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INTA/NASA SLD Physics Research
Droplet Breakup and Splashing

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Outline

- Background
- Objetives
- Approach
- Experimental Set-up, Experimental Observation, Data Analysis, Results
- Why to extend Droplet Breakup Experiments to include Splashing
- Results from Proof-of-Research for Splashing Studies using the Rotating Rig Facility
- Additional Comments

Background

- In 2007 INTA and NASA began an SLD Icing Physics Research collaboration through a Space Act Agreement
- The experimental research program studies droplet breakup on an airfoil configuration
- A rotating rig was designed and built at the INTA installation
- Droplet breakup experiment were conducted in 2008, 2010, 2011 and 2012
- Proof-of Research for Splashing Studies was conducted in April 2013

Objectives

- Objectives of the research effort:

  1.- To study and measure large droplet deformation and break-up near the leading edge of large transport airfoils

  2.- To extend droplet breakup studies to include splashing

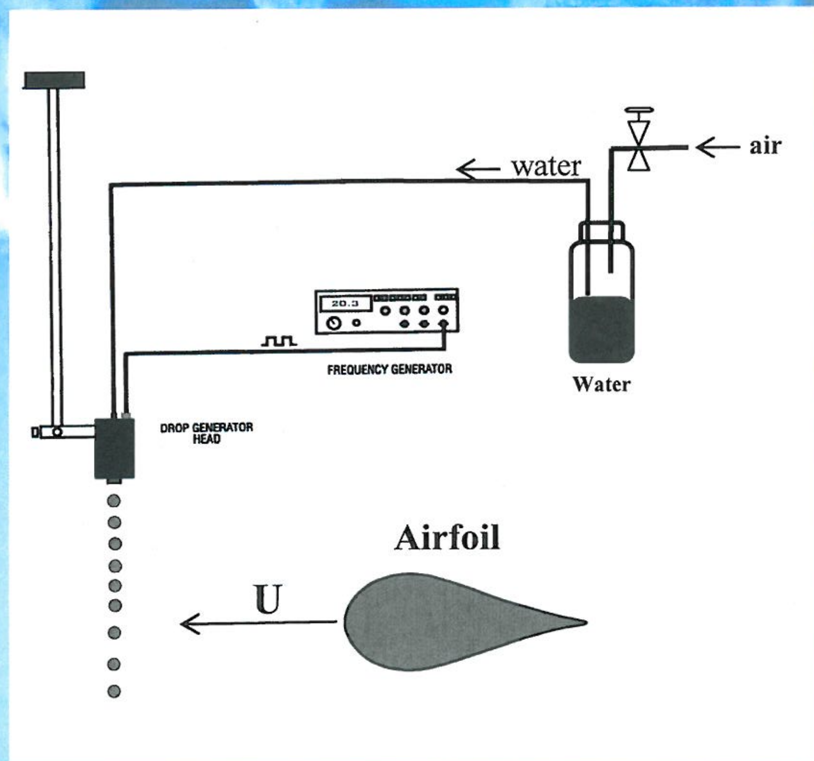
- Use the state of the art high speed imaging for observation of droplet deformation, breakup and splashing

- Measure total mass loss due to splashing and droplet breakup

- Measure horizontal and vertical displacement of droplets, and calculate main parameters: velocity, acceleration and Weber number

Approach

Conceptual View of Experiment

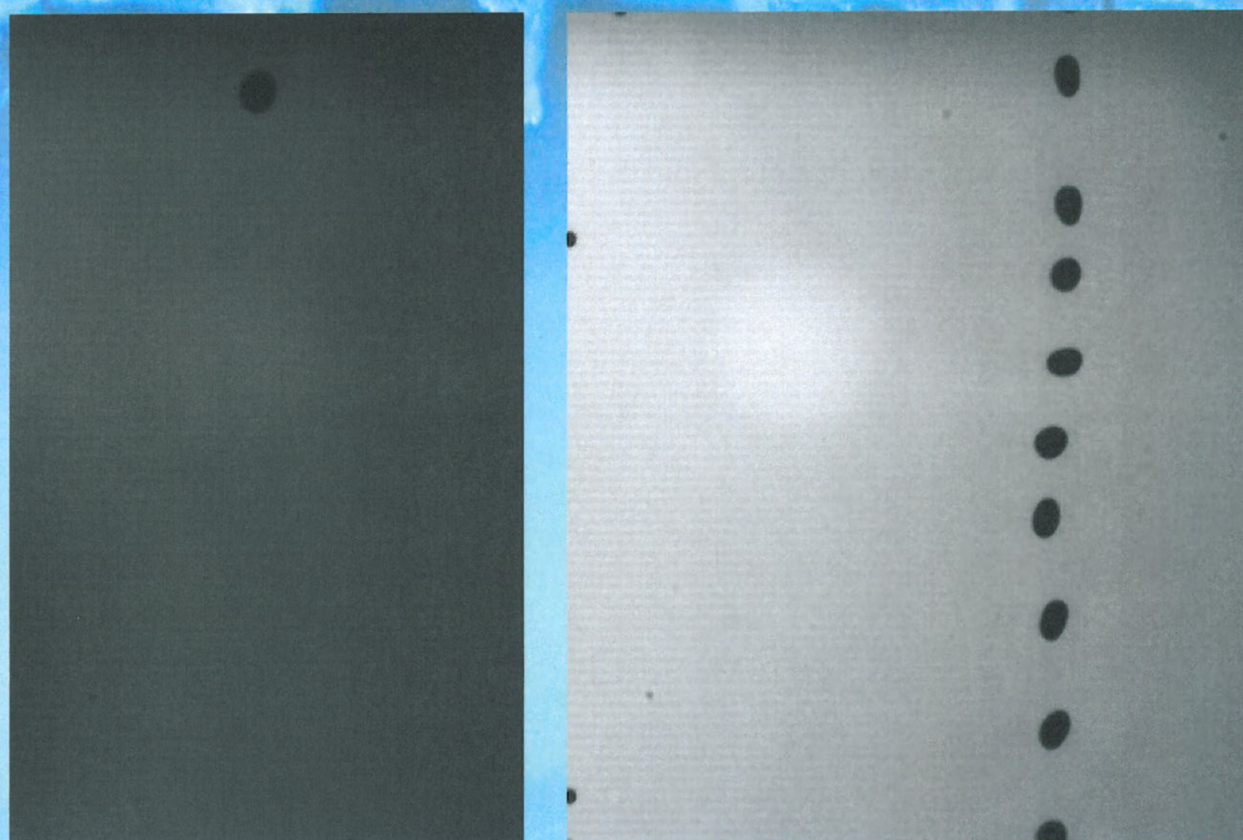


Experimental Setup

Rotating Rig Facility at INTA

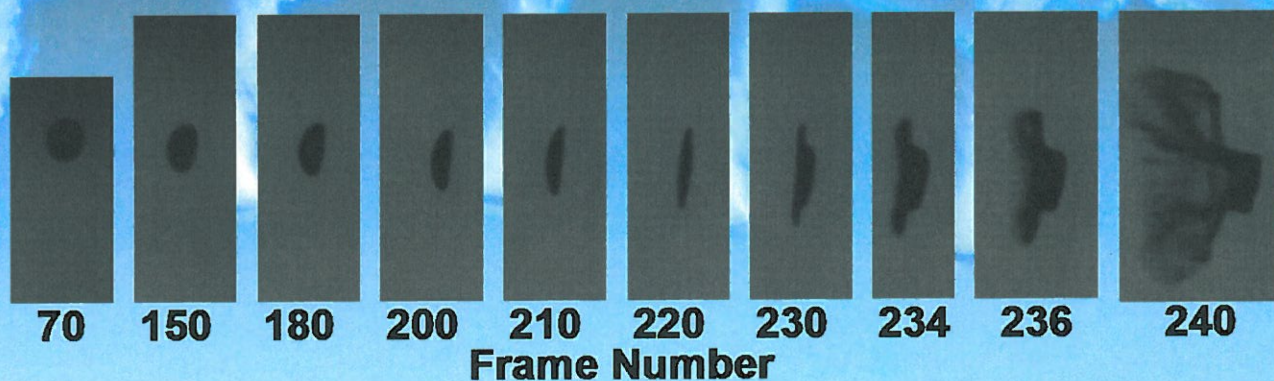
Experimental Observations

Two Examples of Shadow Image Video



Experimental Observations

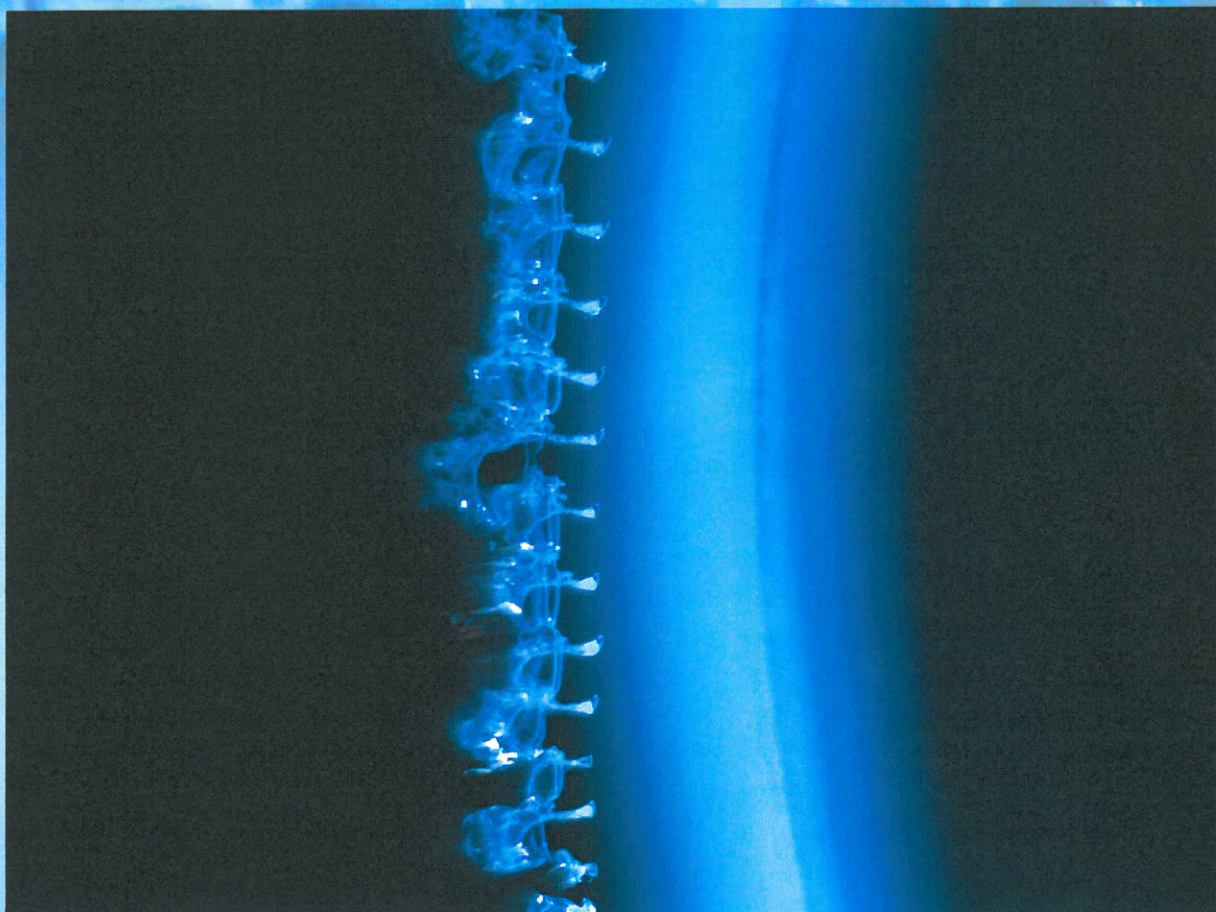
Droplet Shadow Image Video Evolution



Droplet Image Photo Evolution

Experimental Observations

Chain of Droplets Breaking Up Photo



Data Analysis

- SITEA : Software program for the data analysis developed at INTA using MATLAB

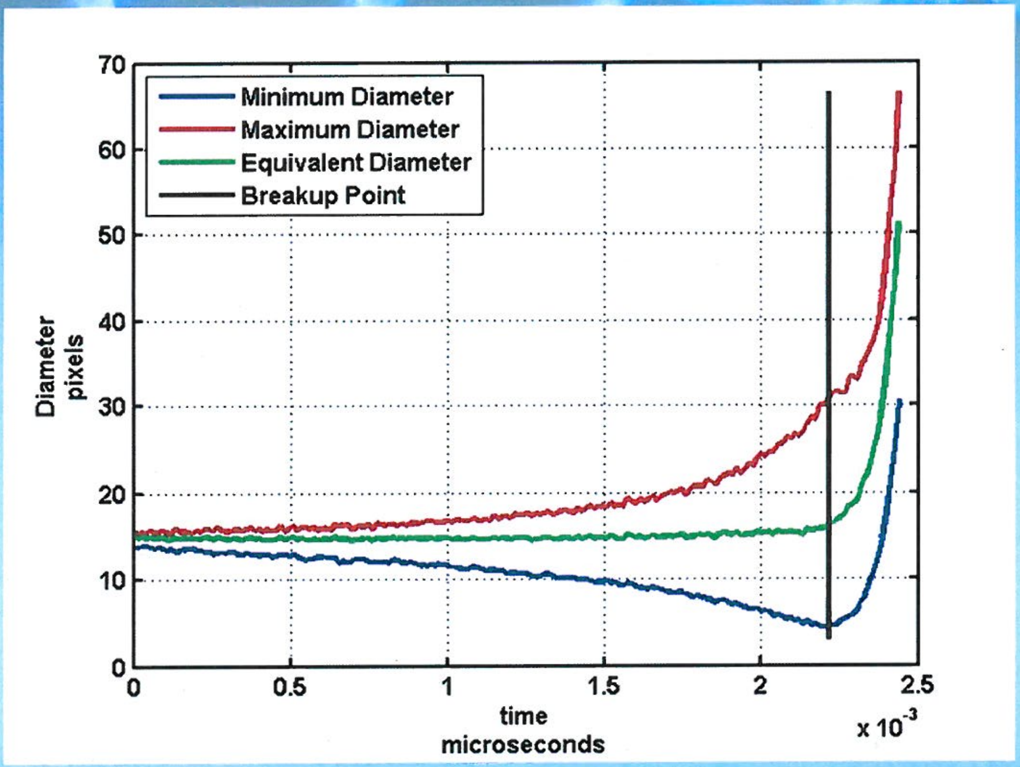
- The first part of the program tracks the selected droplet obtaining the trajectory and the evolution of the major and minor axis of an ellipse superimposed on the droplet

- The second part calculates velocity and acceleration of the droplet, position of the droplet with respect to the airfoil, slip velocity, Weber, Reynolds and Bond numbers, and drag coefficient

- SITEA Software was validated with the data analysis software developed at NASA

Results

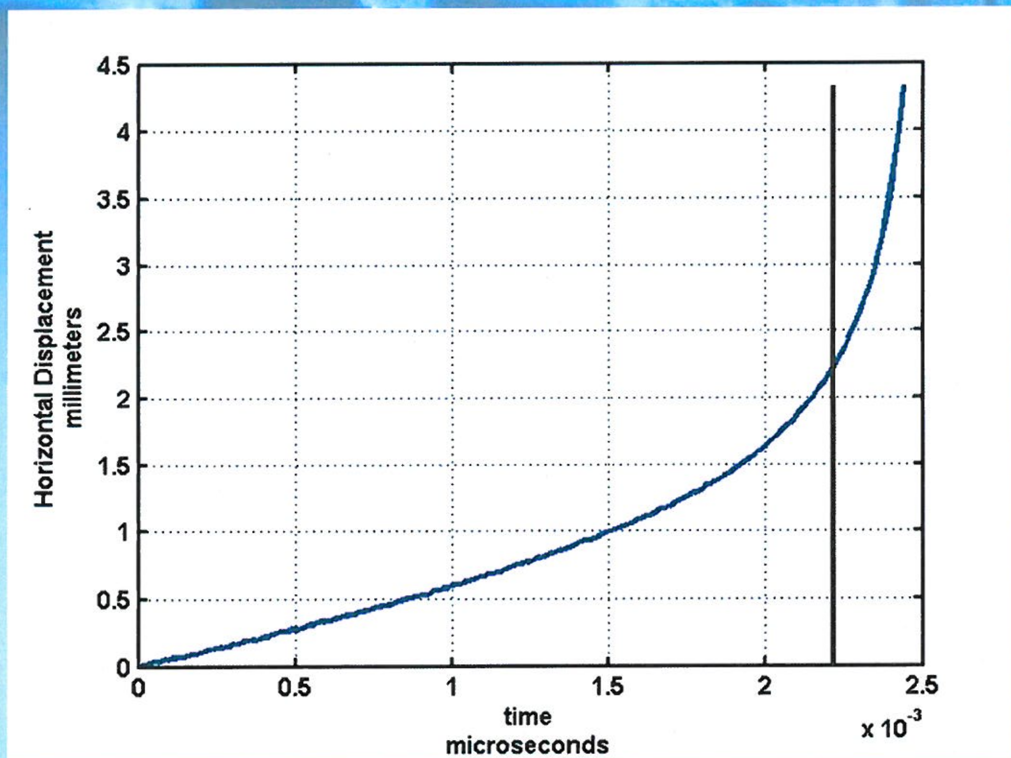
Droplet diameters vs Time



Droplet diameter= 1042 µm, airfoil chord= 0.69 m, airfoil velocity= 90m/s

Results

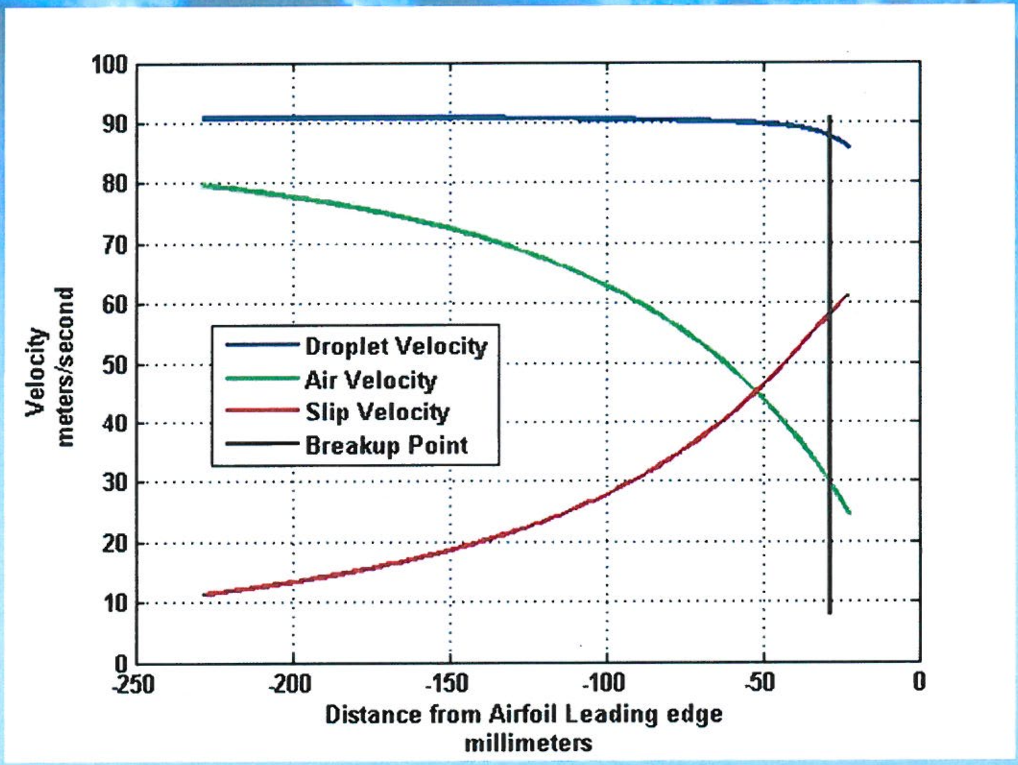
Horizontal displacement vs Time



Droplet diameter= 1042 µm, airfoil chord= 0.69 m, airfoil velocity= 90m/s

Results

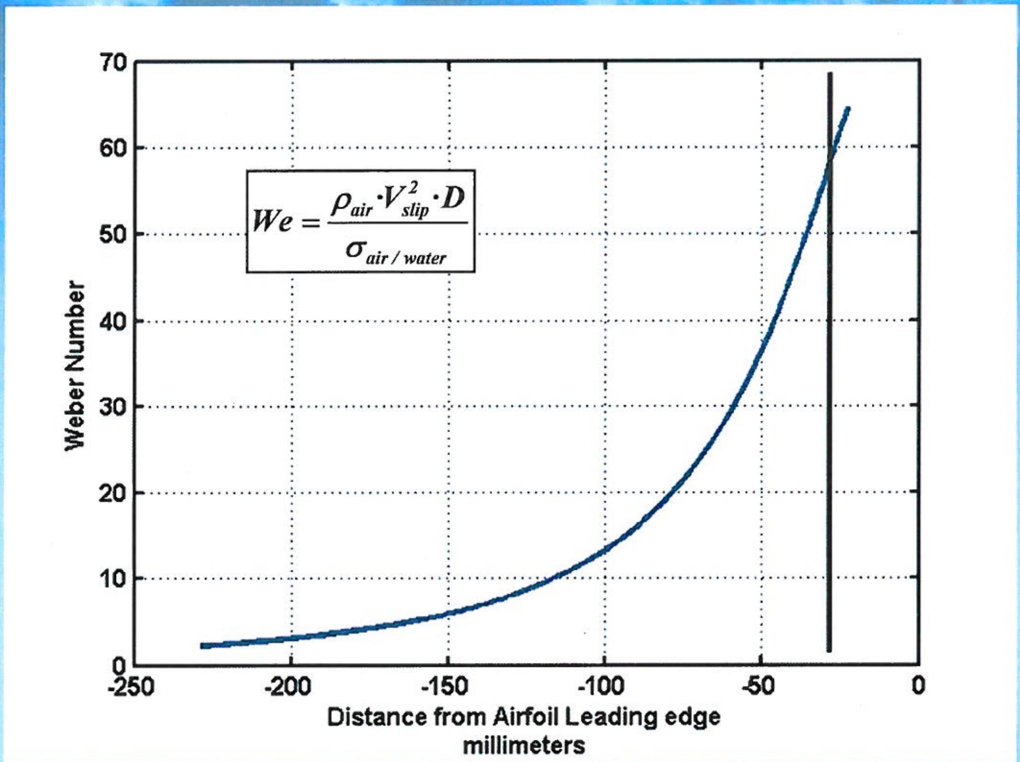
Droplet Velocity, Air Velocity, Slip Velocity vs Distance from Airfoil



Droplet diameter= 1042 µm, airfoil chord= 0.69 m, airfoil velocity= 90m/s

Results

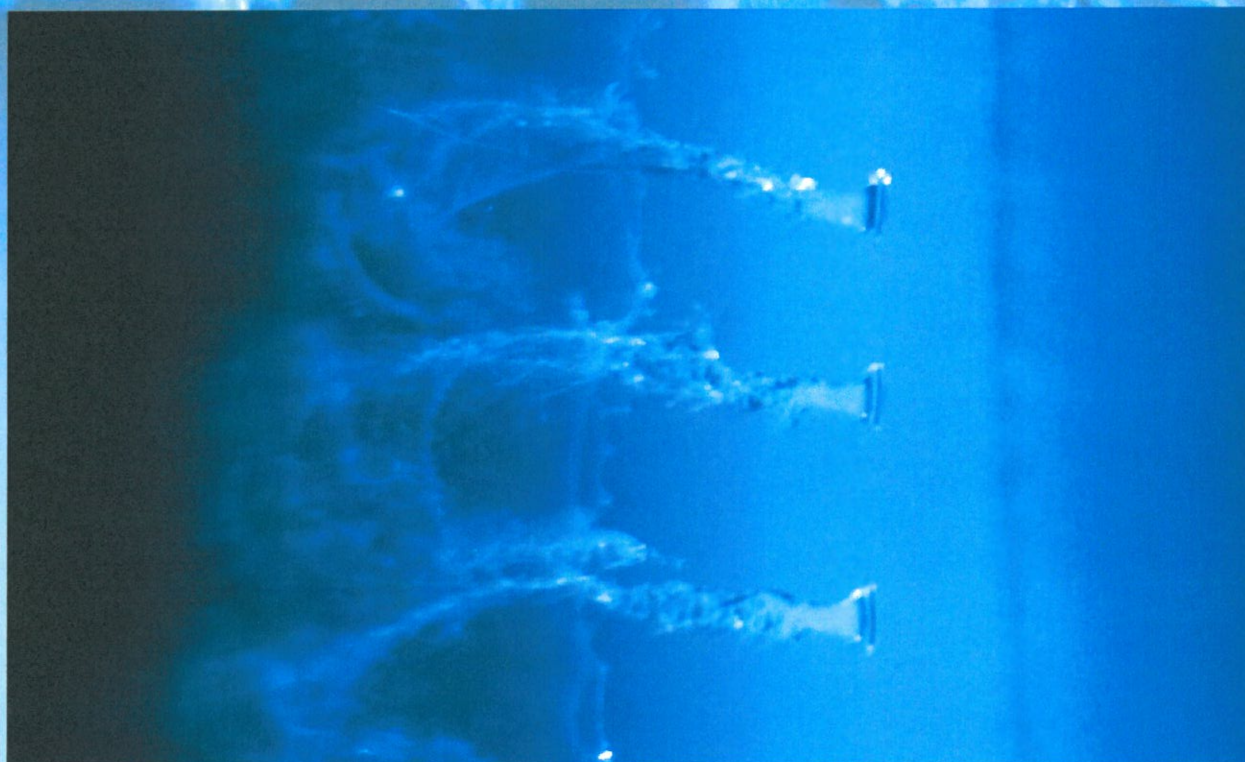
Weber Number vs Distance from Airfoil



Droplet diameter= 1042 µm, airfoil chord= 0.69 m, airfoil velocity= 90m/s

Results

Droplet Breakup Showing Mass Loss



Why to Extend Droplet Breakup Experiments to Include Splashing

- Observations indicate that SLD droplet deformation and splashing are connected

- Drops deform, begin to breakup and lose mass before hitting the airfoil and splashing

- Because mass is lost during breakup, not all of the initial droplet mass will hit the airfoil and cause the splashing. In SLD, splashing needs to be studied together with droplet breakup to determine the total mass lost

- Experimental setup and methodology employed during droplet breakup studies can be extended to observation and measurement of splashing

Proof-of-Research for Splashing Studies at the INTA Rotating Rig Facility

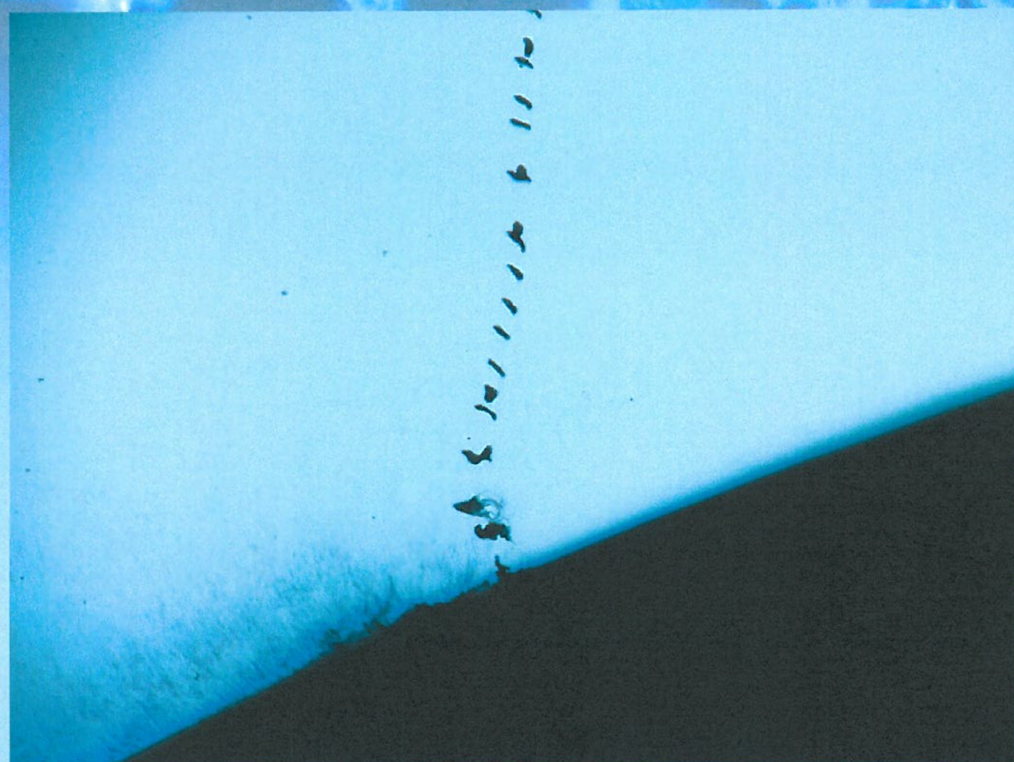
- Preliminary imaging study was conducted at INTA to determine the feasibility of capturing imaging data for a droplet approaching, deforming, hitting the airfoil and splashing

- Imaging data captured droplet deformation and splashing

- Results indicate the feasibility of measuring the total mass splashed

Results of Proof-of-Research

Stream of Droplets Impinging on the Shoulder Model. Shadowgraph Illumination Technique



Droplet Diameter= 650 µm, Airfoil Chord= 0.47 m, Airfoil Velocity= 90m/s

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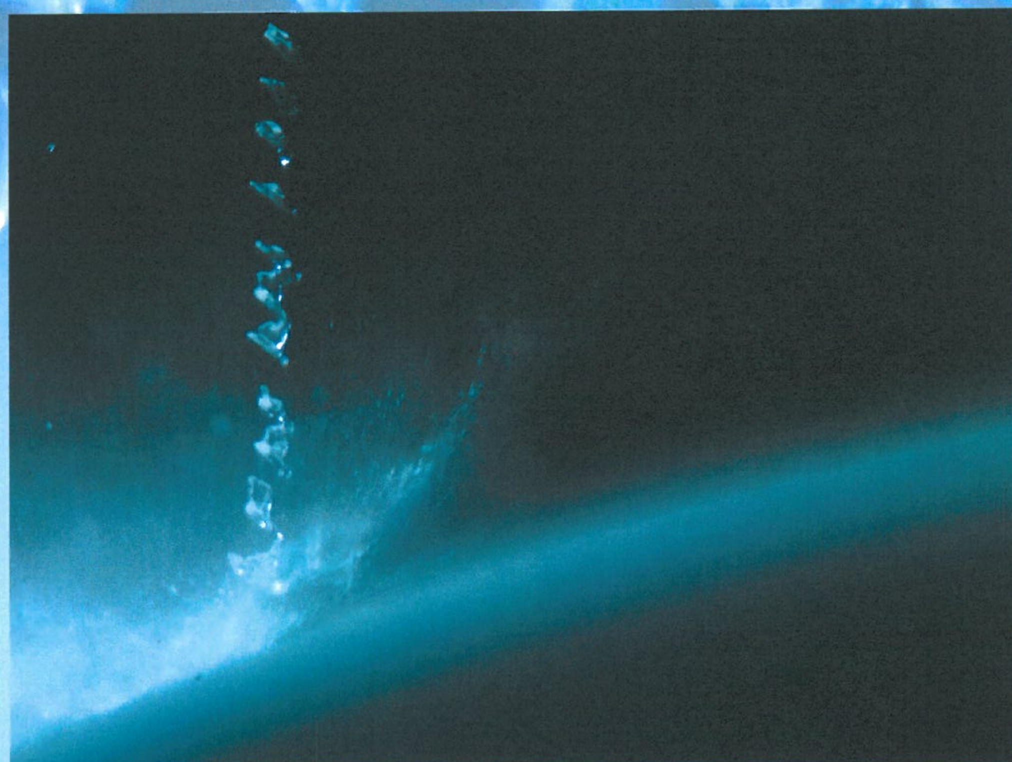
Results of Proof-of-Research

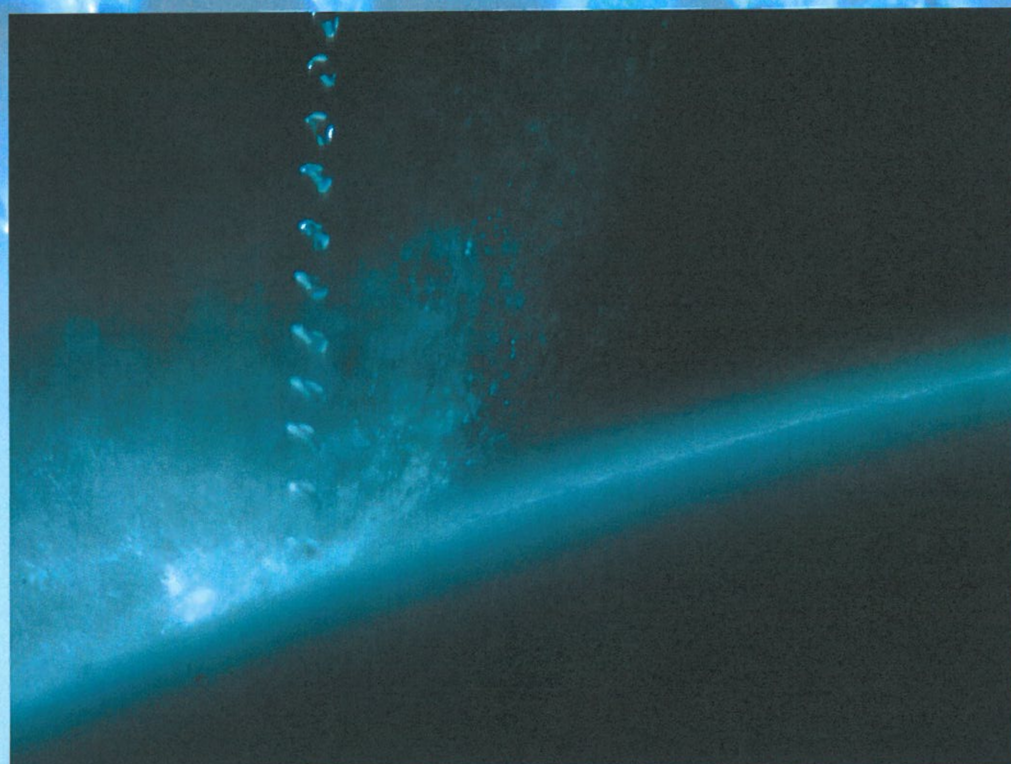
Stream of Droplets Impinging on the Shoulder Model.
Direct Illumination Technique



Droplet Diameter= 1000 µm, Airfoil Chord= 0.47 m, Airfoil Velocity= 90m/s

Results of Proof-of-Research

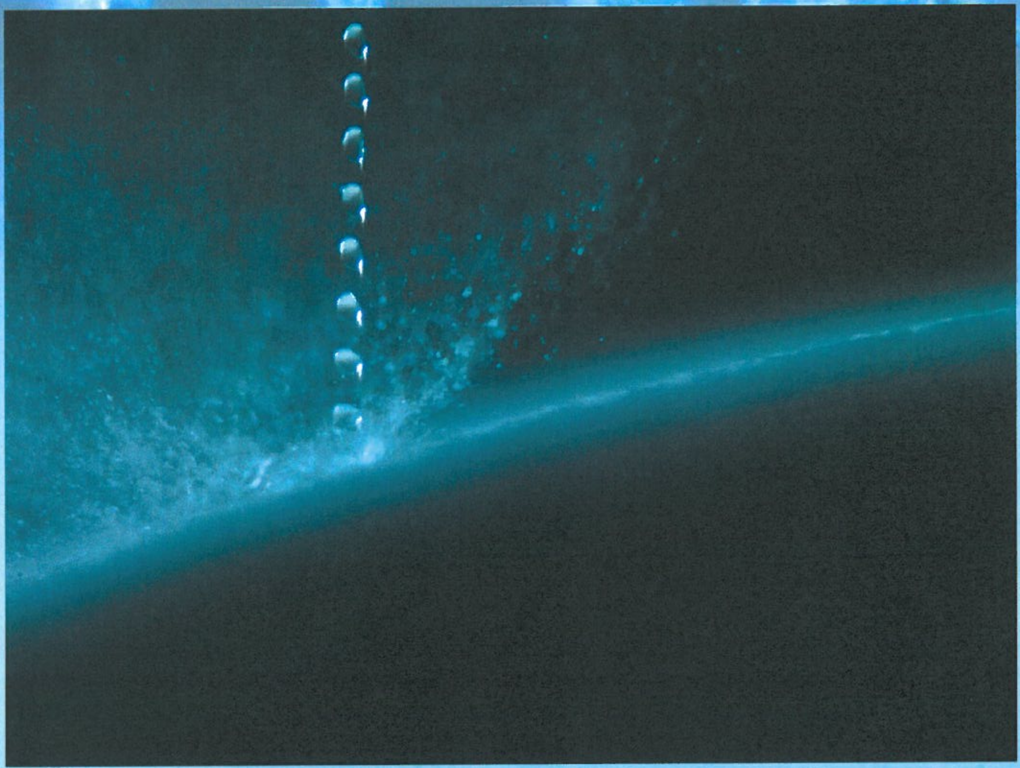
Stream of Droplets Impinging on the Shoulder Model.
Direct Illumination Technique



Droplet Diameter= 1000 µm, Airfoil Chord= 0.47 m, Airfoil Velocity= 50m/s

Results of Proof-of-Research

Stream of Droplets Impinging on the Shoulder Model.
Direct Illumination Technique



Droplet Diameter= 1000 µm, Airfoil Chord= 0.47 m, Airfoil Velocity= 26m/s

Additional Comments

- We are in the process of extending our imaging technique capabilities. We are learning how to combine two cameras and capture some of the 3D aspects of droplet splashing

- The next experiment at INTA will be dedicated to observe and measure splashing for droplets sizes from 200 μm to 3600 μm, speeds from 20 m/s to 90 m/s

- If INTA/NASA splashing studies could be part of EXTICE 2, INTA would have access to needed resources

- The possibility of building and entirely new rotating rig facility that allows for larger airfoils and higher speeds should be open to discussion