Comparison of Cross Correlation and Optical Flow Methods for Processing Retroreflective and Natural Background BOS data

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Introduction

- Motivation
- Processing methods
  - Normalized cross-correlation
  - Optical flow
- Data sets
  - **Wind tunnel data**: retroreflective BOS NASA plume/shock interaction
  - **Flight data**: natural background AirBOS T-38
- Schlieren image results
- Conclusions

Motivation

- Cakebos/BOSCO early initial oflow?

BOS Processing Methods

- Displacement calculation between wind-on and reference
- Normalized cross-correlation
  - Well established technique in BOS, PIV
  - "Window matching" displacement
  - Subpixel localization via correlation peak finding
- Optical flow
  - Technique from computer vision community to detect motion, segmentation, and identification in video
  - Directly solve for the "brightness velocities"
- Registration, map to grayscale, and sequence averaging

Optical Flow I

- Horn Schunck: global regularization method
  - Dense solution method
  - Intuitive formulation
- Brightness constancy: $I_x \mathrm{u} + I_y \mathrm{v} = -\mathrm{I_t},$
- Smoothness constraint: $\|\nabla u\|^2 + \|\nabla v\|^2$
- Minimize the functional:

$$\int \left(I_x \mathrm{u} + I_y \mathrm{v} + \mathrm{I_t}\right)^2 + \alpha^2 (\|\nabla u\|^2 + \|\nabla v\|^2)\, \mathrm{d}x\mathrm{d}y$$

Optical Flow II

- Euler-Lagrange yields simple iterative method
  - Jacobi vs. Gauss-Seidel
  - Converge to 10E-6

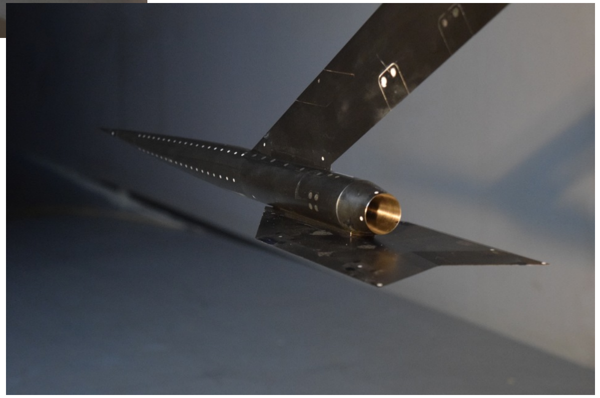
$$u = \bar{u} - I_x \frac{I_x\bar{u} + I_y\bar{v} + I_t}{\alpha^2 + I_x^2 + I_y^2} \qquad v = \bar{v} - I_y \frac{I_x\bar{u} + I_y\bar{v} + I_t}{\alpha^2 + I_x^2 + I_y^2}$$

- Numerical considerations
  - $u, \bar{u}$ separated via 9-pt Laplacian stencil (window)
  - 8^{th} order spatial derivatives
  - Image spatial derivatives from 2 frames

NASA shock-plume interaction wind tunnel data

Diamond airfoil

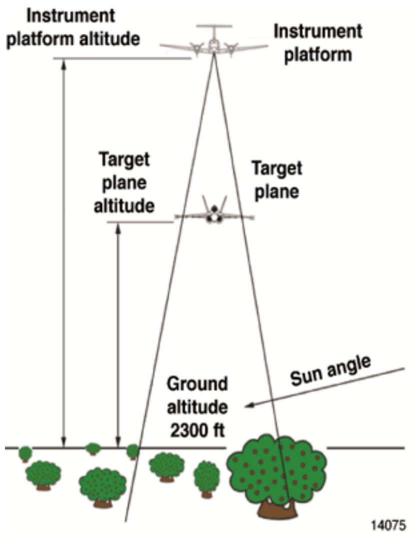
Aft-swept deck

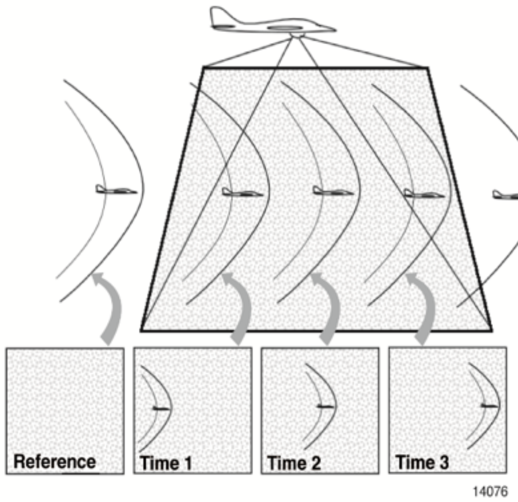


- Shock Interaction studies with nominal Mach 2 jet exit
  - Freestream Mach 1.6 and 2
  - Multiple shock generating geometries
- RBOS speckle pattern below pressure rail

RBOS Raw data

AirBOS Flight Data

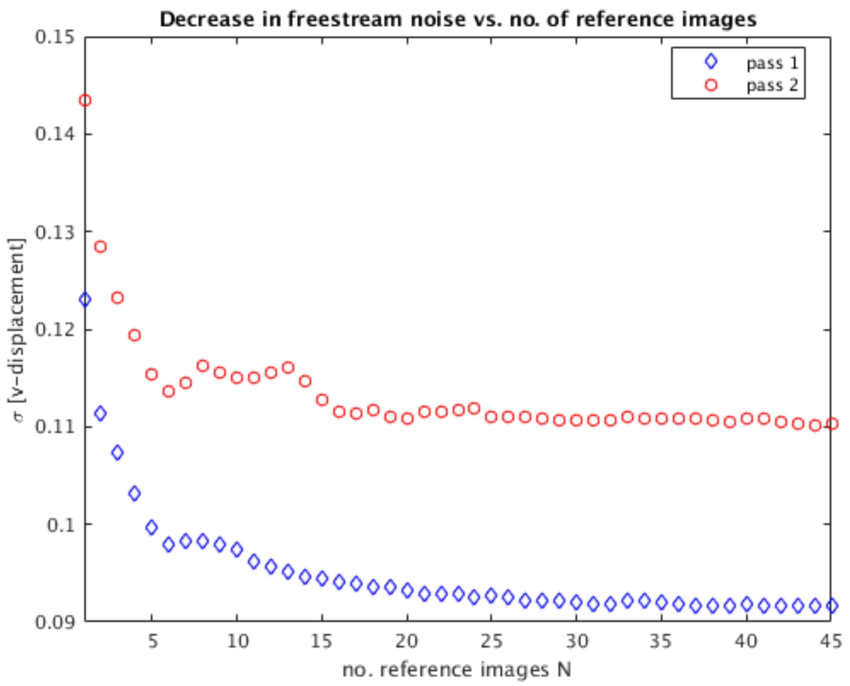




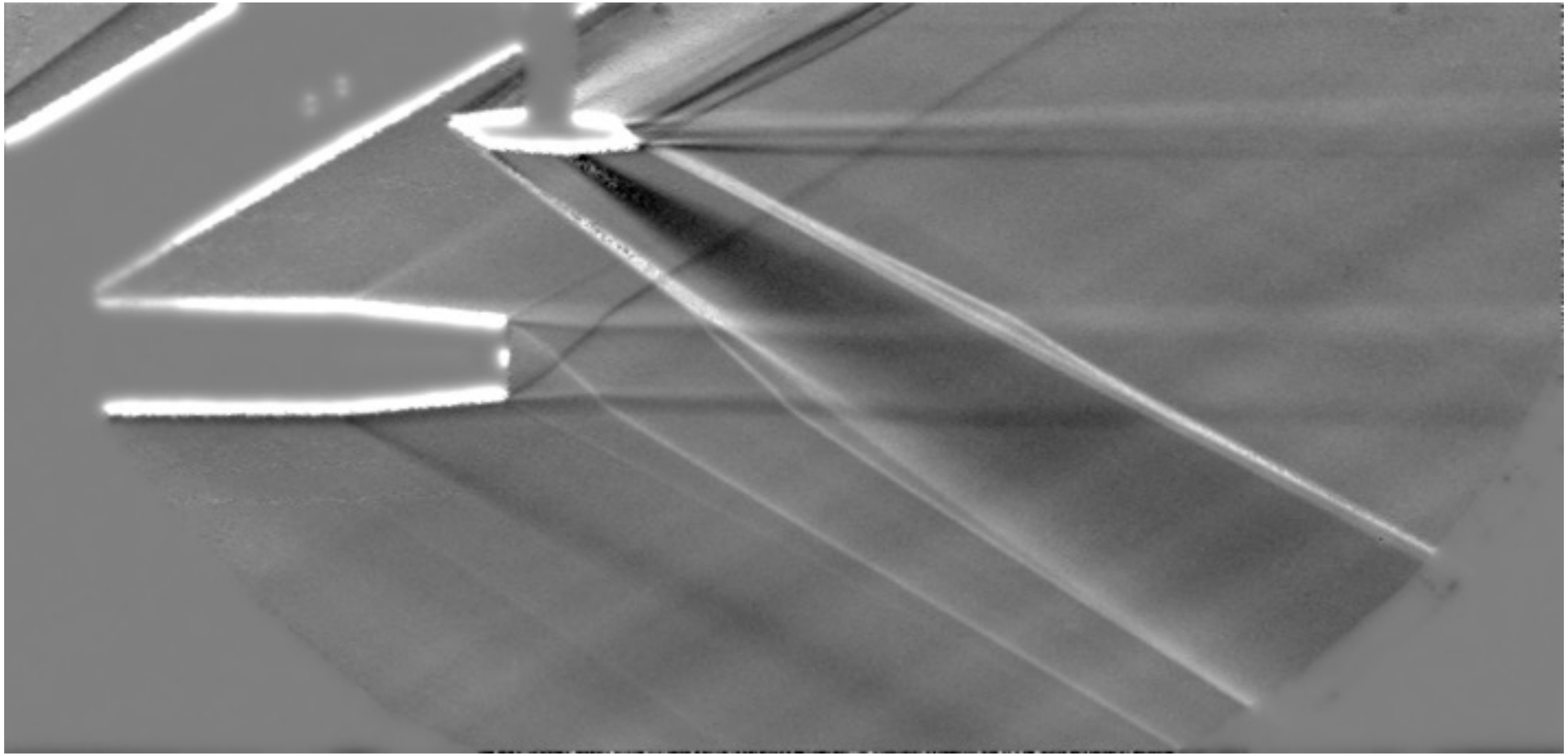
- Desert used as natural background speckle pattern
- Observer plane photographs target from above
- Pass 1 – 5000ft separation, Pass 2 – 2000ft separation

Use of multiple reference images

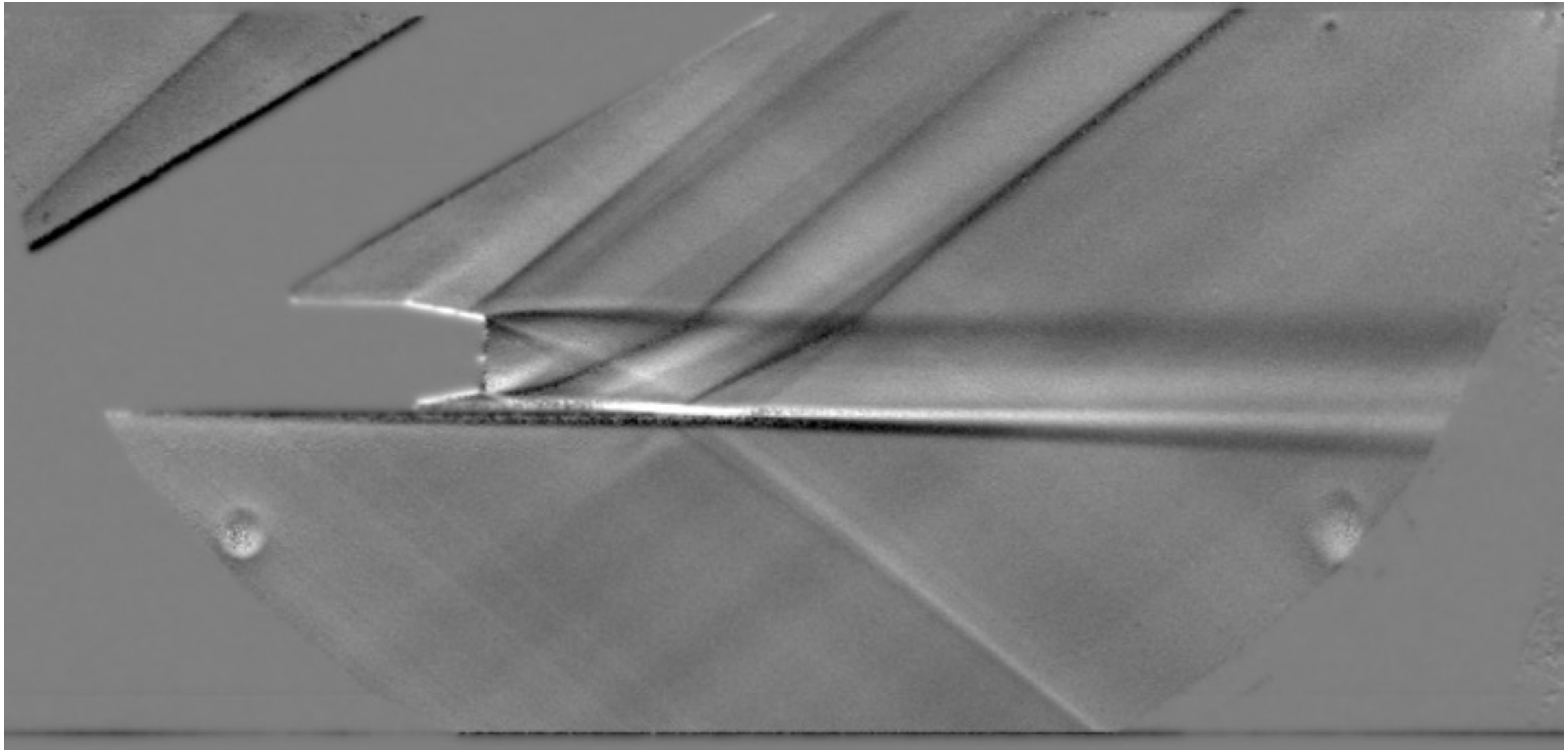
- Multiple AirBOS reference images available
  - Reduce freestream noise, Moiré patterns
  - Potentially clarify additional structure
- Standard deviation of freestream ROI
  - Significant reduction after 5 images
  - Tradeoff between cost and noise
- Difficult to used in RBOS images
  - Backgrounds must be distinct
  - Out of plane model rotation



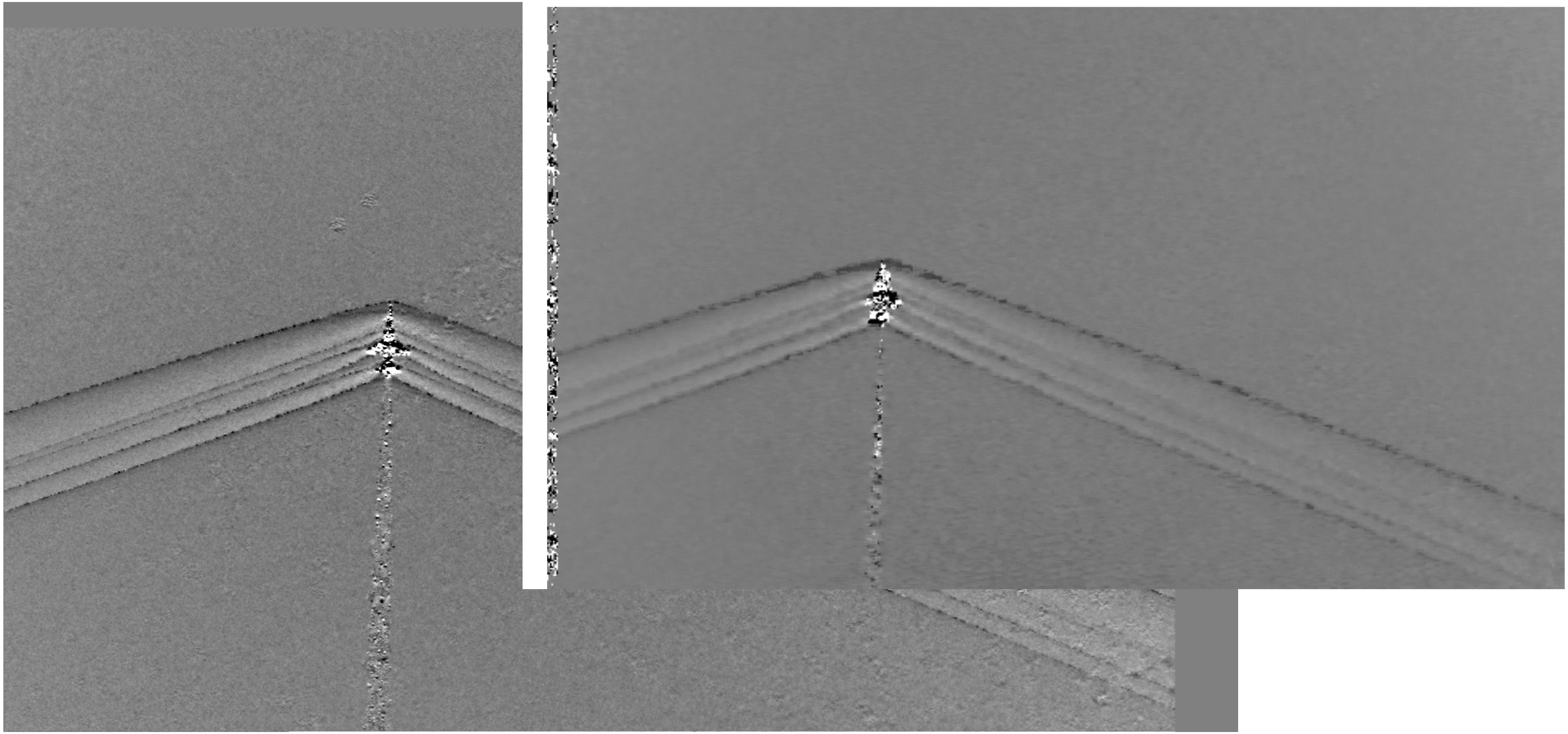
Shock-plume interaction I: double-wedge airfoil



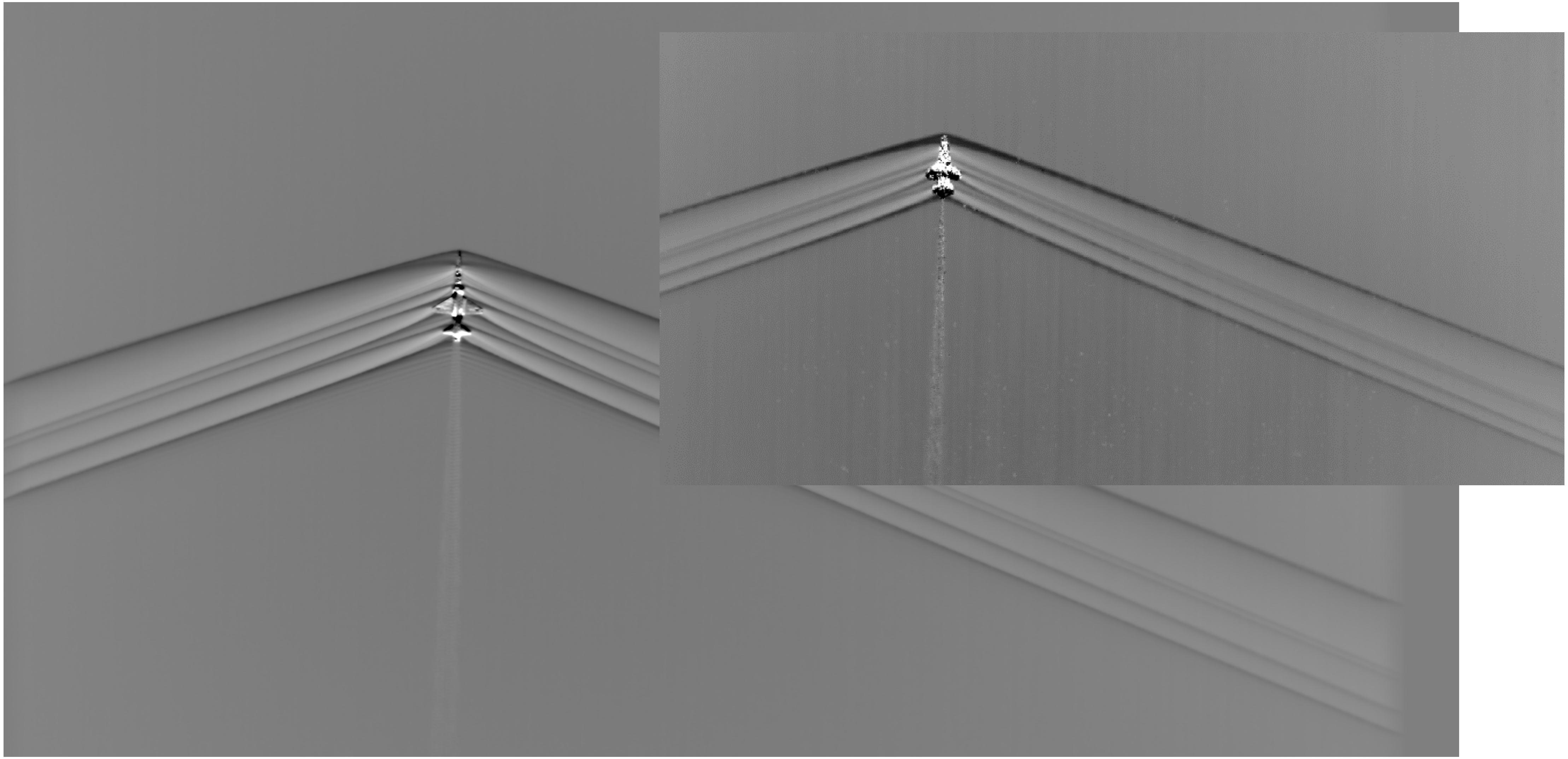
Shock-plume interaction II: aft-swept deck



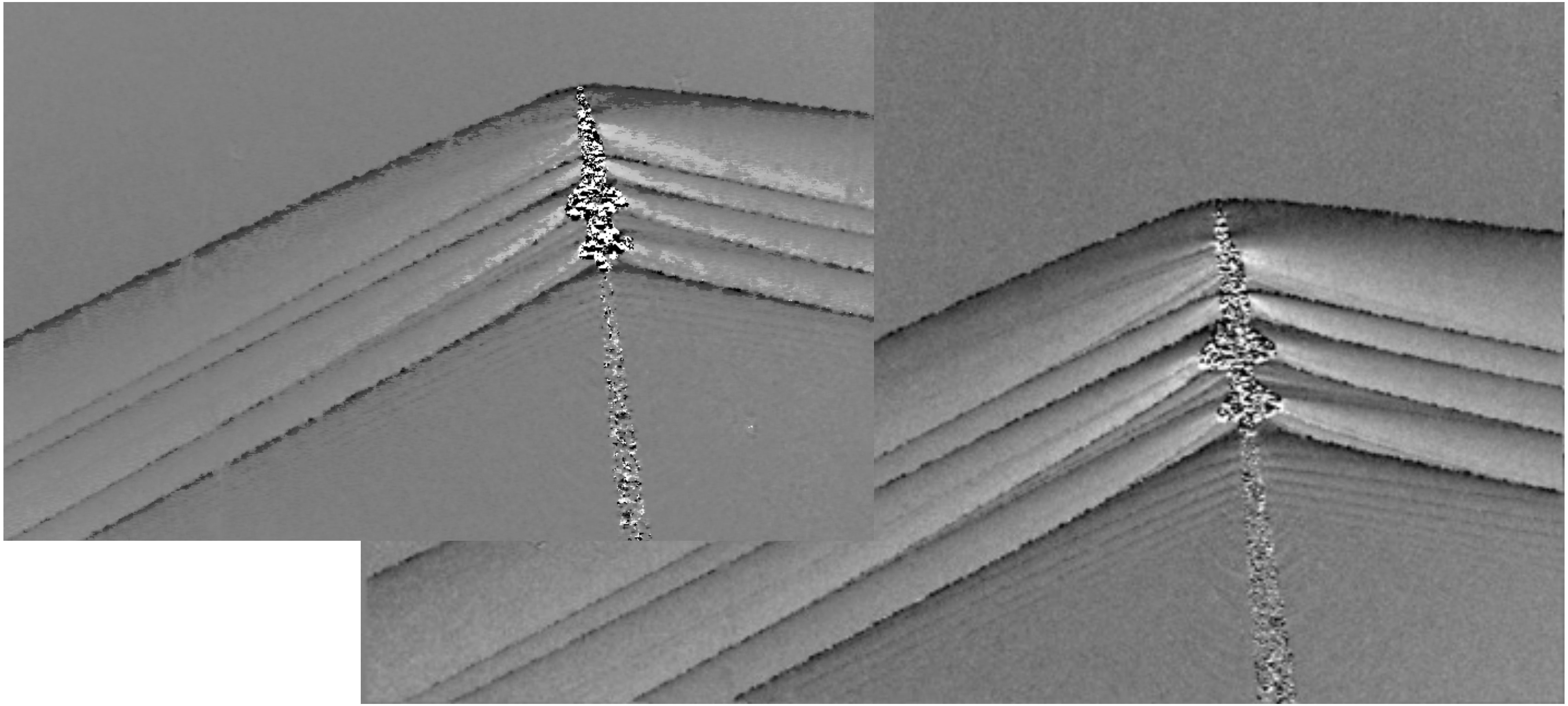
AirBOS pass 1: single instance



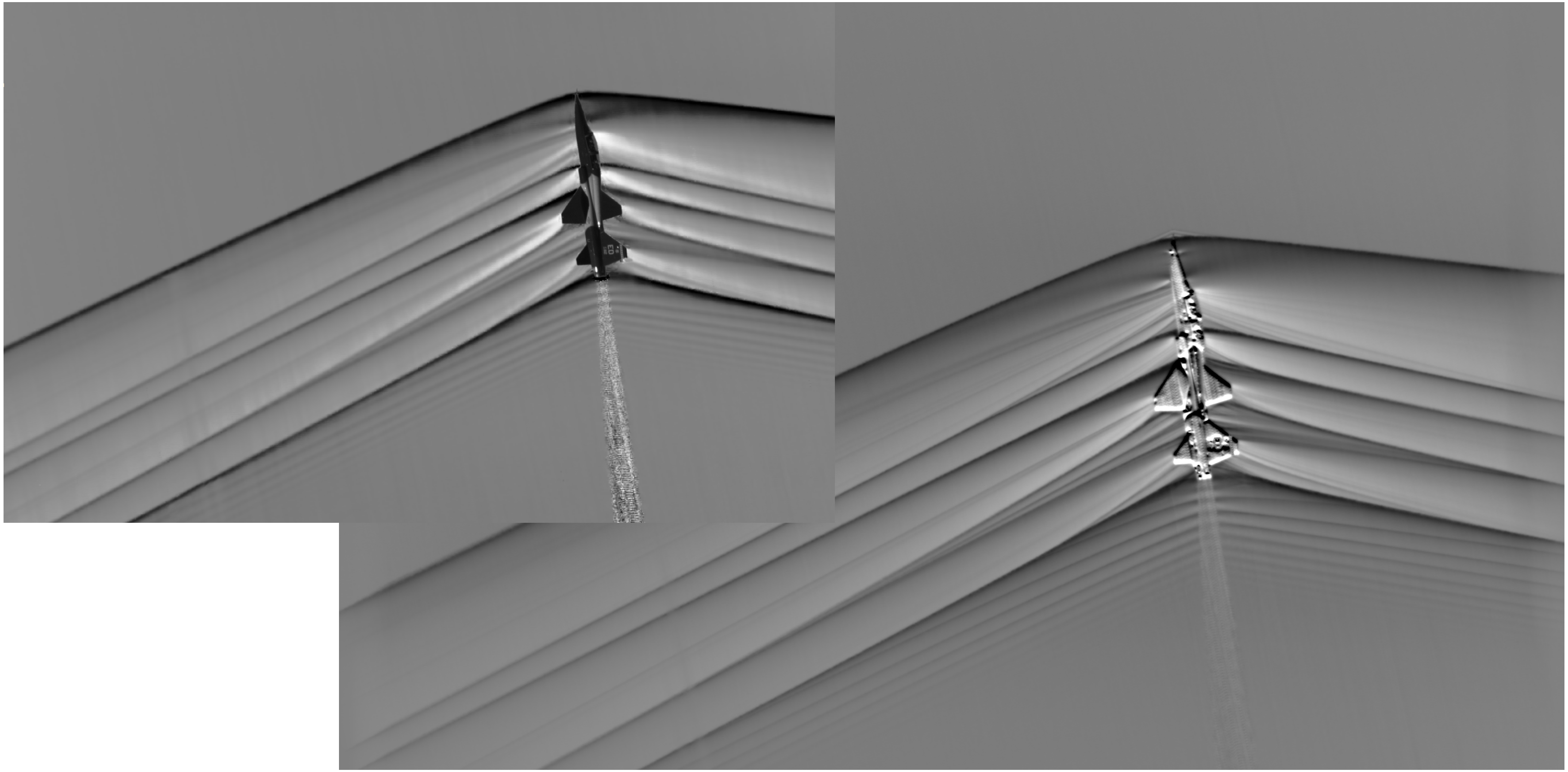
AirBOS pass 1: full sequence average



AirBOS pass 2: single instance



AirBOS pass 2: full sequence average



Conclusions

- Optical Flow
  - Improved flow feature detail over cross-correlation, for both flight and wind tunnel data
  - Regularization method appears robust to data sets
  - Easily parallelized
- Use of multiple reference images
  - Decrease solution noise
  - Significant improvement with five distinct reference images
- Provided most detailed AirBOS schlieren images to date
- First use of optical flow for production test at NASA Ames Research Center
- Caveats
  - More sensitive to hard shadows than cross-correlation
  - Additional lighting considerations for wind tunnel applications
  - “Brightness constancy” violations: no solution in shadowed region

Questions?