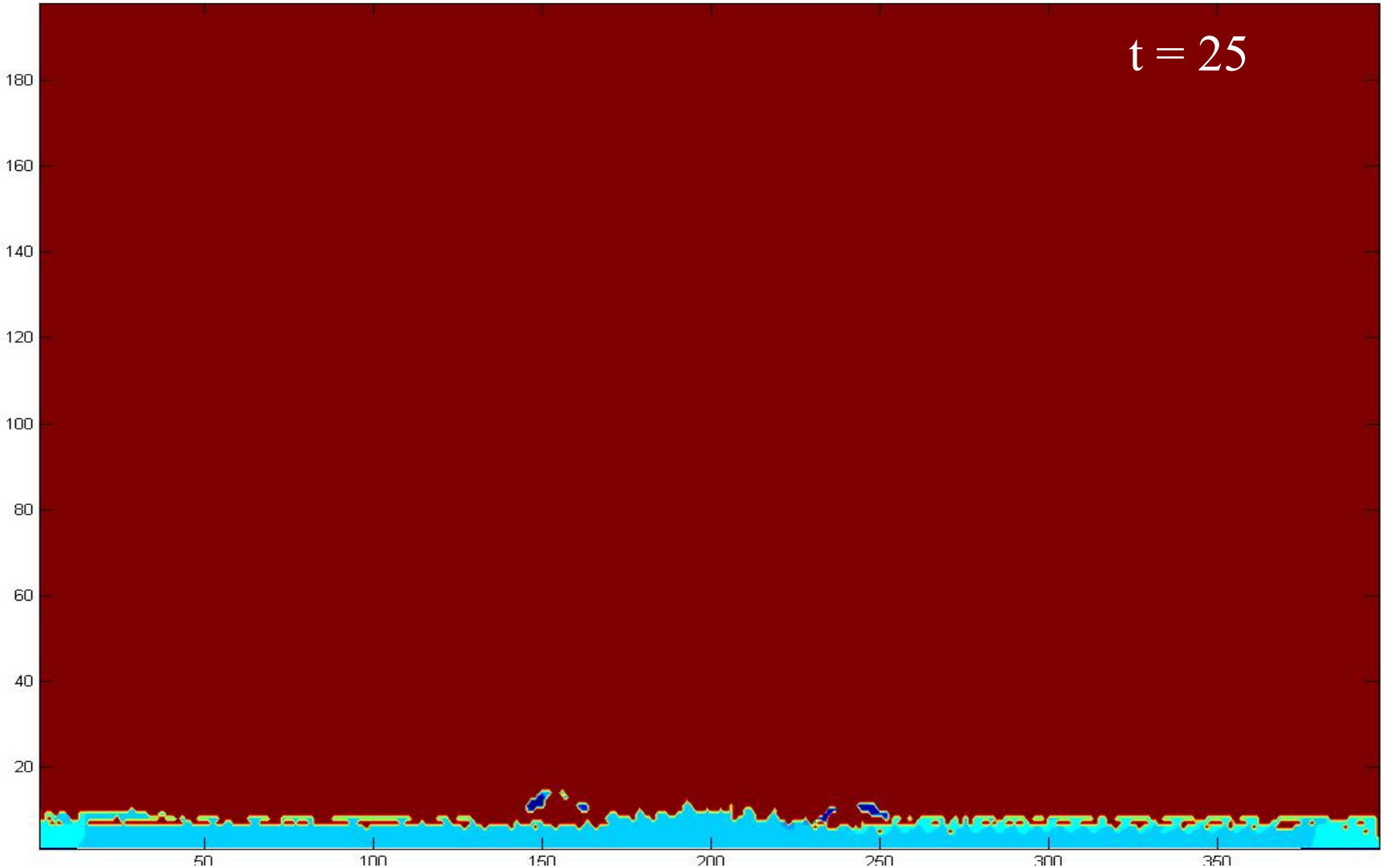

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Cranfield/UCL droplet splash modelling conclusions

- Experiment versus Modelling
  - Trends generally agree with experiment
- Temperature distribution
  - shows splash mass consists largely of ‘warm’ fluid layer
- Solidification model
  - Temperature of droplet and ice modelled
  - Problems and future work
    - Ice growth velocity - too high
    - Ice formation within a droplet
    - Numerical instabilities at the end of simulation due to separation in the segments

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Ice accretion code developments

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NASA/QinetiQ Collaboration

- QinetiQ awarded 3-year fundamental research contract in FY01, split approximately equally between experiment and analysis (theory)
- *Aim: Develop splash mass loss algorithm for use in icing codes*
- Funded by DTI under Civil Aircraft R&D (CARAD) programme
- Scope of work extended by collaboration with NASA Glenn
- Joint tunnel test conducted in May 2002
  - GKN Luton Icing Research Wind Tunnel

National Aeronautics and Space Administration

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2002 SLD Trial Aims

- The aims of the QinetiQ trial were to:
  - Modify GKN Luton Icing Wind Tunnel to allow simulation of SLD conditions
  - Quantify mass loss due to droplet splash
  - Record a number of SLD ice shapes for use in future icing code validation (TRAJICE2, ICECREMO, etc)

- The aim of the NASA trial was to develop high speed photographic imaging techniques with which to quantify mass loss.

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Method

- Calibrate tunnel (especially LWC) for Appendix C (20 μm) and SLD conditions
- Use each of the following techniques to quantify mass loss on a macro scale
  - (1) Measure response of an LWC instrument known to be subject to droplet splash
  - (2) Collect and measure water-film retained on surface of a model
  - (3) Collect and measure mass of accreted ice

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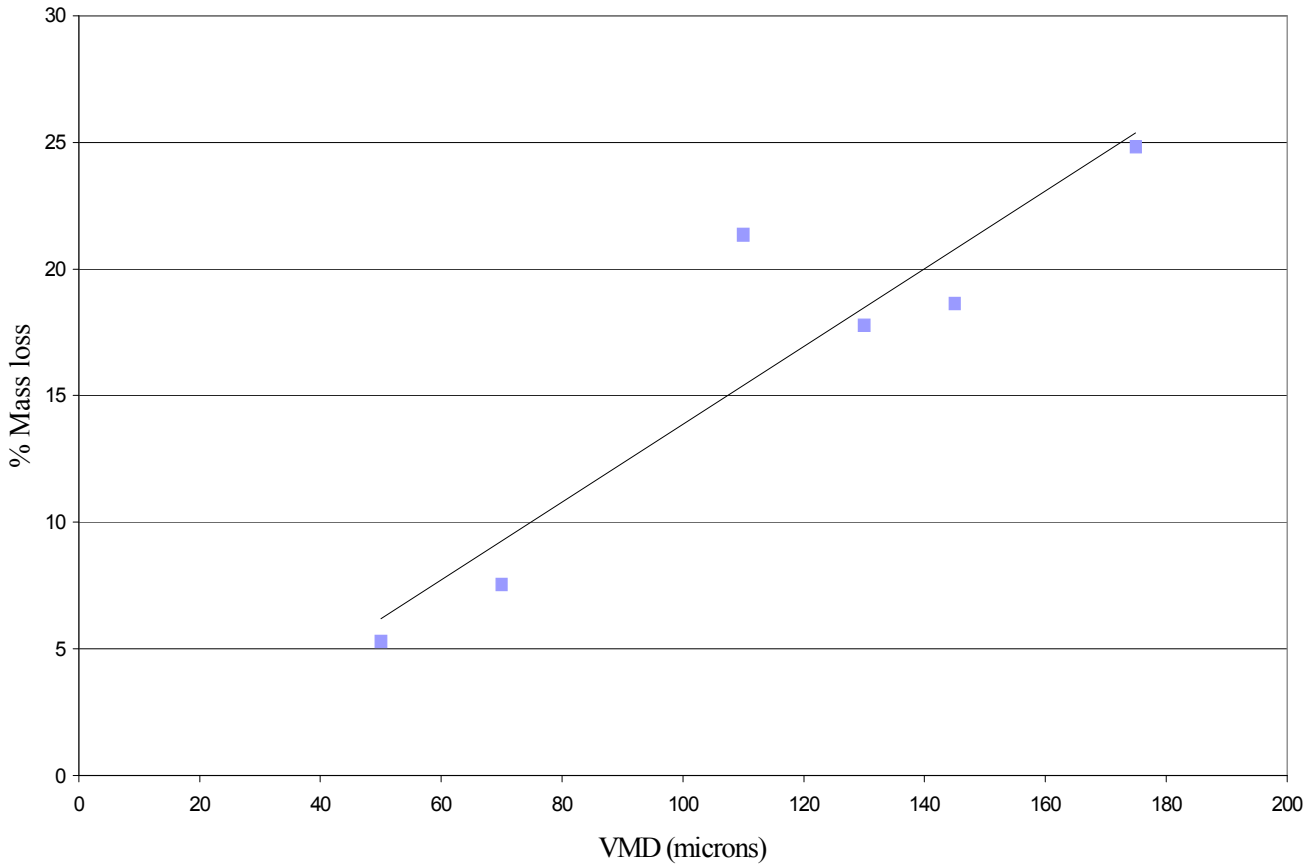
Results - Method 1 (Nevzorov TWC/LWC)



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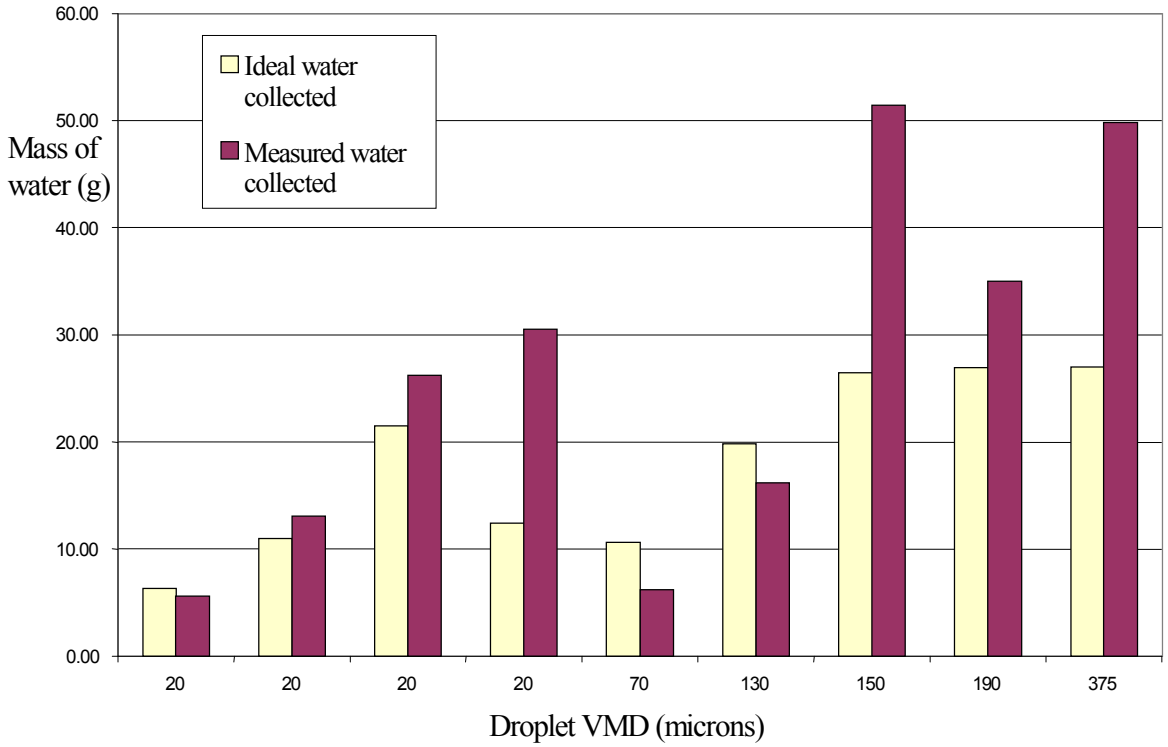
Results - Method 2: Water film collection on ellipse



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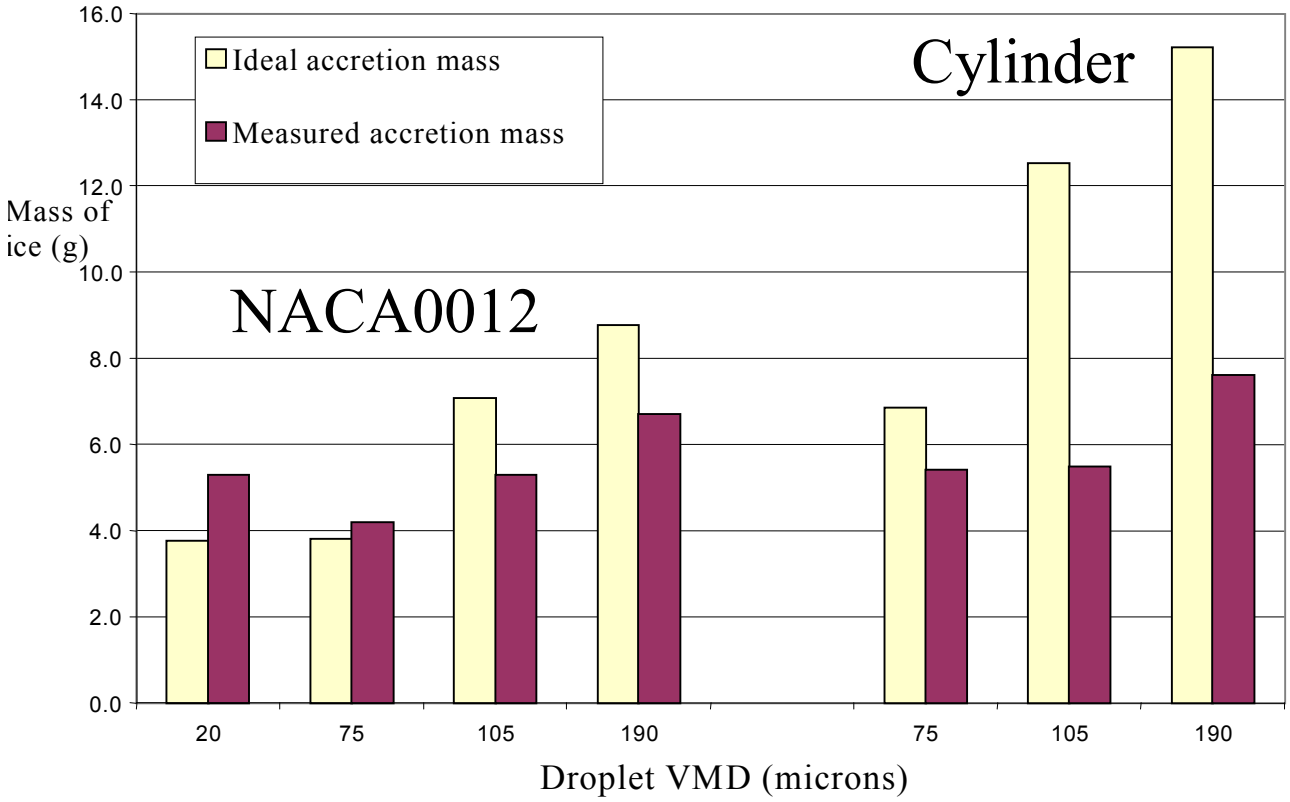
Results - Method 3 (Mass of accreted ice)



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2002 Trial Conclusions

- Mass loss trials partially successful
- For the specific conditions tested (<200 μm VMD, 150 kn)
  - Method 1 gave mass loss in range of +5% to +25%
  - Method 2 gave mass variation from +45% to -90% !!!
  - Method 3 gave mass loss in range
    - -10% to +30% on aerofoil specimen
    - up to +55% on cylinder, >> i.e. larger than aerofoil
- *Shape of surface important to mass loss*
- Reason for mass gain (Method 2) postulated as results of moisture condensation out of the air, but needs to be confirmed

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Current Predictive Capability - Examples

- QinetiQ has evaluated several splash methods and code implementations
  - Initial Mass Loss Algorithm ('J M Ford' – QinetiQ icing team)
  - Published Mass Loss Algorithm ('Samenfink')

  - *Initial application – 'Modify droplet catch, Beta'*
    - Initial consensus was that this was the correct process
    - However, can predict 'Rime' ice under 'Glaze' ice conditions

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Current Predictive Capability - Examples

- *Current application – 'Modify surface water mass, Mw'*
  - QinetiQ postulation
  - Avoids removing too much 'latent heat' – which leads to rime ice
  - *Subsequently confirmed by UCL/Cranfield University analysis*
  - At present, calculations based on VMD
    - Splash mass varies due to local impact angle and velocity

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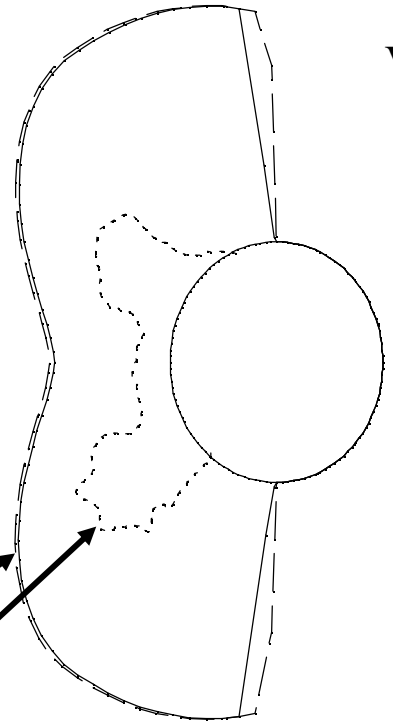
J M Ford Algorithm - Example TRAJICE2 results

- Improvement in predicted ice shape on cylinders at high LWC

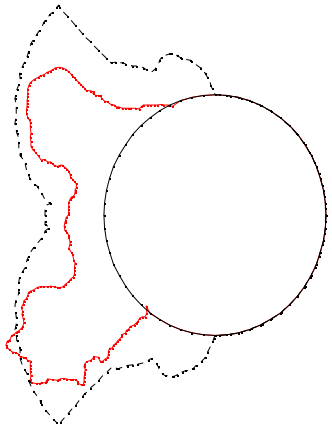
VMD=170μm, V=150 m/s, LWC=2 g/m^3

Old Splash Routine



Predicted

Measured



New Splash Routine

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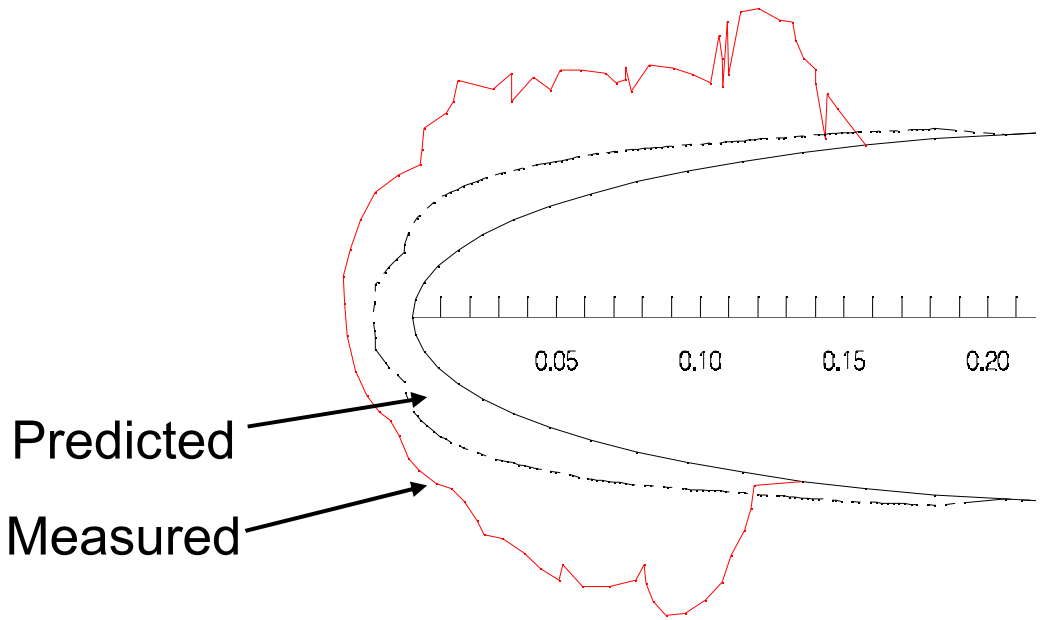
J M Ford Algorithm - Example TRAJICE2 results

- NACA0012 cases less well predicted



VMD = 105μm, V = 77.2m/s,
LWC = 0.88g/m^3

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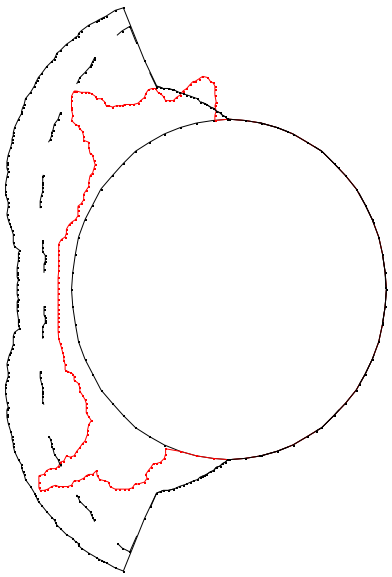
Mw based algorithm - Example TRAJICE2 Results

JMF-Mw



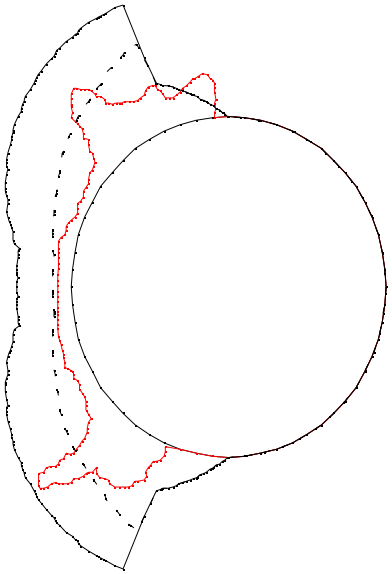
Experiment
No splash
JMF_Mw
SamenfinkM

ONERA5

180μm, 0.8 g/m³

Samenfink

Modified



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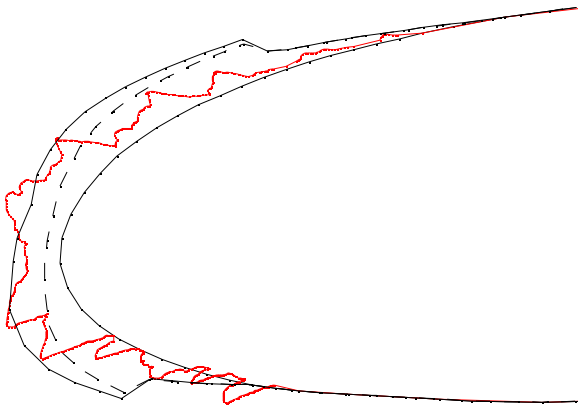
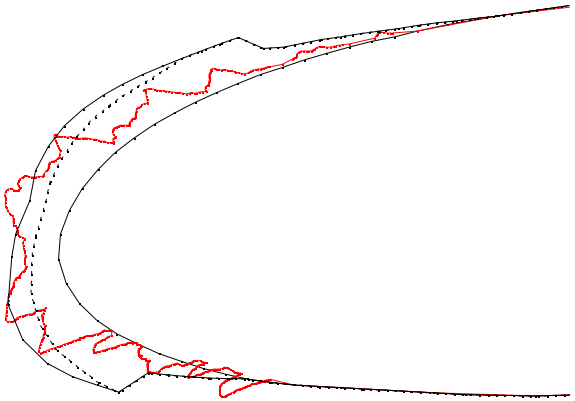
Mw based algorithm - Example TRAJICE2 Results

JMF-Mw

Experiment
No splash
JMF_Mw
Samenfink M

Samenfink
Modified





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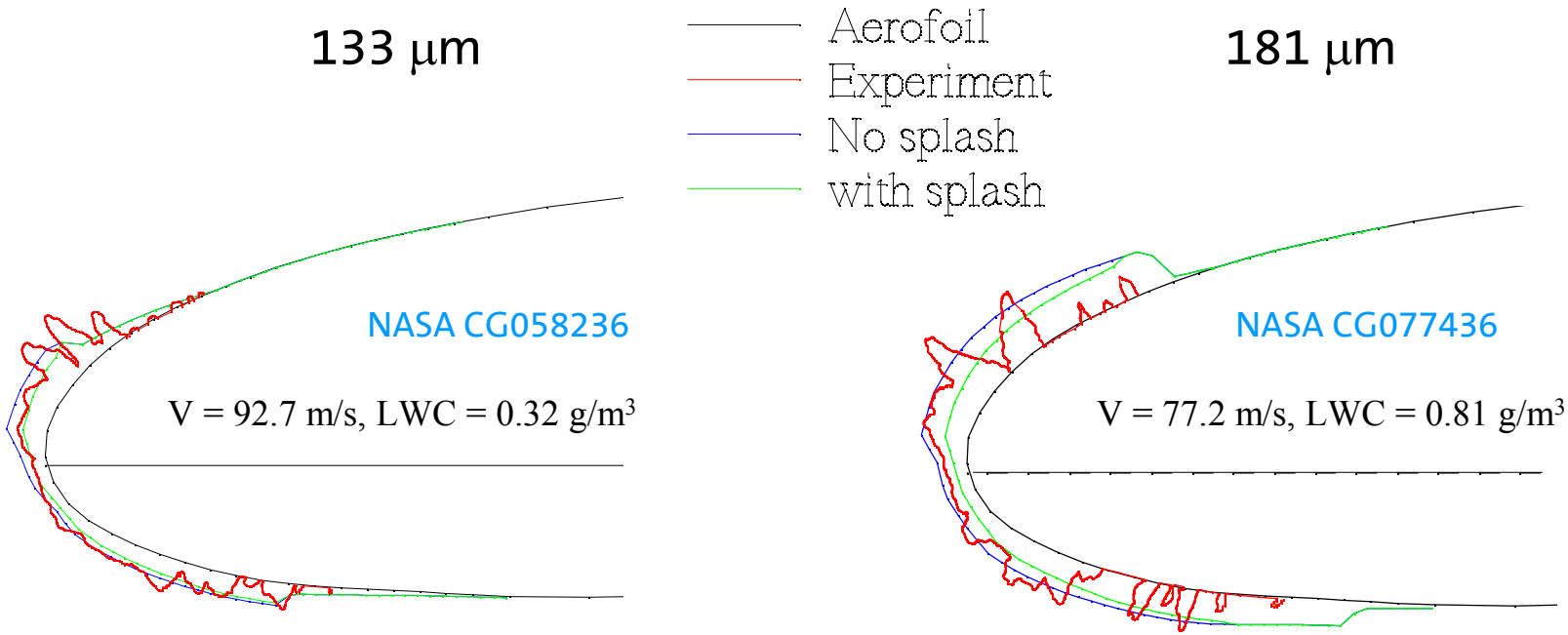
Mw based algorithm - Example TRAJICE2 Results

Samenfink based algorithm

133 μm

181 μm



NACA4415, 1.98m Chord

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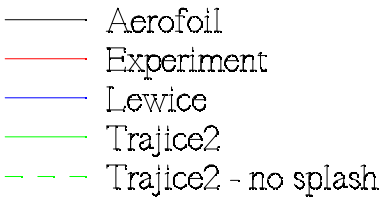
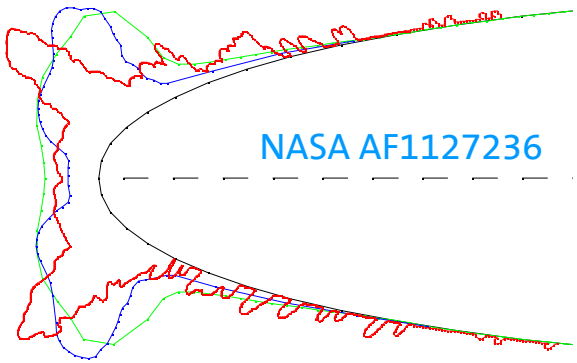
Example results (concluded): Lewice and TRAJICE2

NACA0012, 0.914m Chord

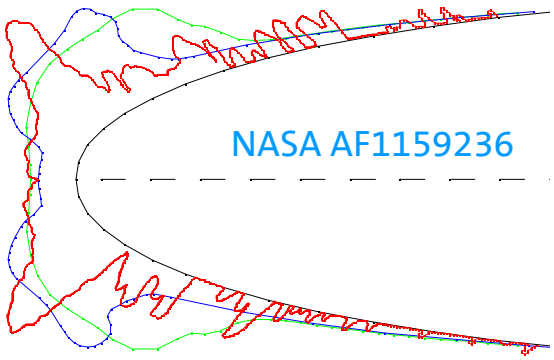


50 μm



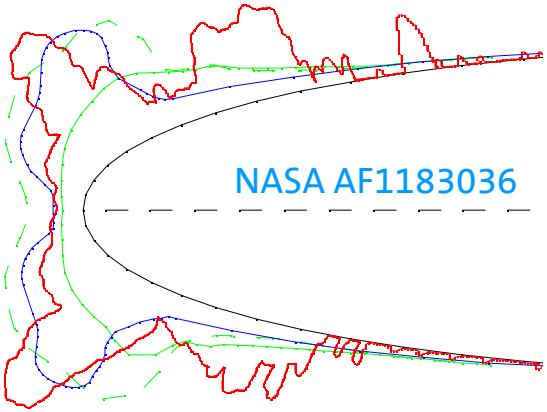
V = 98.4 m/s, LWC = 0.58 g/m^3

110 μm



V = 77.4 m/s, LWC = 0.69 g/m^3

188 μm



V = 102.8 m/s, LWC = 0.48 g/m^3

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SLD Modelling Conclusions

- QinetiQ research aimed at predicting SLD ice accretion
- UK University research provides fundamental supporting analysis/test
- Work consists of both ice accretion code development and tunnel testing
- QinetiQ mass loss algorithm developed
- Samenfink correlation evaluated
- Applying mass loss to water film/growth rates avoids tendency for rime ice prediction
- Some improvement in SLD ice shapes, but further improvement desired
- Still lacking key physics?

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Future Activities

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Future Activities

Topics under consideration include;

- Increase number and range of validation database cases evaluated
- Apply mass loss algorithm for a spectrum, rather than mono-dispersed (MVD)
- Complete development of in-Air VOF droplet splash model and extend to 3D (UCL/Cranfield/UEA)
- Establish whether splash re-impingement is significant/important?
- Evaluate other (published) mass loss algorithms
- Implement optimum method in UK, 3D, icing code (ICECREMO II)
- Continue to contribute towards NASA led, SLD Roadmap

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Thank you for your attention

Questions?

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