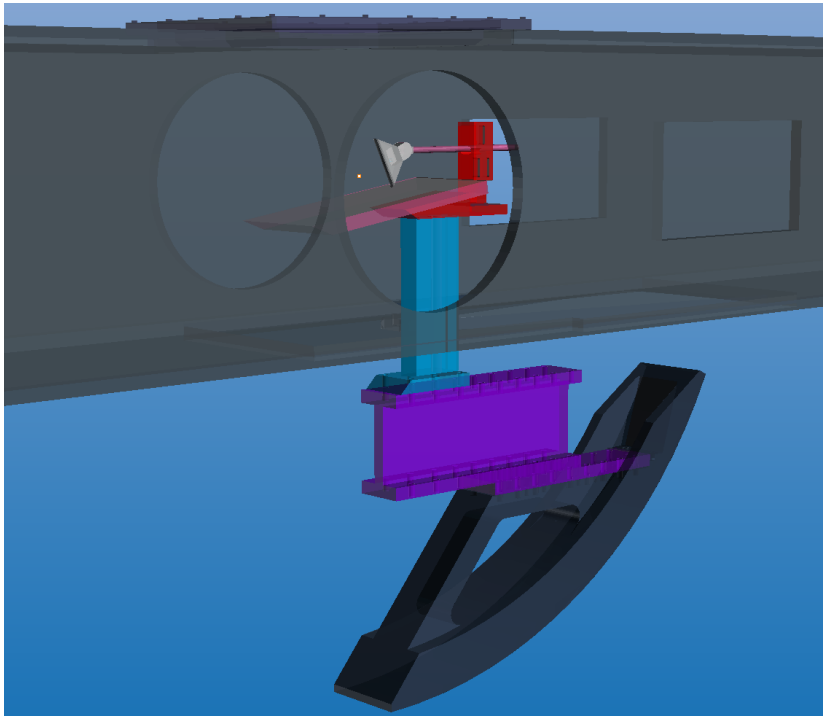
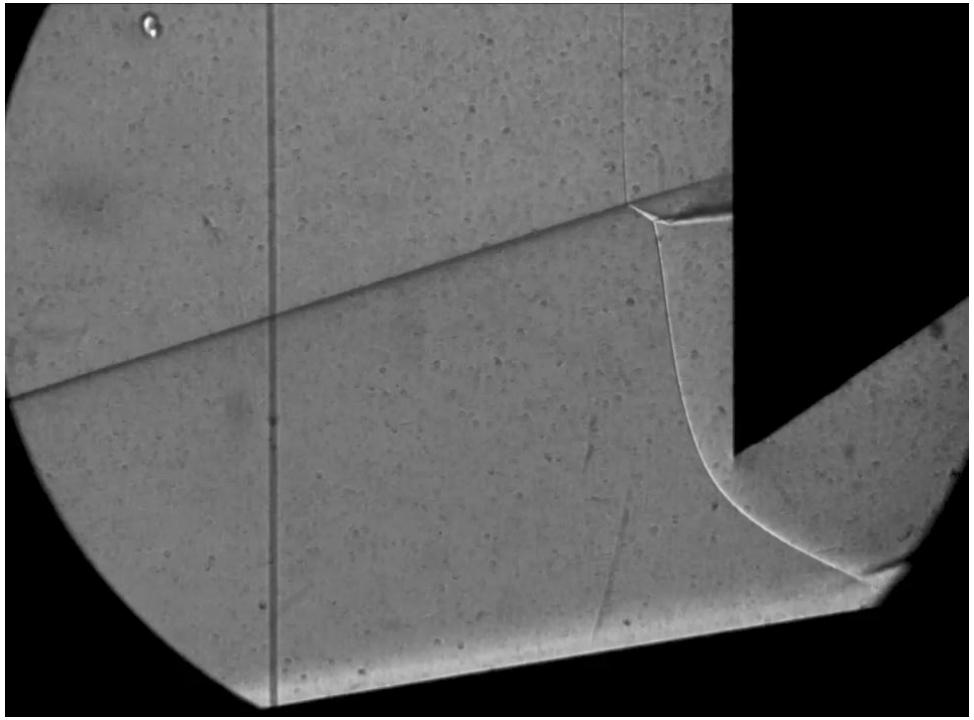
Computational Investigation of Shock-Shock Interactions at Mach 6

Michelle Jones, Alireza Mazaheri
NASA Langley Research Center





Thermal & Fluids Analysis Workshop (TFAWS 2013)
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Outline

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Introduction

Purpose

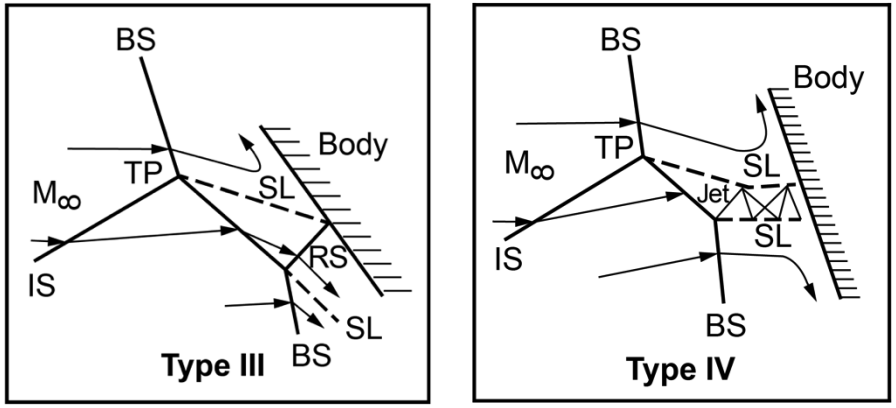
Computationally compare the schlieren, oil flow and heat transfer results from an experimental investigation of shock-shock interactions that can affect the surface heating of supersonic and hypersonic flight vehicles

Study Impact

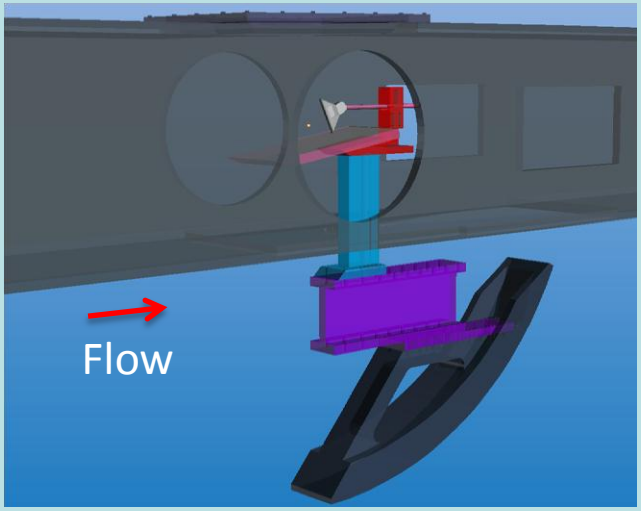
- Provides insight into the three-dimensional flow phenomena associated with the investigated shock-shock interactions
- Demonstrates the capability to process the output from a modified version of the LAURA code to calculate the density gradients and the heat transfer behavior of the investigated shock-shock interactions
- Compares the current results to a previous study using DPLR to simulate the flow for three types of shock-shock interactions

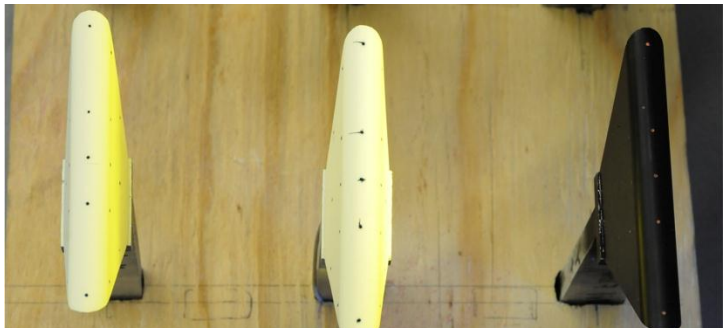
Experimental Set-up

Type III and IV Shock-Shock Interactions
(Barry Edney, ARI of Sweden, 1968)

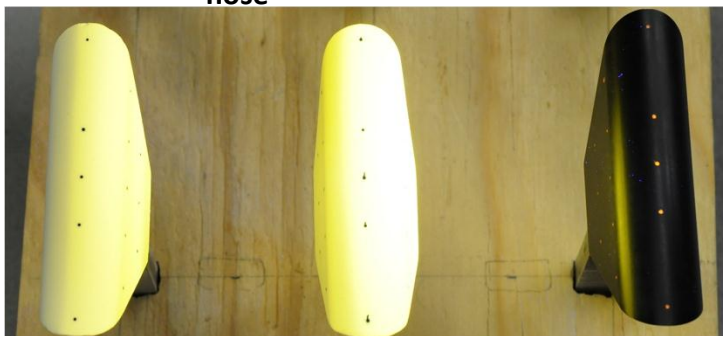


Graphic rendering of the present model in the test section:

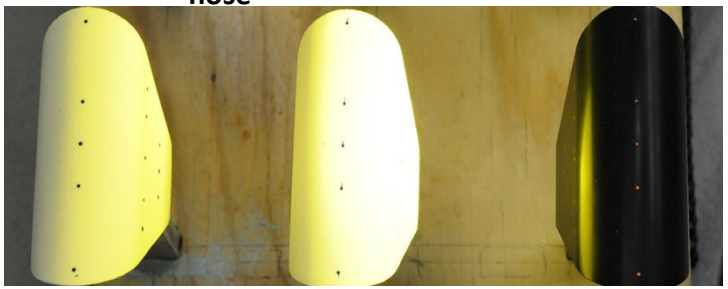




r_{nose} = 0.25 inches



r_{nose} = 0.50 inches

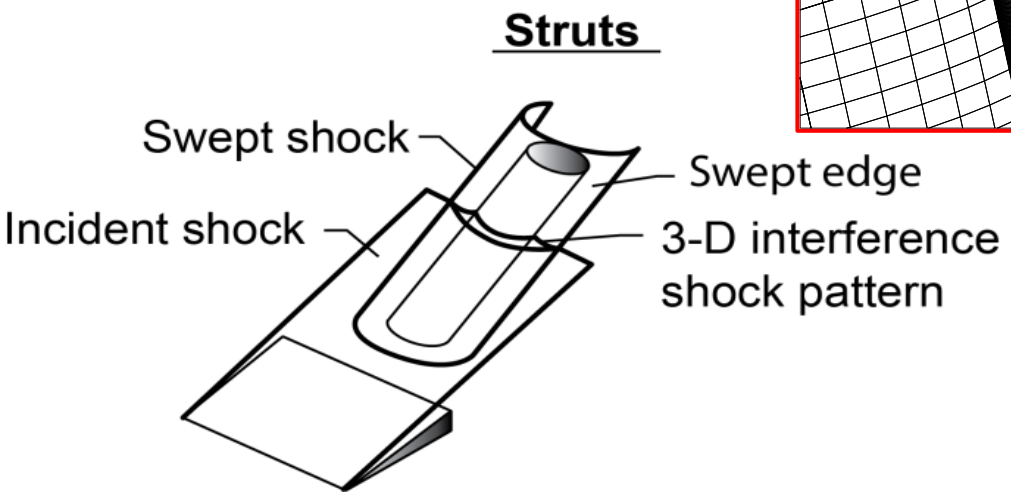


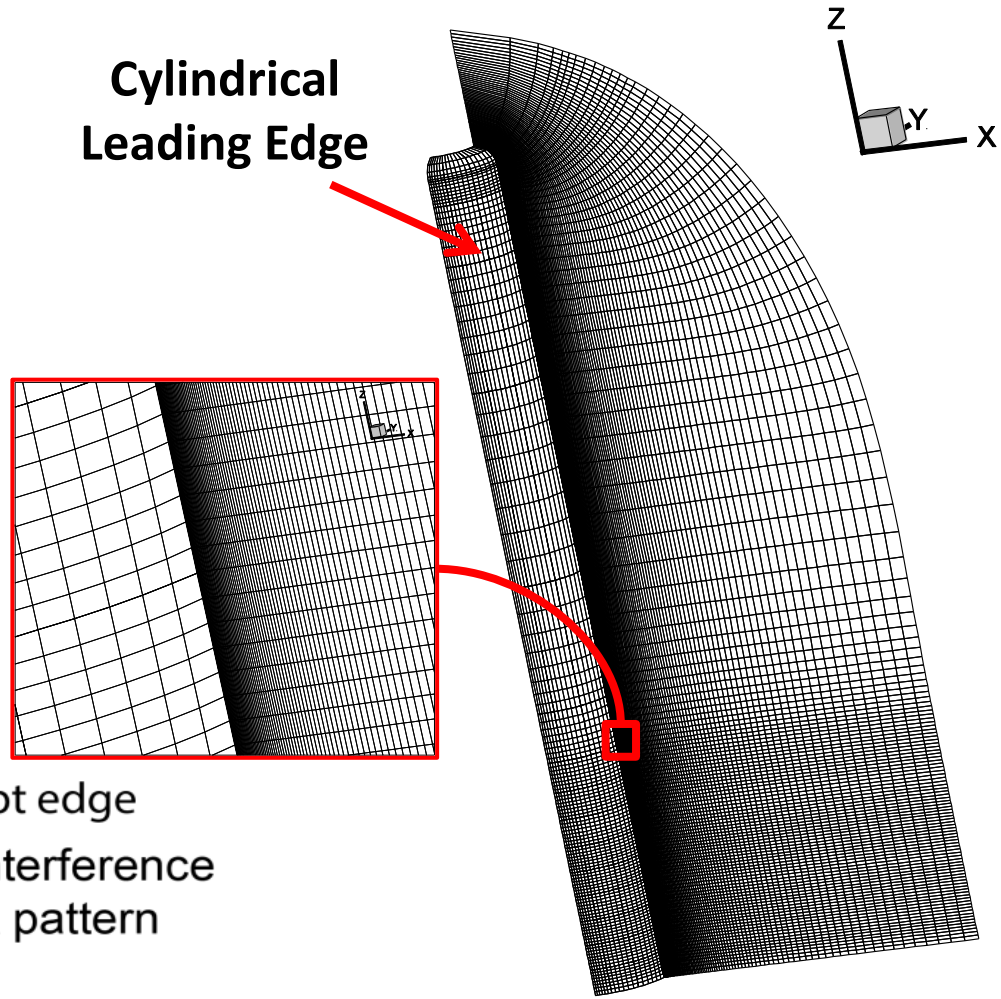
r_{nose} = 0.75 inches

Fused Silica **Metal**

Computational Set-up

- Time step: Δt = 1.0e-4 s
- Assumed laminar, perfect gas, Mach 5.96 free-stream flow with a temperature of 62.5K
- Fine grid (in i, j, k coordinates):
  - 0° AoA: 73 x 501 x 501 cells
  - -15° and -25° AoA: 73 x 737 x 511 cells

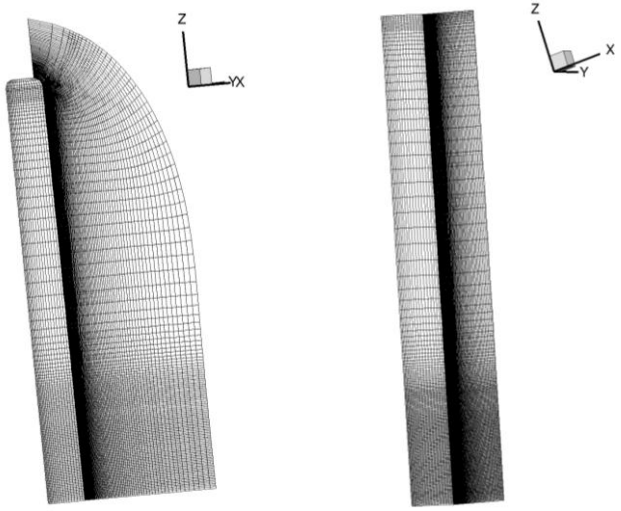




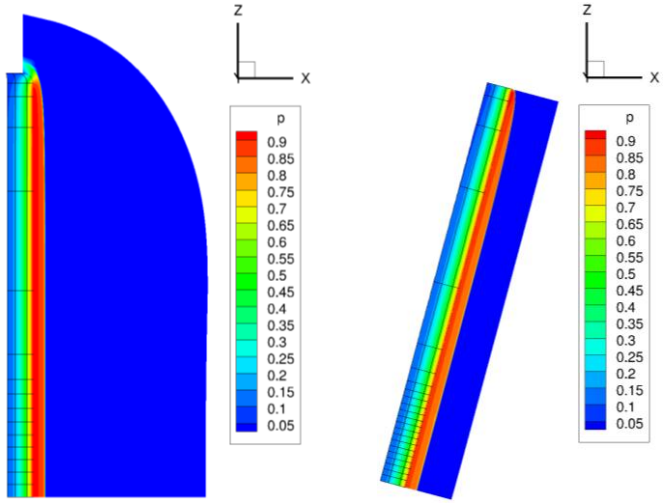
Coarse Grid

Computational Approach

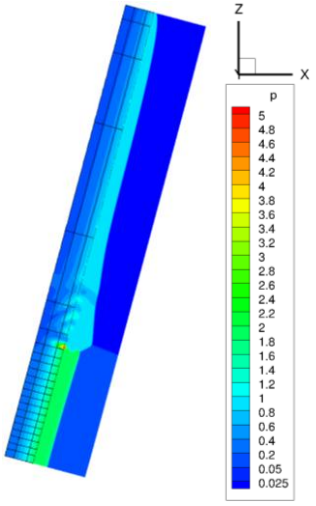
1) Generate the grid



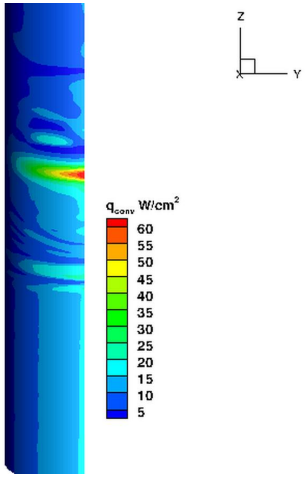
2) Run simulation to obtain bow shock



3) Add the incident shock



4) Run a time-accurate simulation



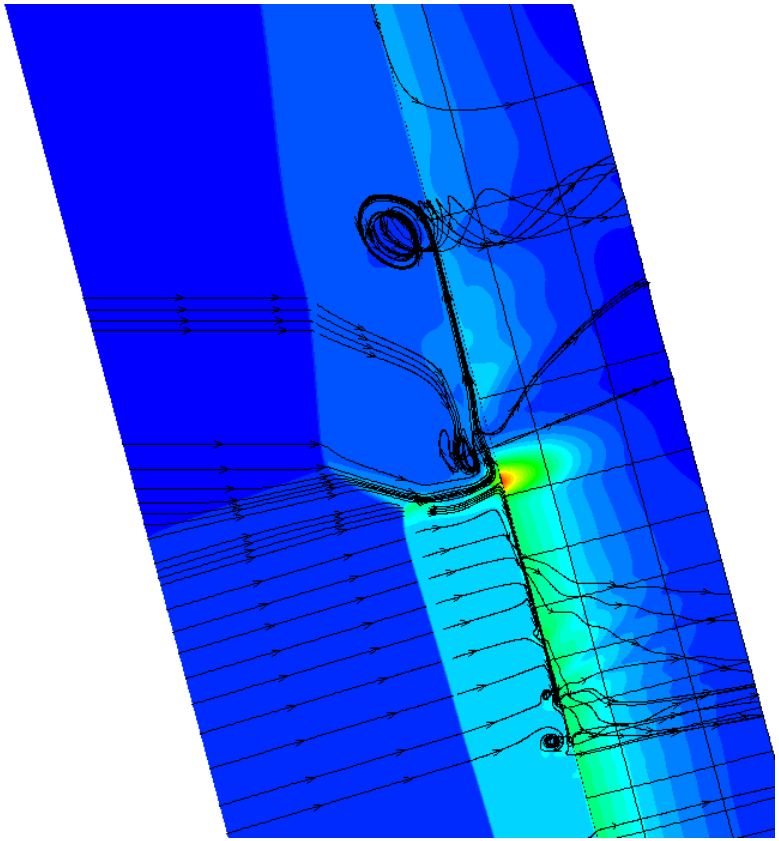
Previous Computational Studies

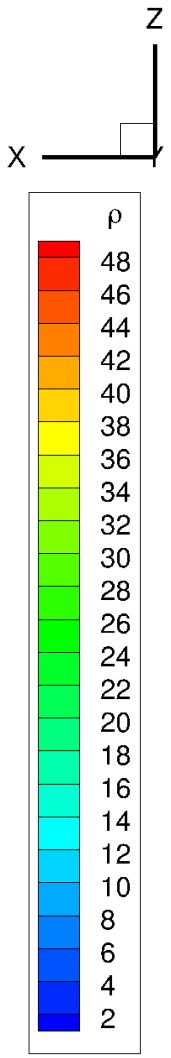
- Stewart et al. (AIAA, 1988):
  - Investigated shock-on-cowl interactions using a Galerkin-Runge-Kutta method to model the compressible Euler equations
  - Used adaptive re-meshing technique

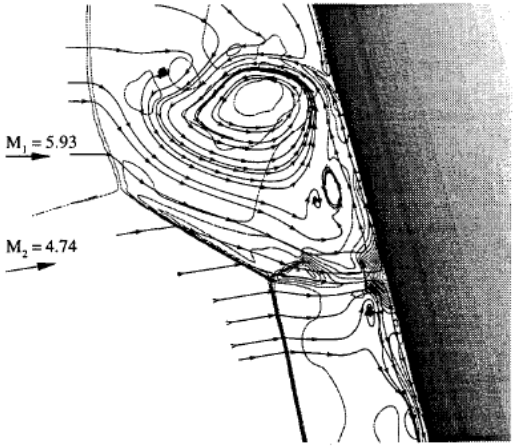
- Vemaganti and Wieting (AIAA, 1990):
  - Investigated shock-on-cowl interactions using SUPG/least squares method to model the Navier-Stokes equations
  - Used adaptive re-meshing technique with structured grid near the surface and unstructured grid to model the free-stream flow

- Michael Wright (AIAA, 1998):
  - Investigated the Type III and IV shock-on-fin interactions using the DPLR and GASP codes to model the Mach 6 flow using the Navier-Stokes equations
  - Compared averaged heat transfer over multiple iterations, schlieren density gradients and streamlines from CFD results to the experimental data from a similar test configuration from Berry and Nowak (JSR, 1997)

Numerical Streamlines: -15° AoA



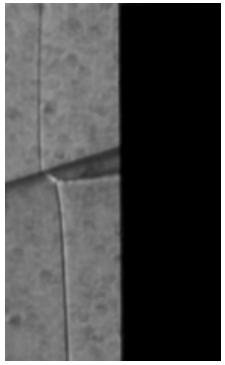
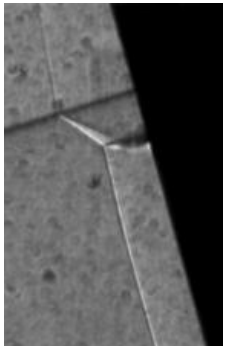
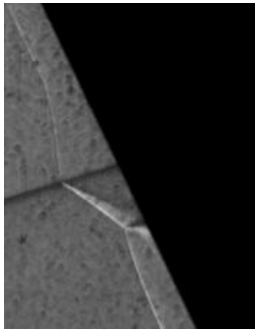
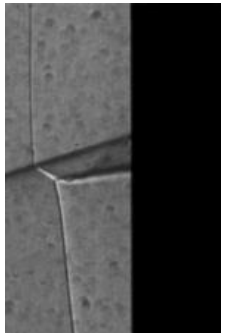
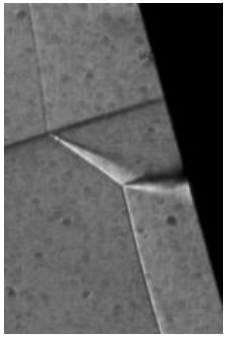
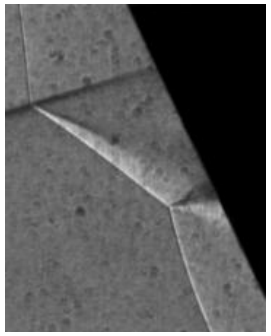
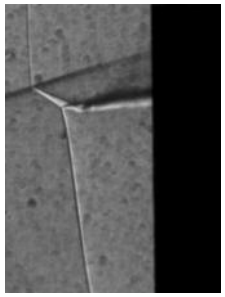
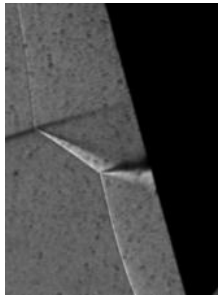
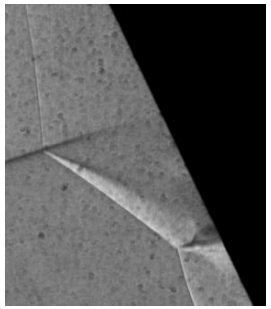




Wright (AIAA, 1998)

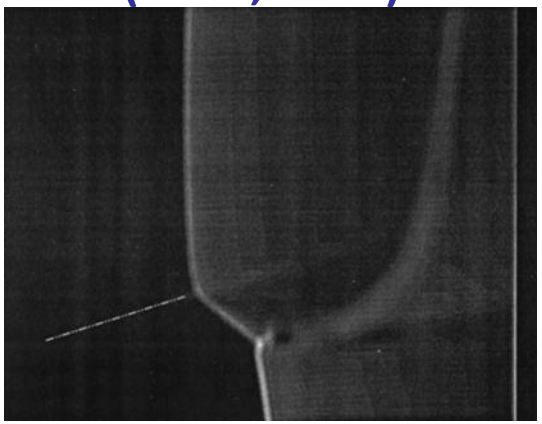
Present Study

Experimental Zoom Schlieren

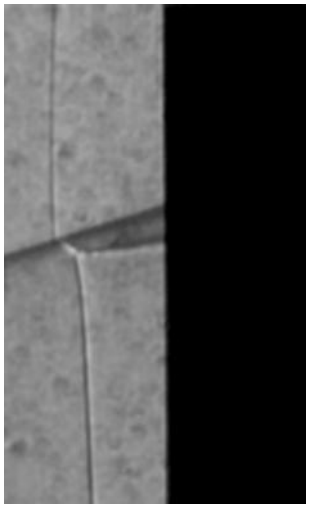
	Type IVa AoA: 0˚	Type IV AoA: -15˚	Type III AoA: -25˚
R_N: 0.25 in			
R_N: 0.50 in			
R_N: 0.75 in			

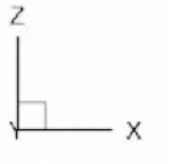
Numerical Schlieren (LAURA)

Wright (AIAA, 1998)



Present Study



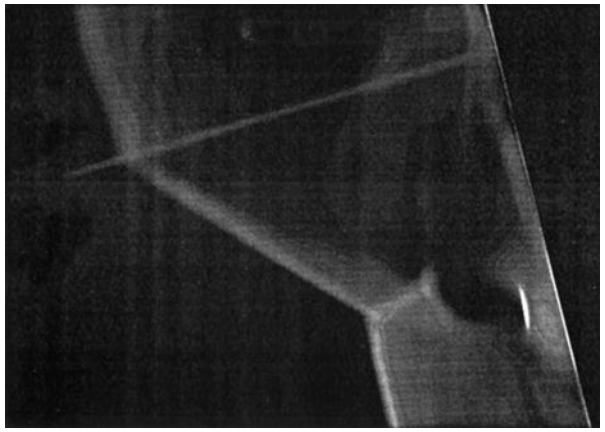


Type IVa
AoA: 0°
SG: 9°
R_N: 0.25 in

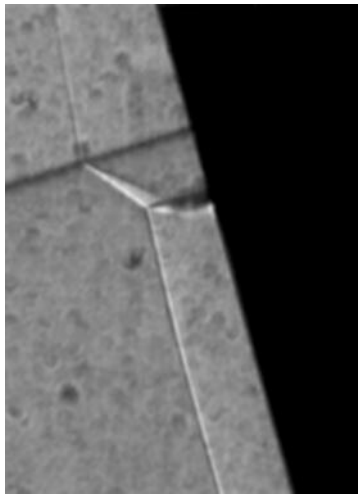
Time step: Δt = 0.0001 seconds (10,000 Hz)

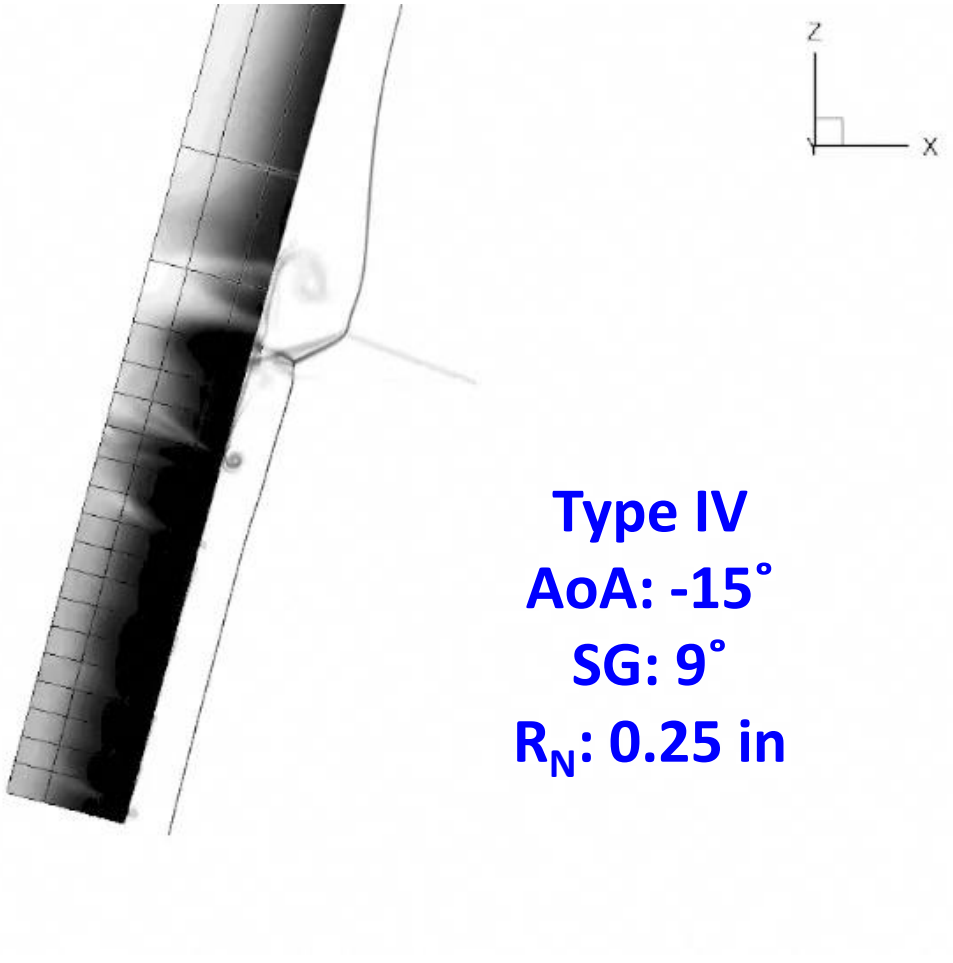
Numerical Schlieren (LAURA)

Wright (AIAA, 1998)



Present Study



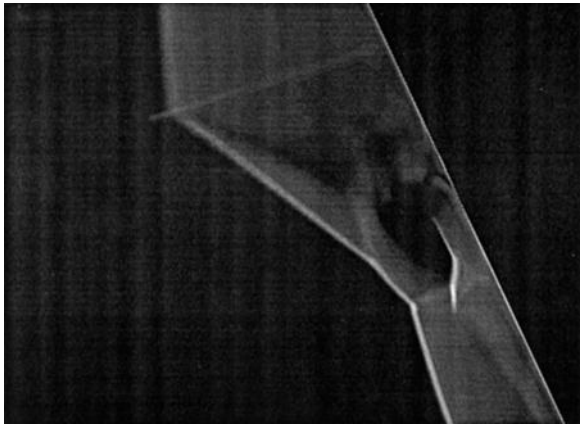


Type IV
AoA: -15˚
SG: 9˚
R_N: 0.25 in

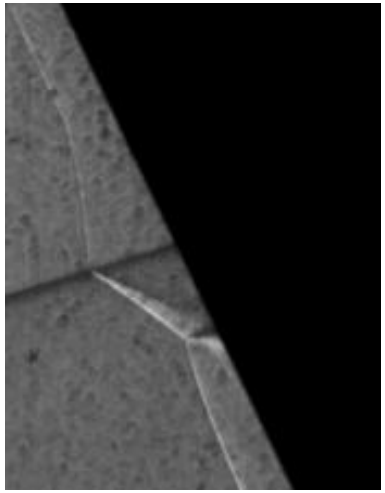
Time step: Δt = 0.0001 seconds (10,000 Hz)

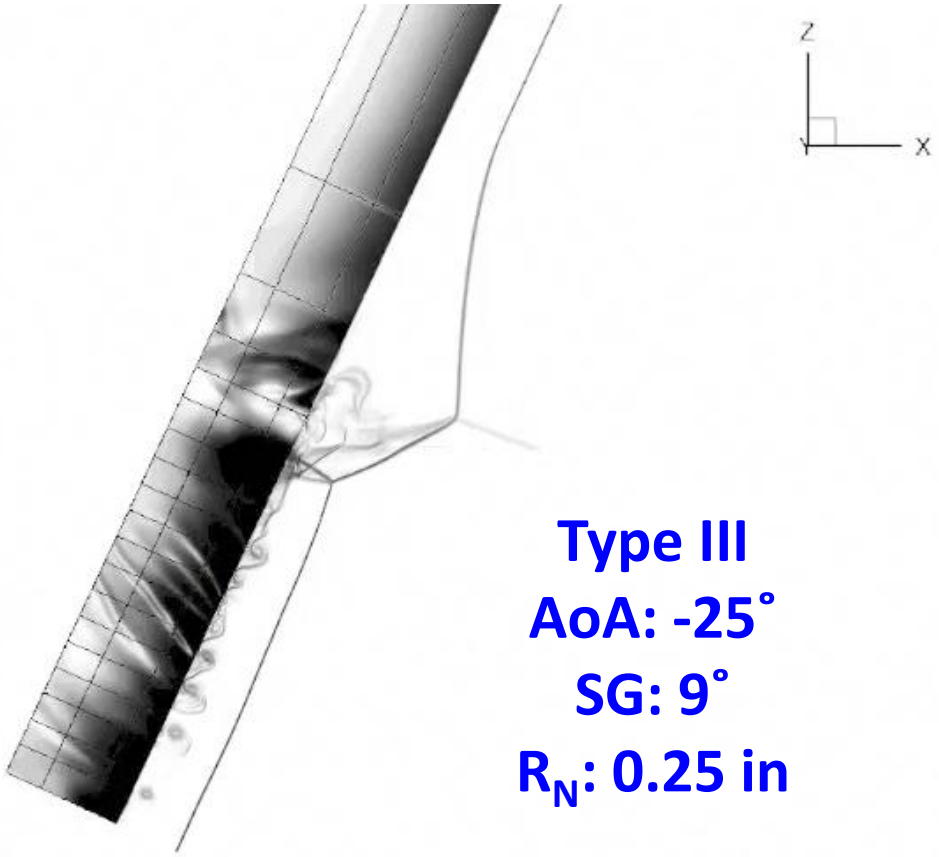
Numerical Schlieren (LAURA)

Wright (AIAA, 1998)



Present Study

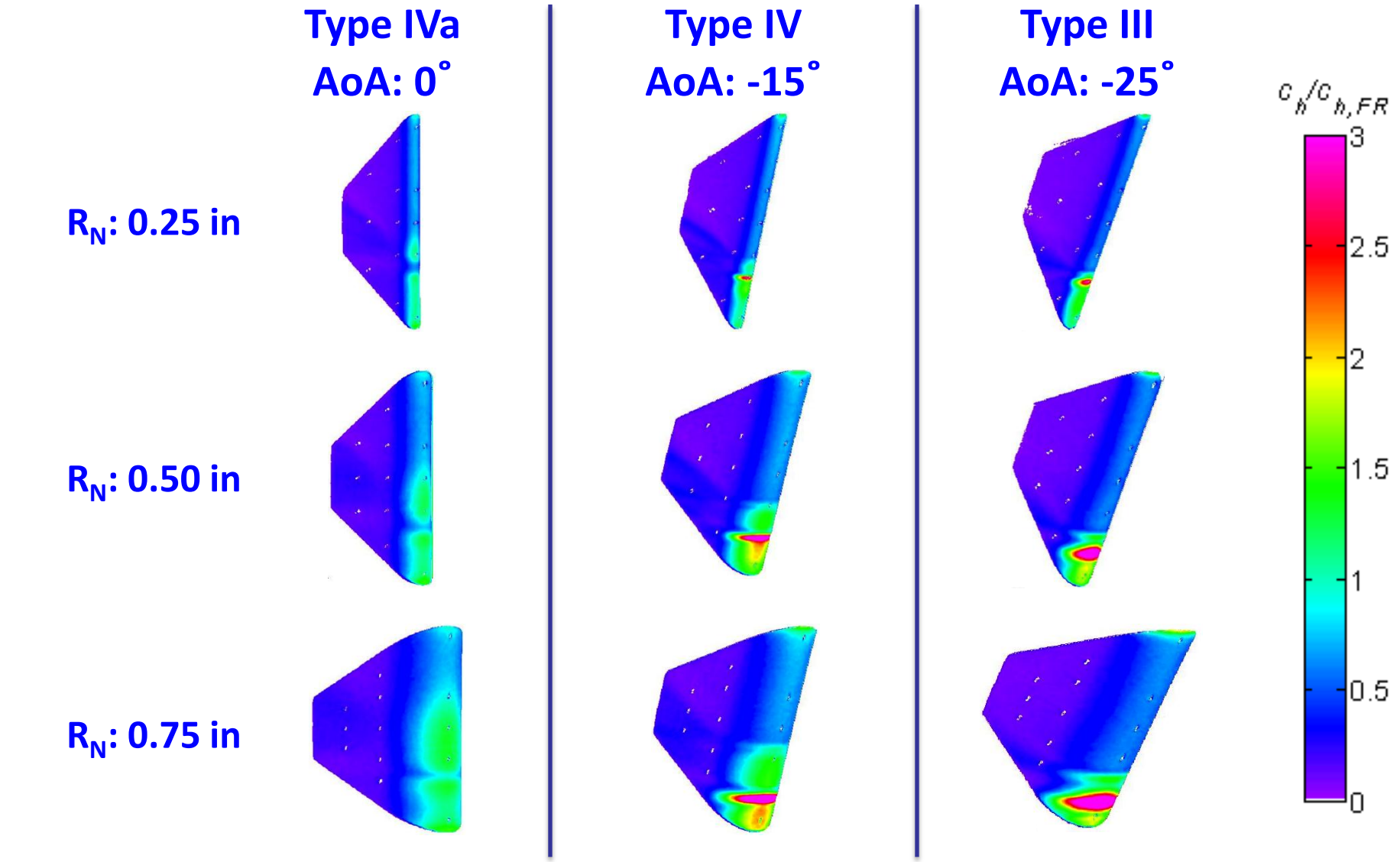




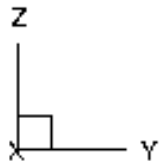
Type III
AoA: -25˚
SG: 9˚
R_N: 0.25 in

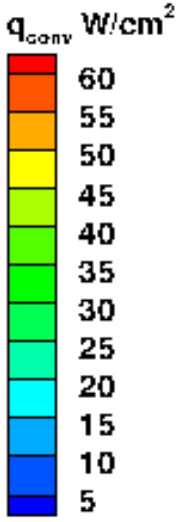
Time step: Δt = 0.0001 seconds (10,000 Hz)

1D Global Heating Contour Maps



Surface Heat Transfer: CFD vs. Experimental

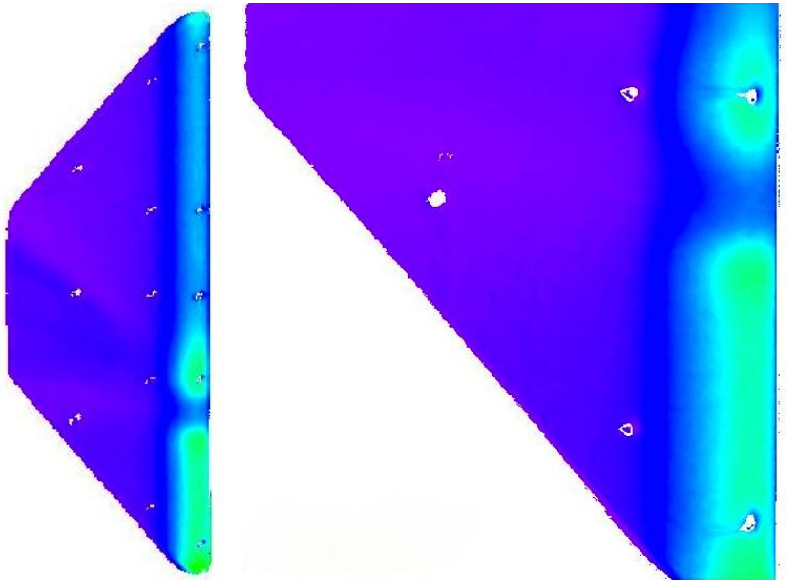




CFD
Type IVa
AoA: 0˚
SG: 9˚
R_N: 0.25 in

Time step: Δt = 0.0001 seconds (10,000 Hz)

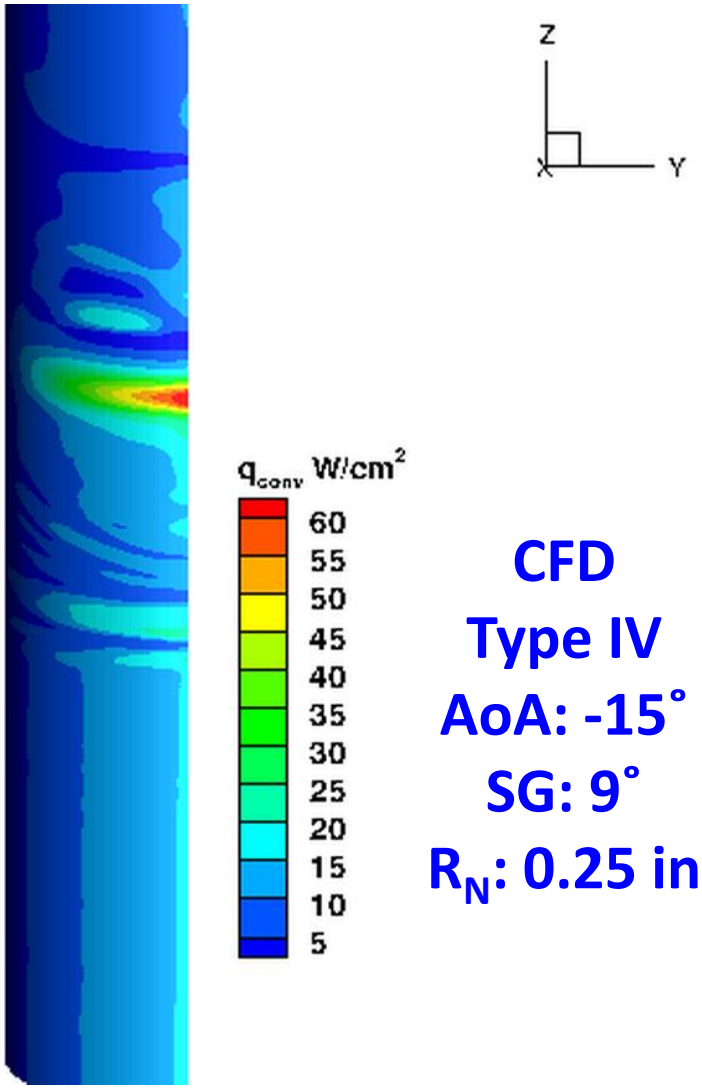
Experimental
Type IVa, AoA: 0˚, SG: 9˚



Run 39 **Run 47**

Time step: Δt = 0.033 seconds (30 fps)

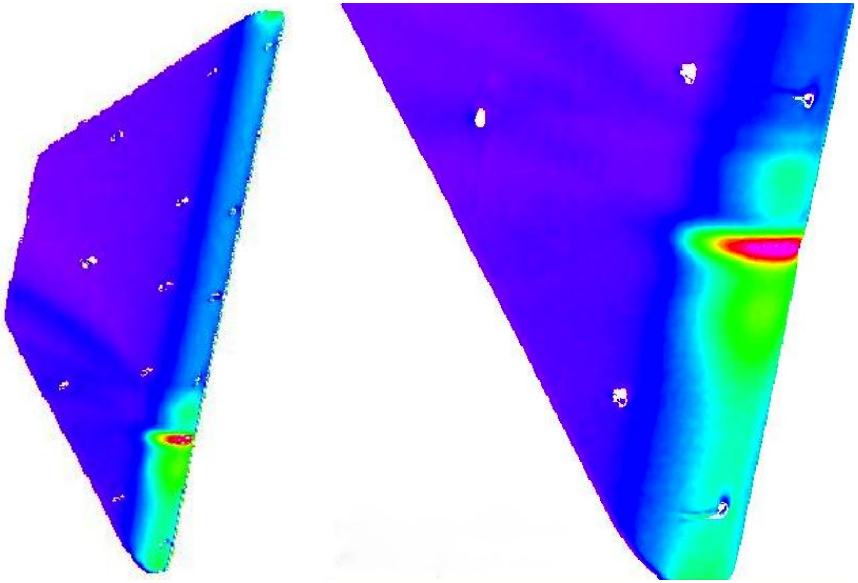
Surface Heat Transfer: CFD vs. Experimental



CFD
Type IV
AoA: -15˚
SG: 9˚
R_N: 0.25 in

Time step: Δt = 0.0001 seconds (10,000 Hz)

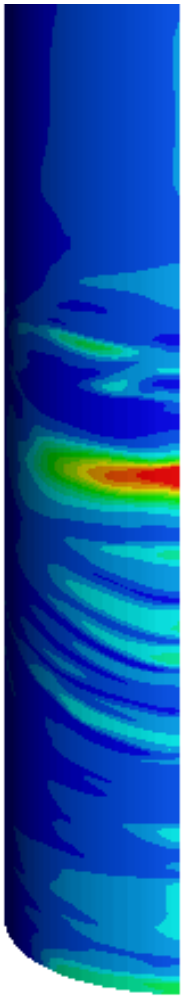
Experimental
Type IV, AoA: -15˚, SG: 9˚

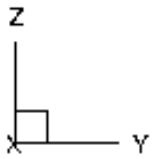


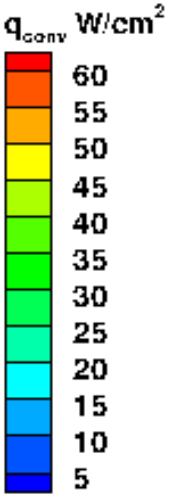
Run 40 **Run 45**

Time step: Δt = 0.033 seconds (30 fps)

Surface Heat Transfer: CFD vs. Experimental

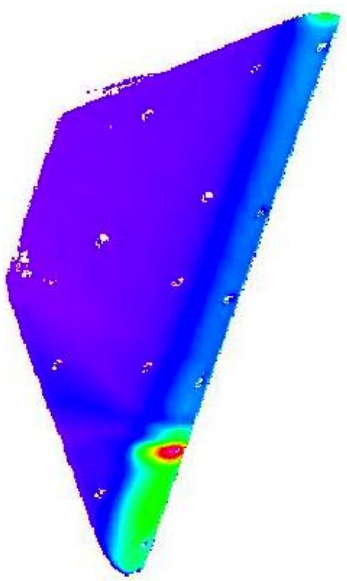


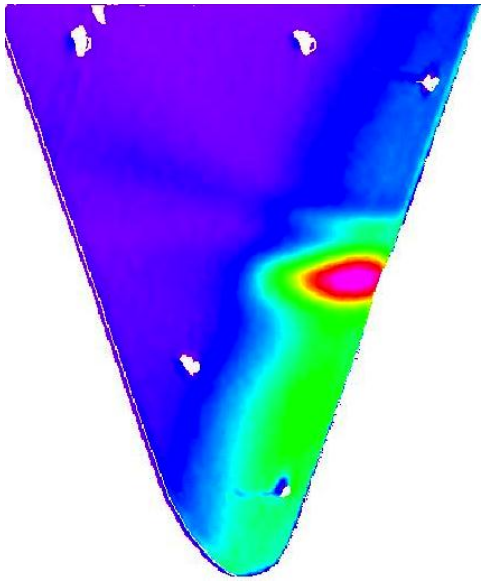




CFD
Type III
AoA: -25˚
SG: 9˚
R_N: 0.25 in

Experimental
Type III, AoA: -25˚, SG: 9˚





Run 41

Run 46

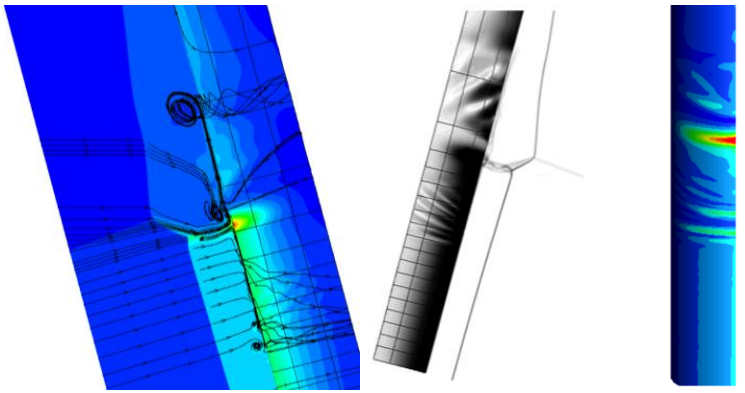
Time step: Δt = 0.0001 seconds (10,000 Hz)

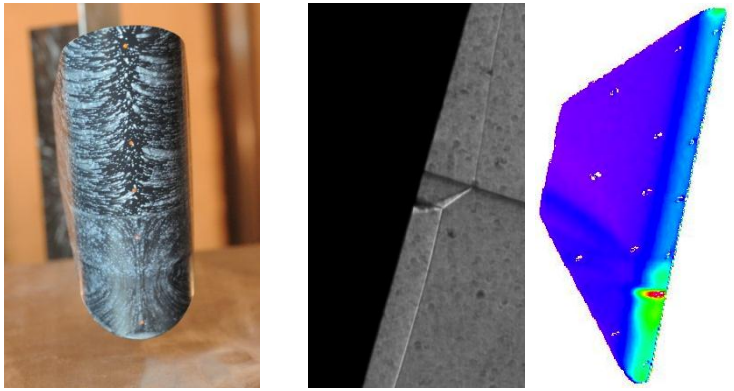
Time step: Δt = 0.033 seconds (30 fps)

Summary of Numerical Results to Date

- Numerical schlieren and heat transfer patterns resemble experimental results for Type III and Type IV interactions
- Time-dependent oscillations due to unsteady flow phenomena in the shock-shock interactions are visible in the CFD results
  - Density gradients are blurred in the experimental zoom schlieren due to poor contrast in images obtained at higher framing rates
  - Heat transfer fluctuations are not observed using the experimental methods
- Streamlines on the experimental oil flow test articles follow similar paths to the streamlines in the numerical solutions

First global thermal imaging study to improve the understanding of 3D shock-on-strut interactions





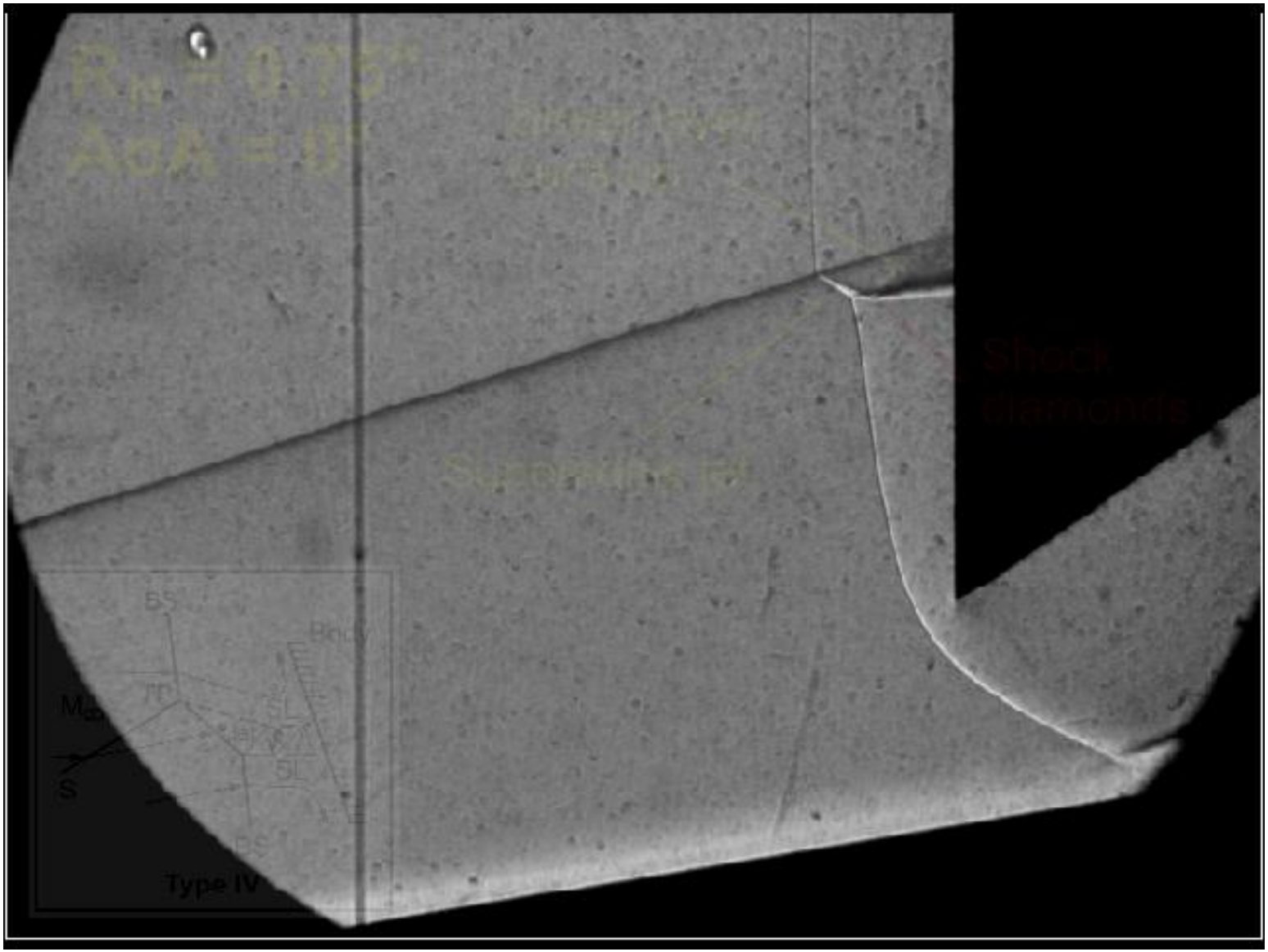
Thank you! Questions?

Suggested Future Work

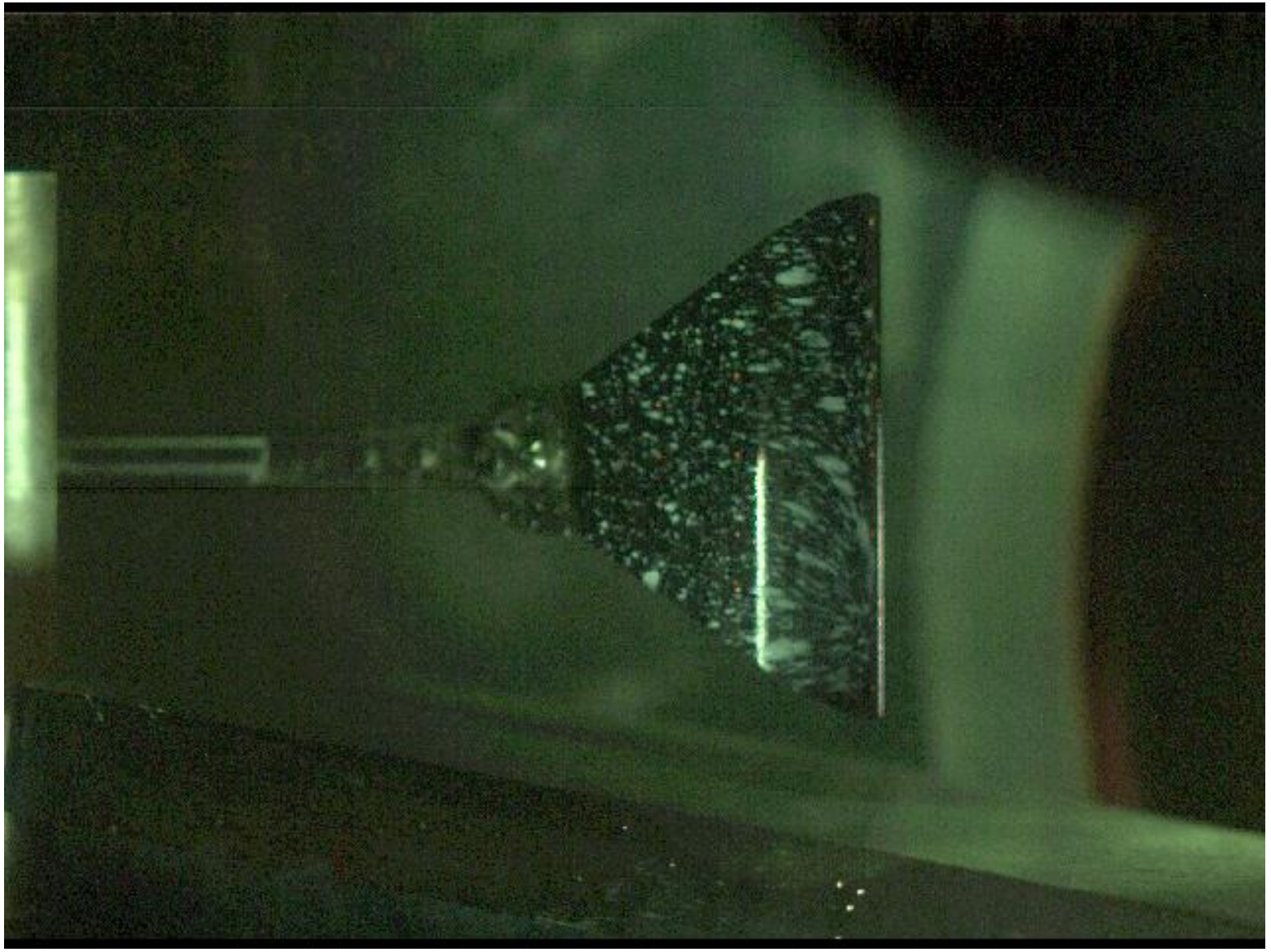
- Use updated LAURA code to continue 3D analysis of shock-shock interactions with the smallest test article geometry
  - Run laminar and turbulent simulations
  - Use finer, adapted grids for all three angles of attack
- Complete a grid convergence study for each case
- Conduct simulations with grids representing the larger test article geometries from the experimental study
- Quantitatively compare the computed heat transfer for the computational cases to the experimental results

Back-up Slides

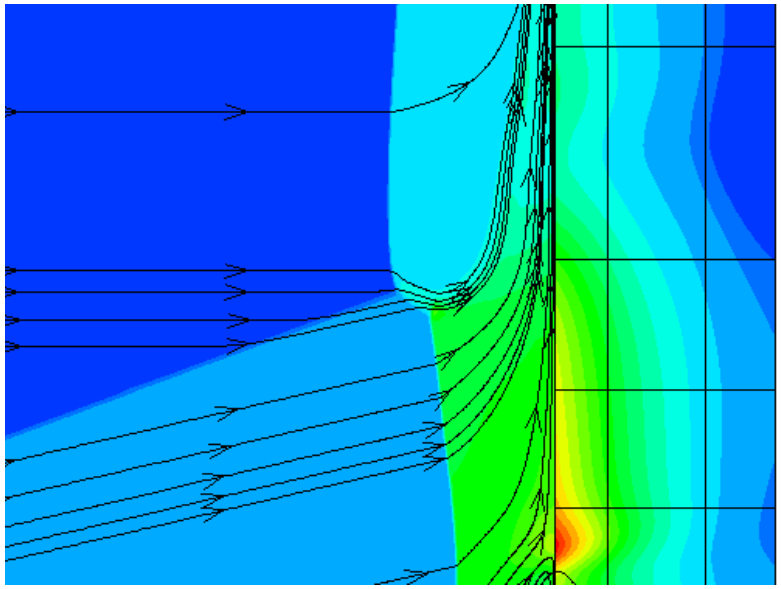
Experimental Zoom Schlieren

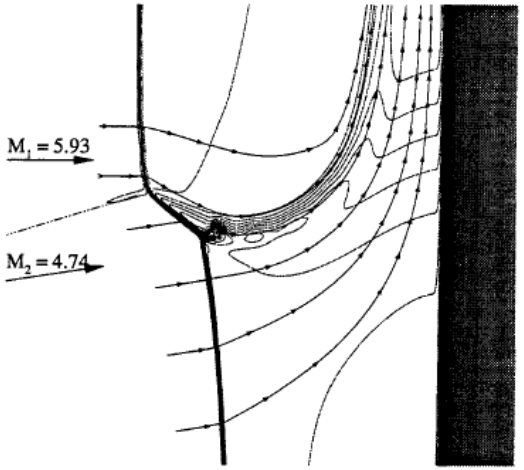


Oil Flow Tests



Numerical Streamlines: 0˚ AoA

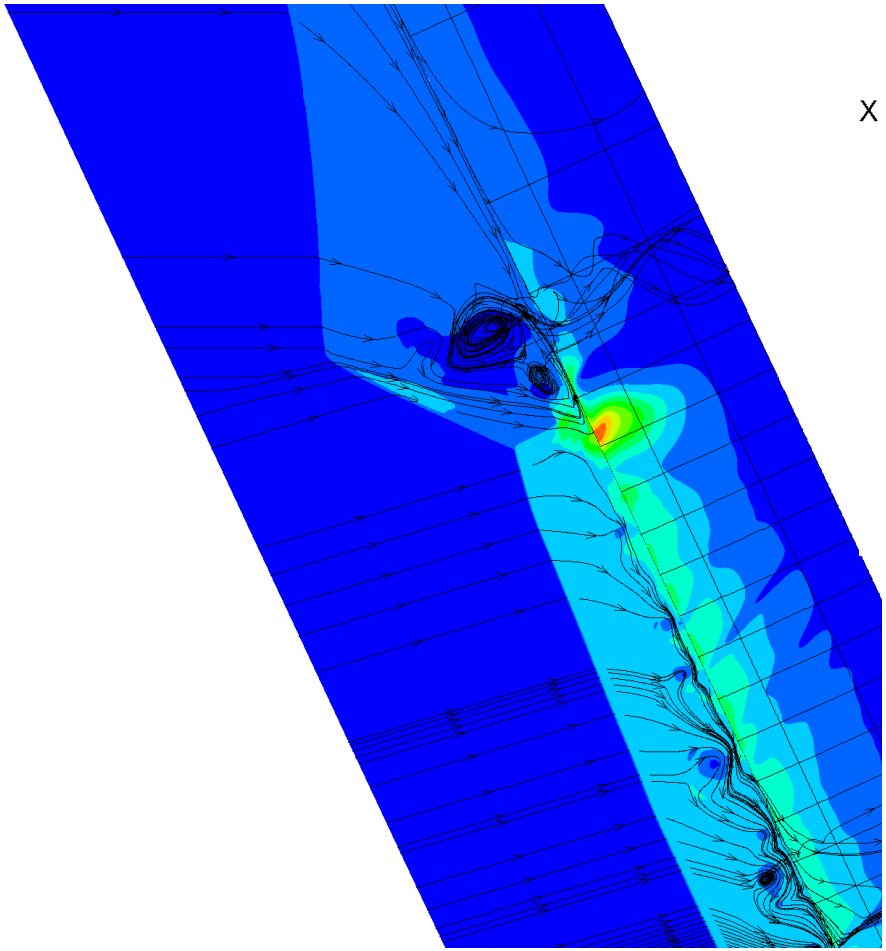


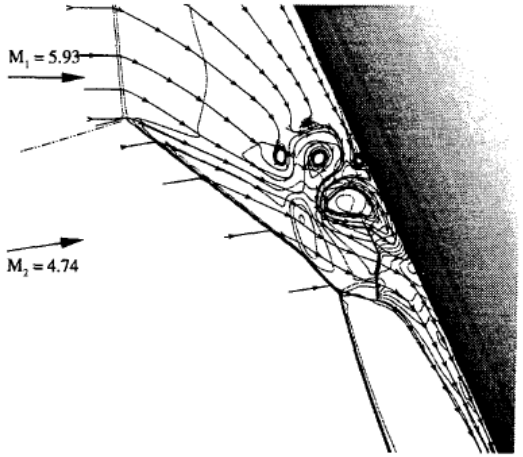


Wright
(AIAA, 1998)

Present Study

Numerical Streamlines: -25˚ AoA





Wright (AIAA, 1998)

Present Study

Flat Plate Shock Generator Simulation