

Recent Development Work with Self-Aligned Focusing Schlieren

Brett Bathel, Joshua Weisberger, Matthew Boyda, Timothy Fahringer

*Advanced Measurements and Data Systems Branch
NASA Langley Research Center, Hampton, Virginia, USA*

James Heineck

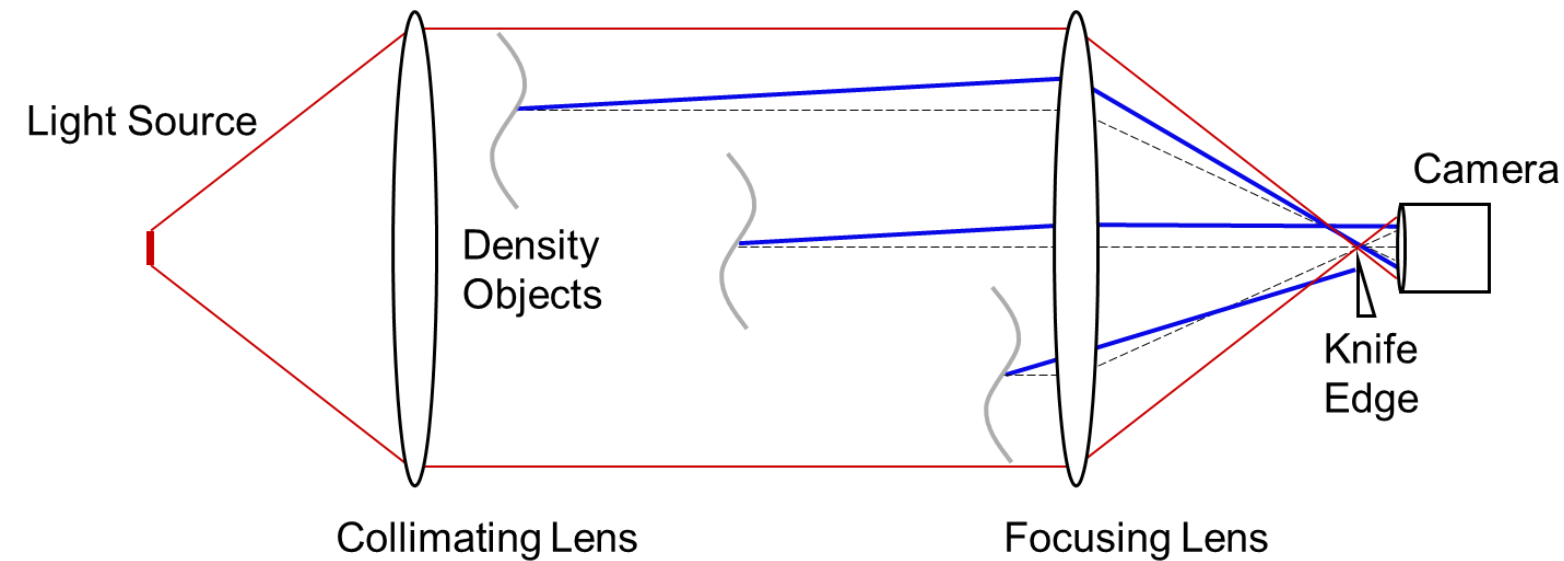
*Experimental Aero-Physics Branch
NASA Ames Research Center, Moffit Field, California, USA*

- Conventional Path-Integrated and Focused Schlieren
- Overview of Self-Aligned Focusing Schlieren (SAFS)
- Recent Applications of SAFS at NASA
 - Shockwave/boundary-layer interaction in Mach 6 and 10 flows
 - Helicopter Rotor Blade Vortex Shedding at NASA Ames' National Full-Scale Aerodynamics Complex
 - Flow visualization in NASA Langley's 0.3-m Transonic Cryogenic Tunnel and National Transonic Facility
- Concluding Remarks

Conventional Path-Integrated Schlieren Flow Visualization

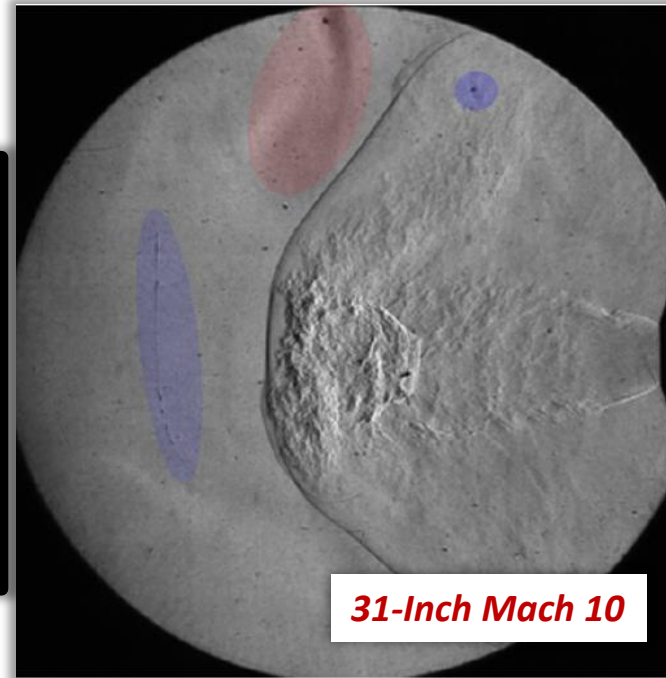
https://www.nasa.gov/centers/ames/research/humaninspace/25th_shuttle.html

- One of the more commonly used flow visualization techniques
- Visualize flow structures that cannot otherwise be observed
- Provides high resolution and sensitivity

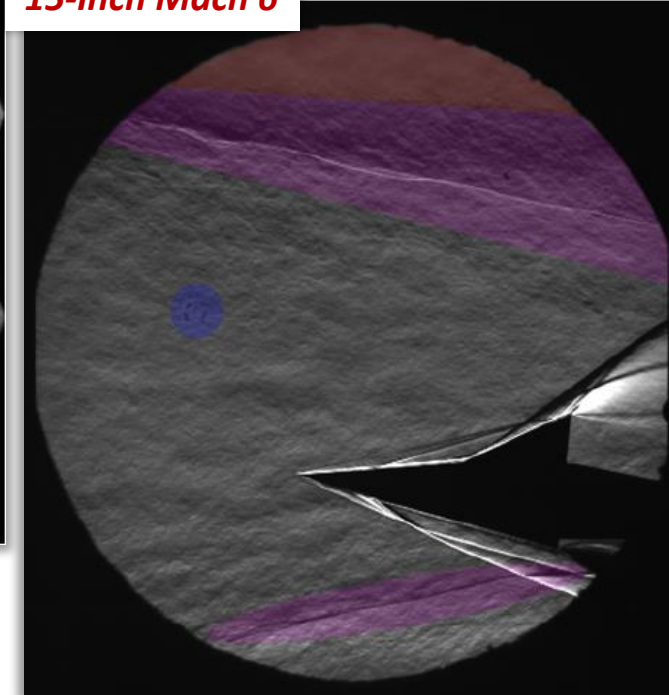


Conventional Path-Integrated Schlieren Flow Visualization

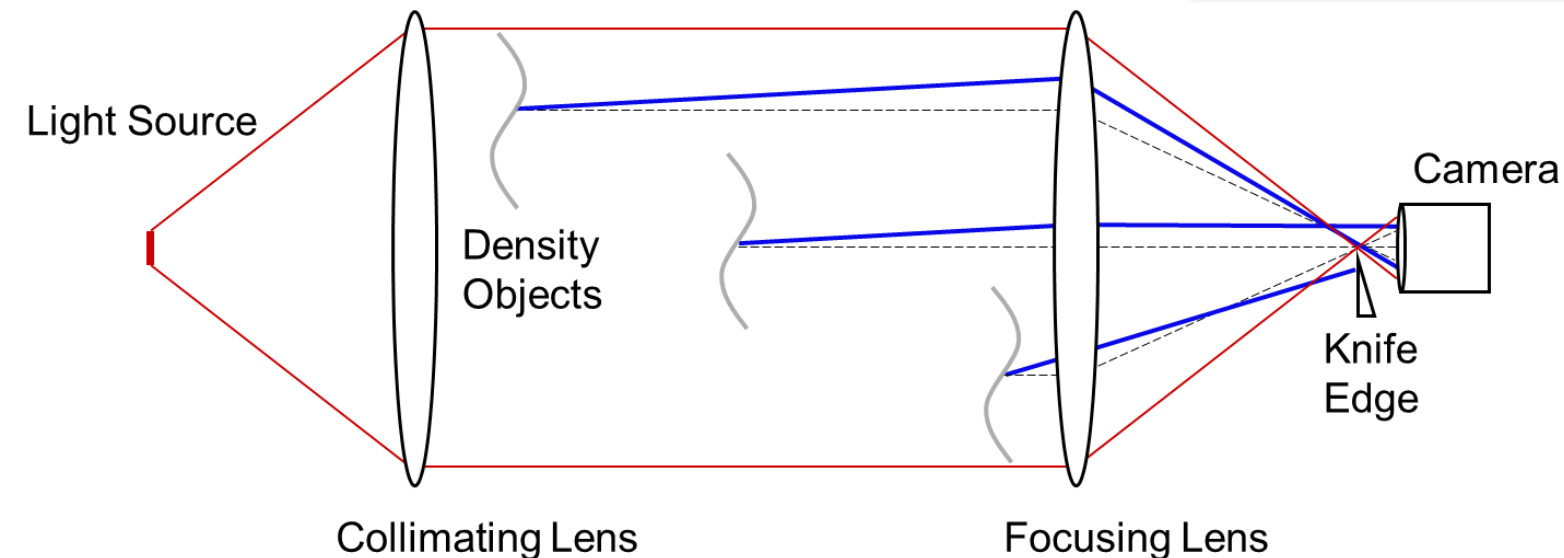
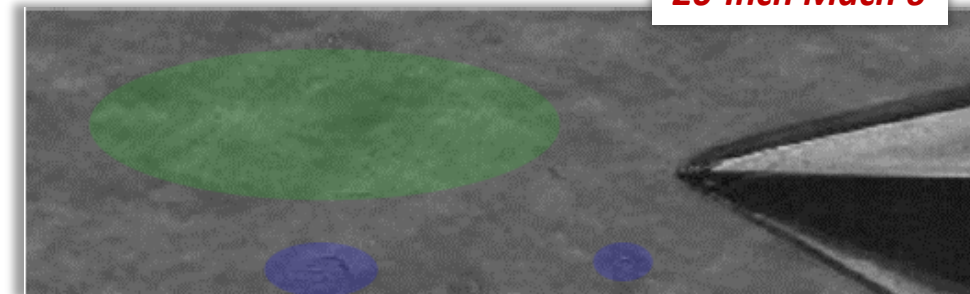
- Optical access requirements
- High quality optics
- Limited field-of-view
- Path integrated



15-Inch Mach 6

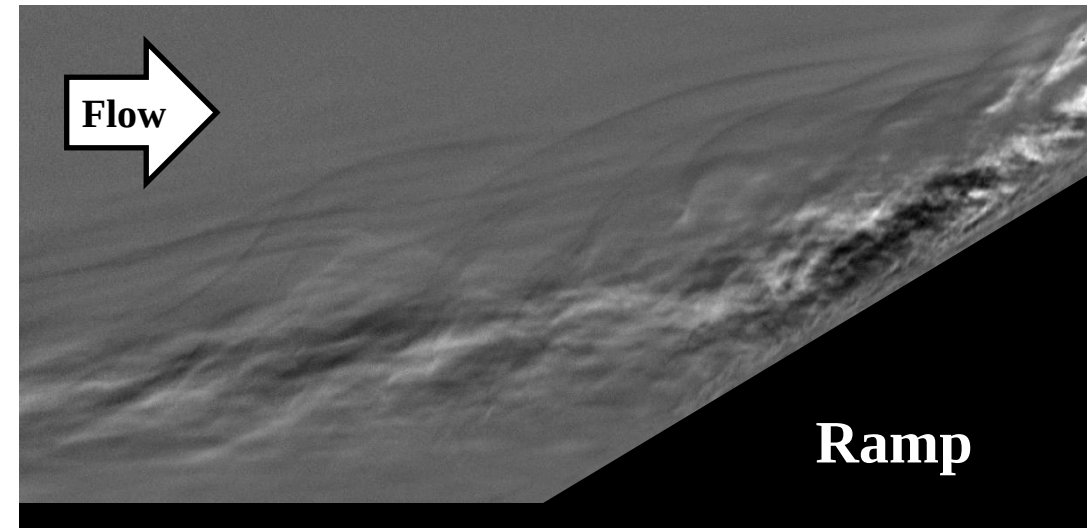


20-Inch Mach 6

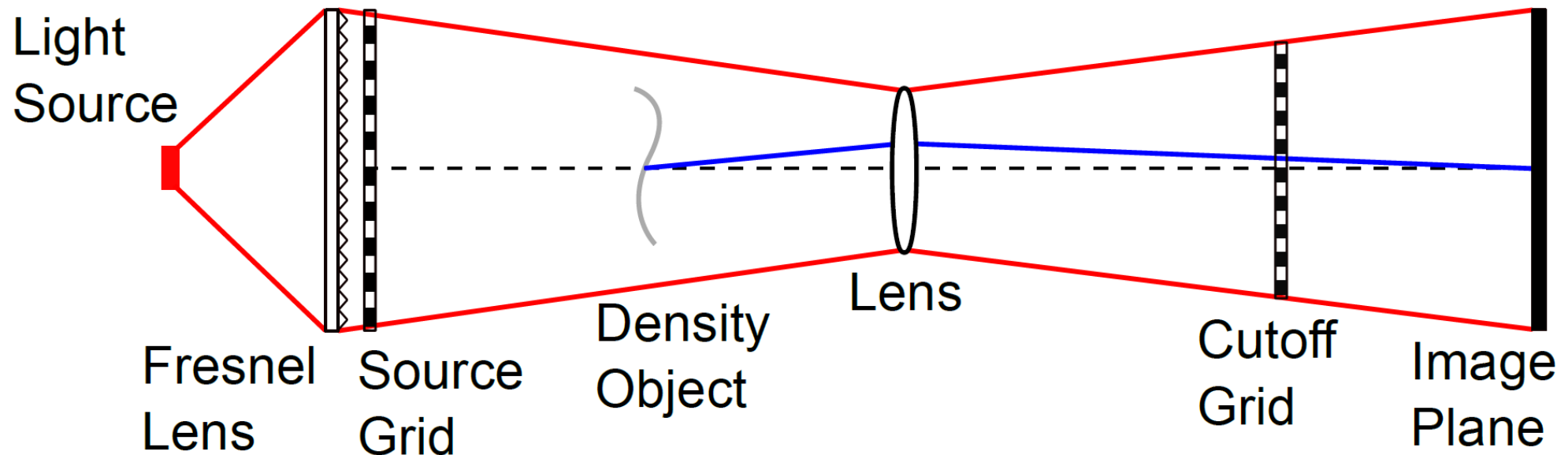


Conventional Focusing Schlieren Visualization

- Resolution and sensitivity similar to conventional schlieren
- Field-of-view not limited by optics
- Provides narrow depth-of-focus

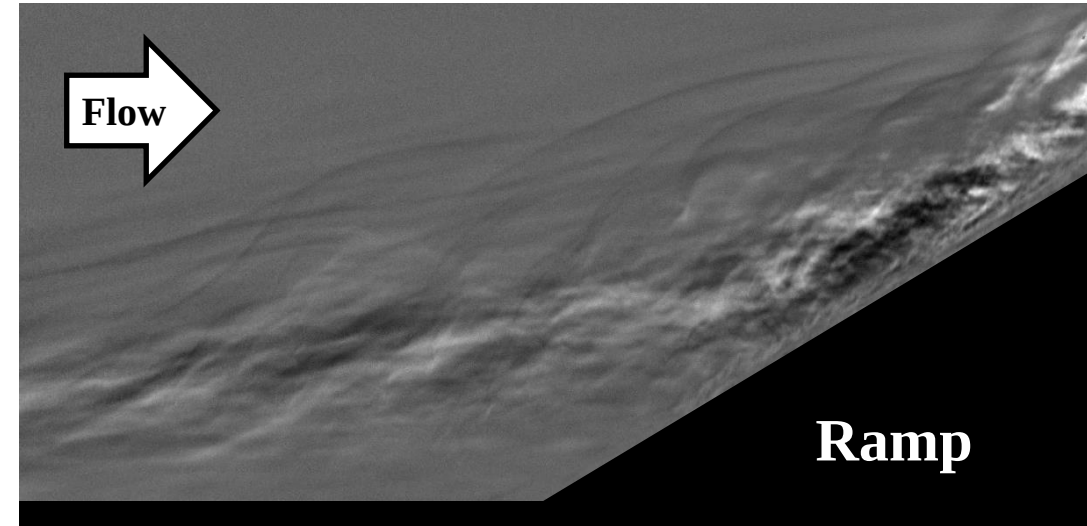


Whalen, T., et al., "Unsteady Surface and Flowfield Measurements in Ramp-Induced Turbulent and Transitional Shock-Wave Boundary-Layer Interactions at Mach 6," AIAA Paper2019-1127.

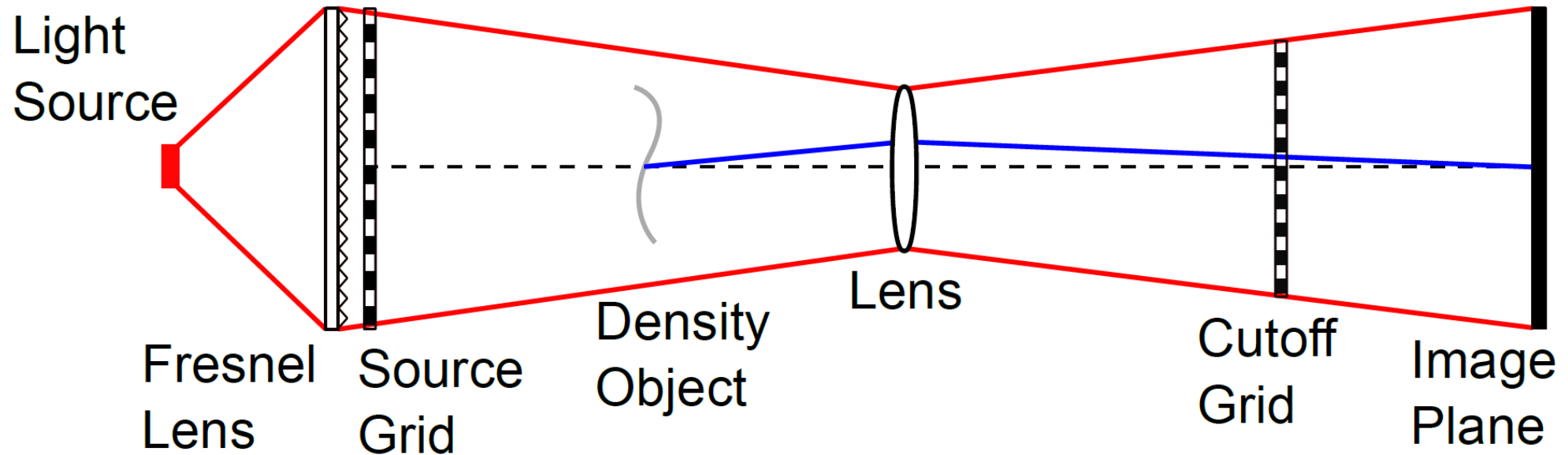


Conventional Focusing Schlieren Visualization

- Requires precise alignment of a source grid and separate cutoff grid
- Sensitive to vibrations
- Optical access typically required on both sides of the test area
- Not compact

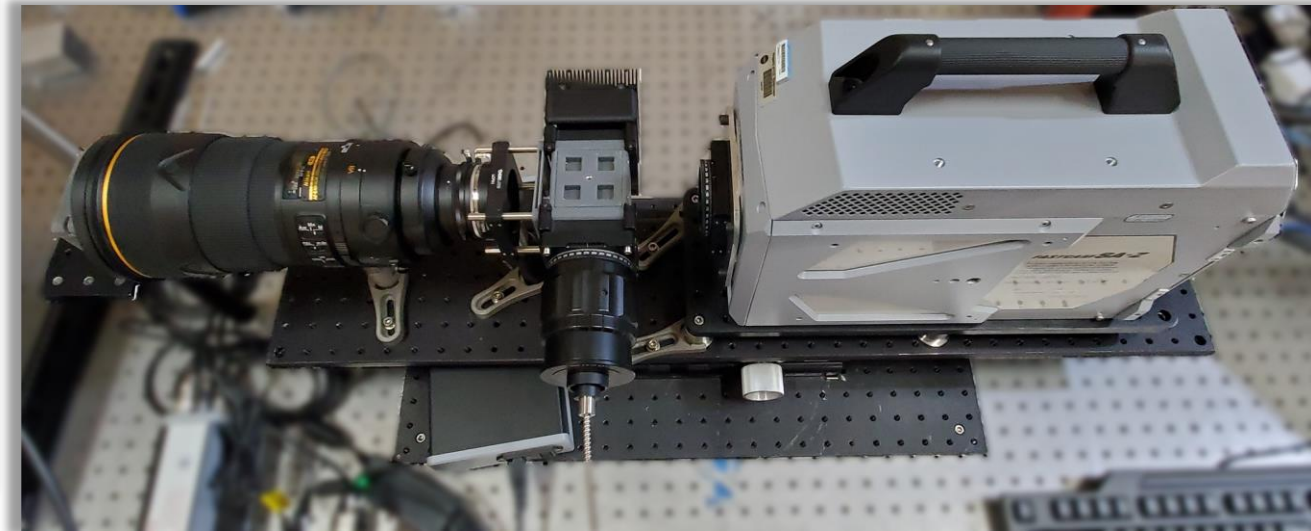
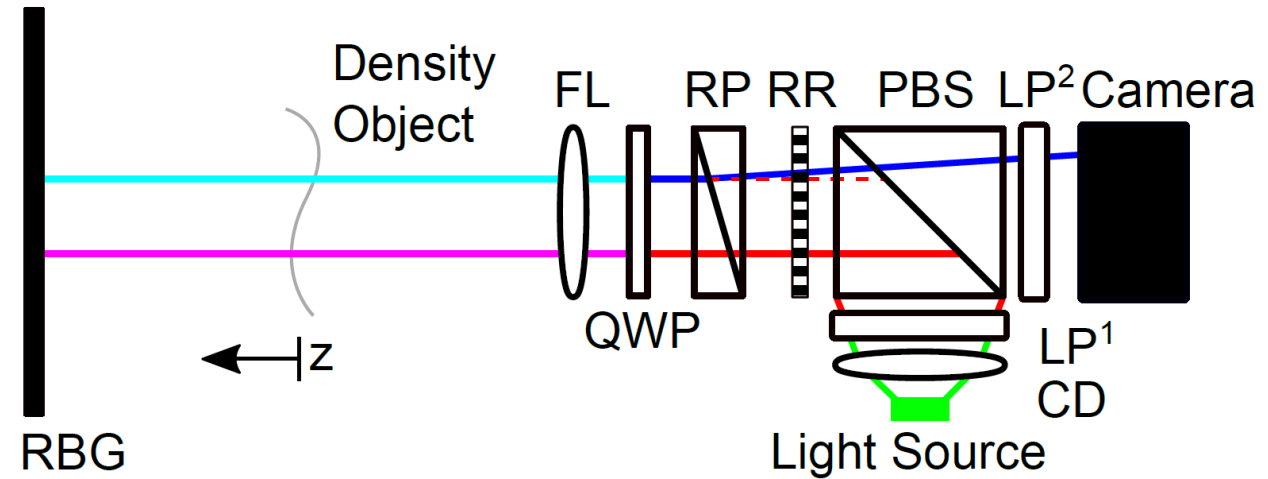


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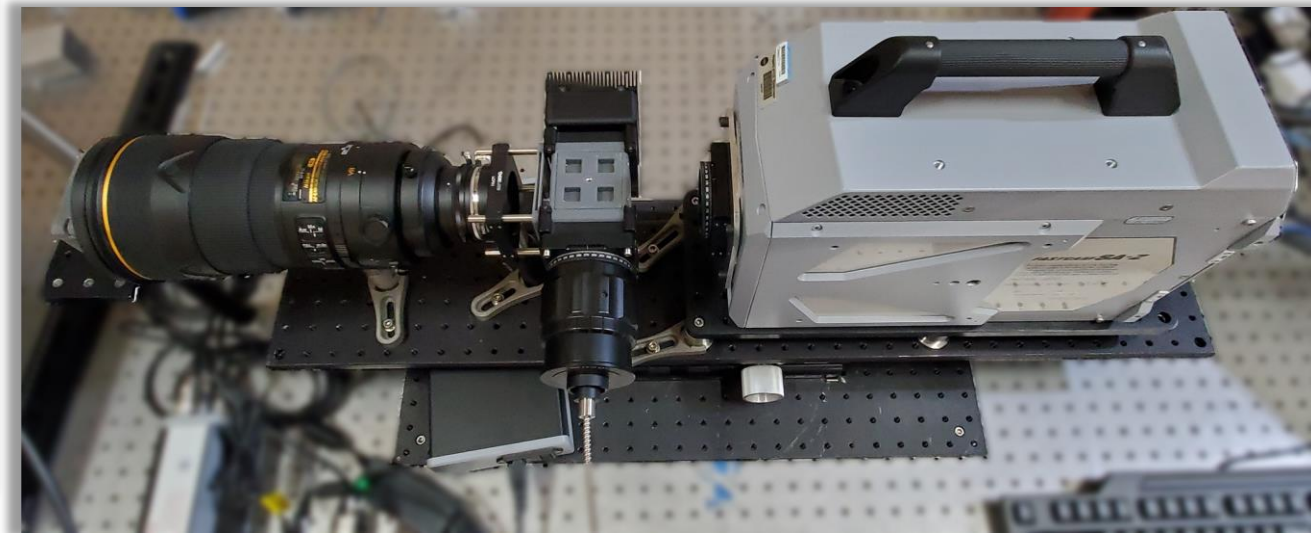
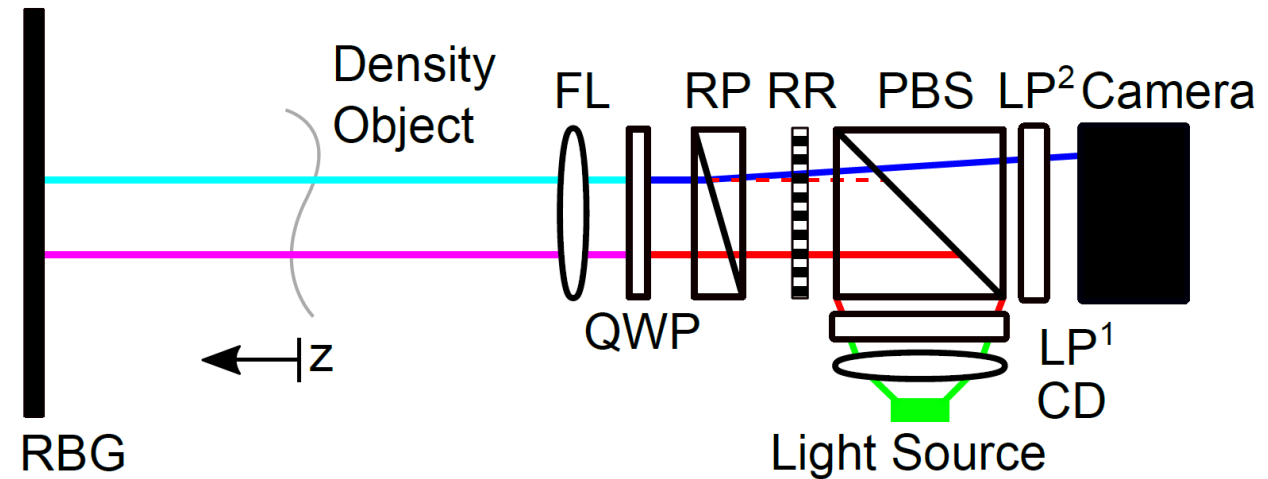


Self-Aligned Focusing Schlieren

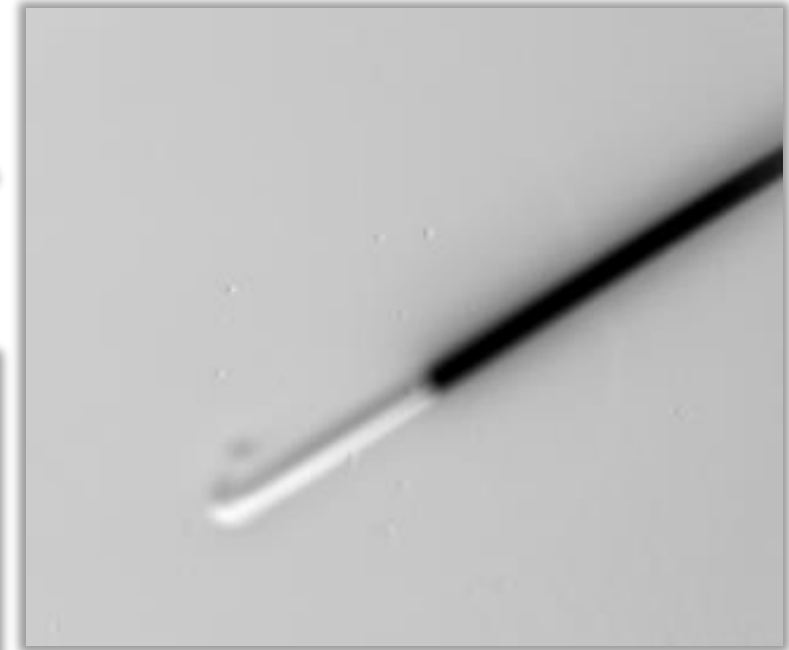
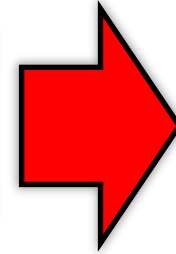
- Light from a **Light Source** is loosely collimated and diffused
- A linear polarizer transmits only **Linear Vertically Polarized Light (LVP)** that is reflected onto the imaging axis and back-illuminates a Ronchi ruling
- The **LVP** light is made **Right Circularly Polarized (RCP)**
- A lens forms an image of the Ronchi ruling onto a retroreflective background



- Upon retroreflection, **RCP** light flips handedness to **Left Circularly Polarized (LCP)** light
- The lens forms an image of the projection onto the original Ronchi ruling
- The LCP is then made **Linearly Horizontally Polarized (LHP)**, resulting in the image being shifted in the plane of the Ronchi ruling
- The **LHP** light is then passes onto an imaging camera

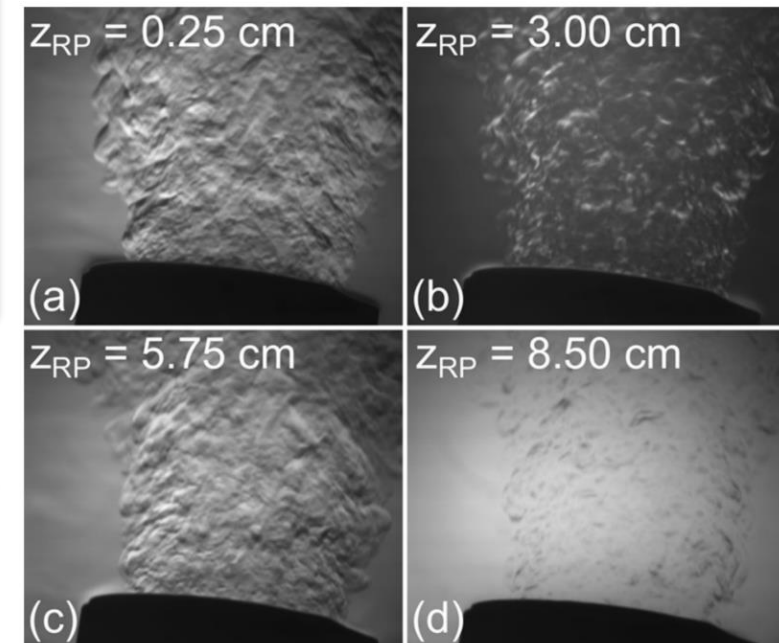
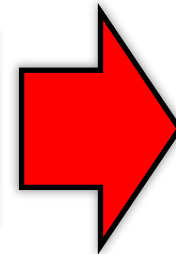


Visualization
of canned
duster flow



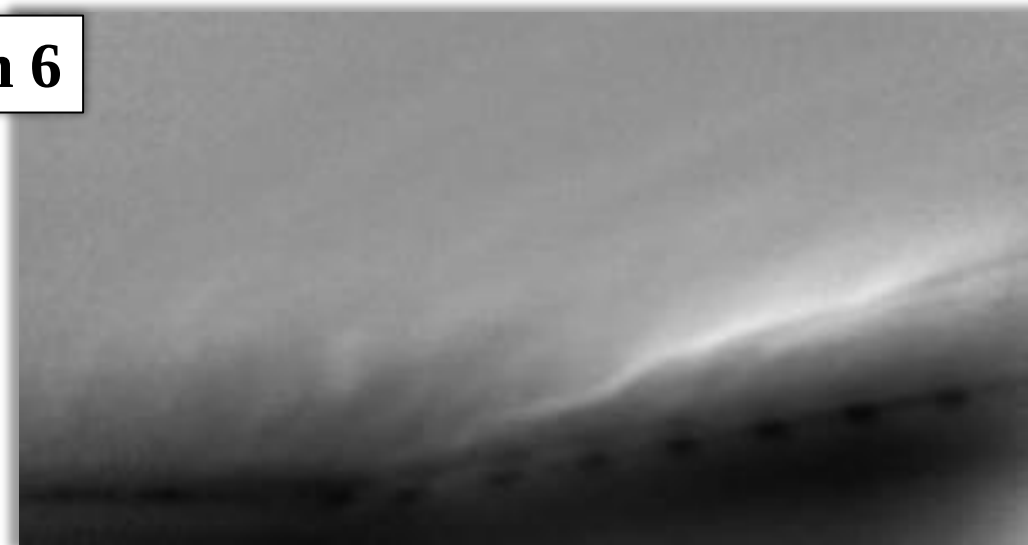
- ✓ Self-aligned nature drastically reduces setup time
- ✓ Insensitive to vibrations
- ✓ Only requires single-sided optical access
- ✓ Extremely compact
- ✓ Manipulating polarization provides both sensitivity adjustment and rejection of window glare/reflections

Translation of Rochon
prism along optical axis acts
as knife edge adjustment



- Shockwave/Boundary Layer Interaction – 20-Inch Mach 6 and 31-Inch Mach 10 Wind Tunnels
 - Visualization of ramp-induced interaction on a flat plate
 - Test sections 0.5 and 0.8 m square
 - Conventional schlieren and SAFS

Mach 6



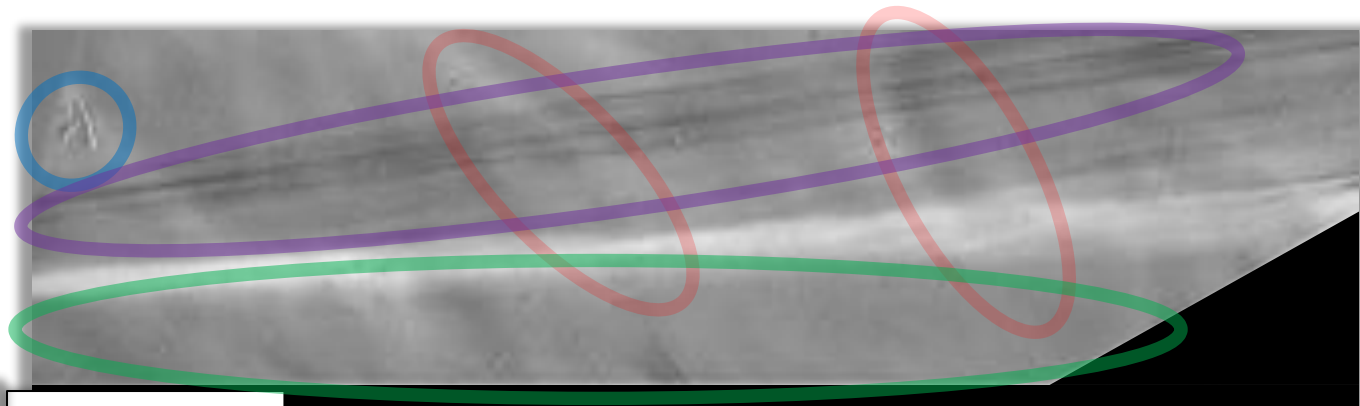
- ✓ **Rejection of artifacts present in path-averaged conventional schlieren**
- ✓ **Narrow depth-of-field**
- ✓ **Ability to compensate for polarization changes induced by windows**

Recent Applications of SAFS at NASA

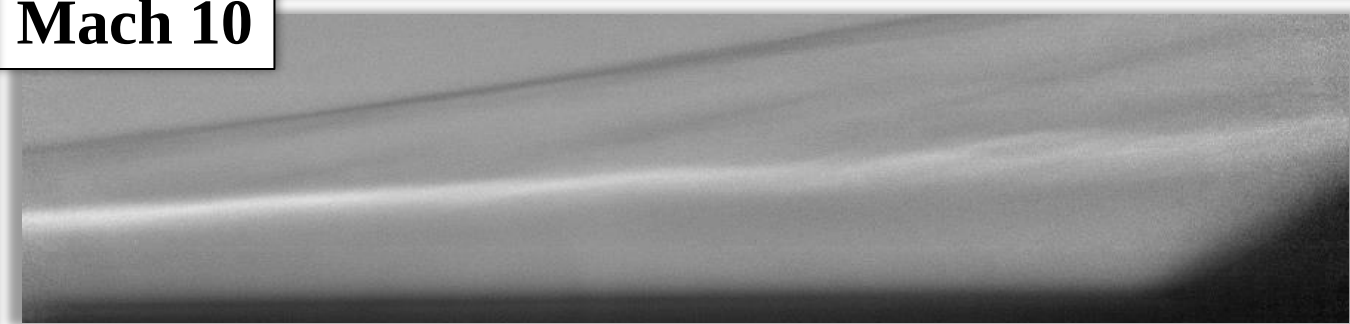
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HVAC Thermals
Window Scratches
Path-Integrated Shock
Tunnel Wall Boundary Layer



Mach 10



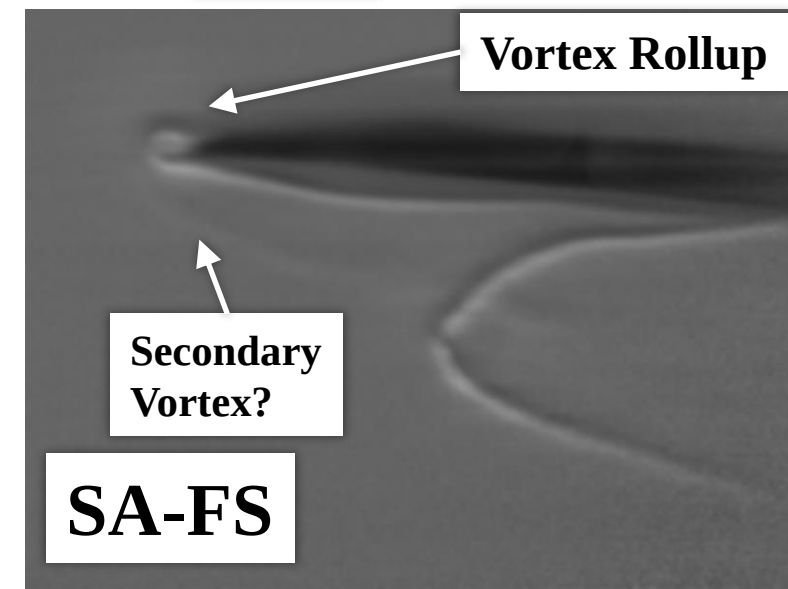
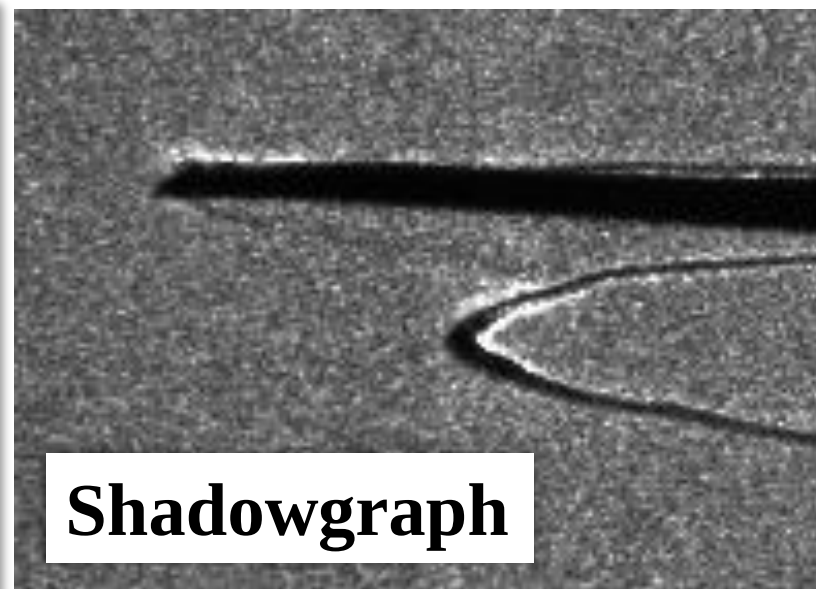
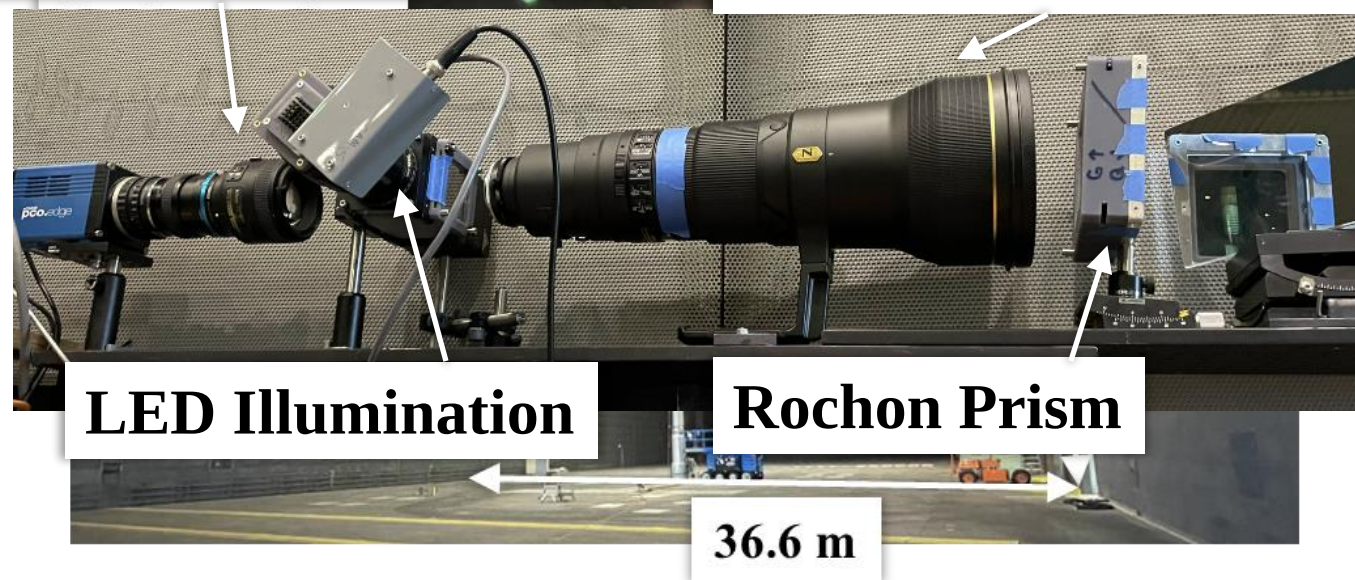
Recent Applications of SAFS at NASA

- Rotor Blade Vortex Shedding – NASA Ames' National Full-Scale Aerodynamics Complex (NFAC)
 - Rotor blade vortex visualization
 - Test Section 36.6-m-wide by 24.4-m-high
 - Shadowgraph and SAFS Imaging

- ✓ Functions over long distances
- ✓ Sensitivity to weak flow features
- ✓ Signal maintained when misalignment of background occurs

85 mm, f/1.8 Relay Lens

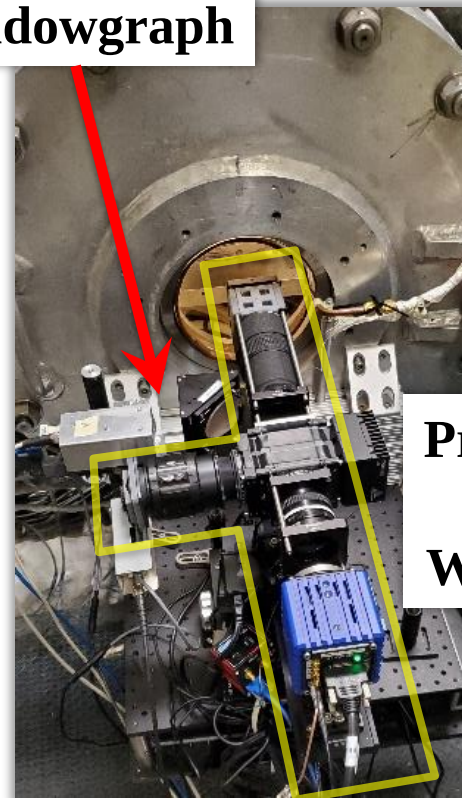
600 mm, f/4 Field Lens



Recent Applications of SAFS at NASA

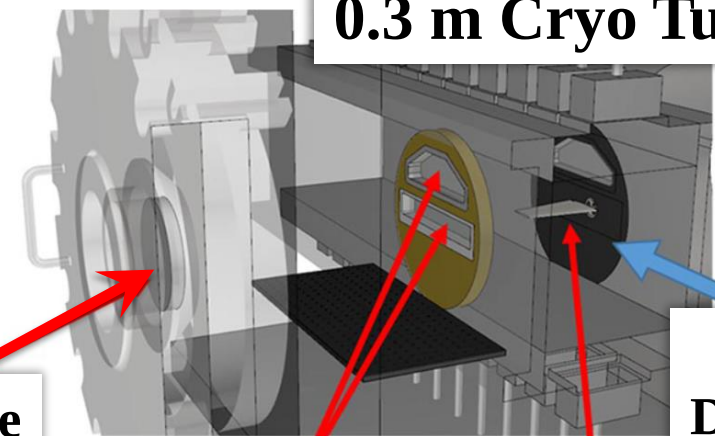
- Transonic Flow – 0.3 m Transonic Cryogenic Tunnel
 - Visualization of flow over an airfoil
 - Camera mounted on translation stage to scan through flow above top surface of airfoil
 - Simultaneous shadowgraph

Shadowgraph



Pressure Shell Window

0.3 m Cryo Tunnel



Internal Windows

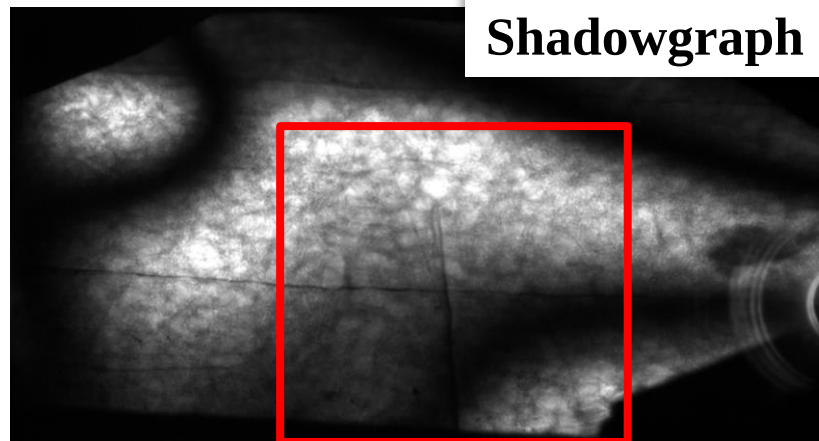
Airfoil

Flow Direction

From Burns, R.A., and Danehy, P.M., AIAA Journal, 55(12), 2017.

- ✓ Ability to reject flow artifacts in plenum
- ✓ Sensitivity exceeded shadowgraph
- ✓ Ability to scan camera and observe flow three-dimensionality

Shadowgraph



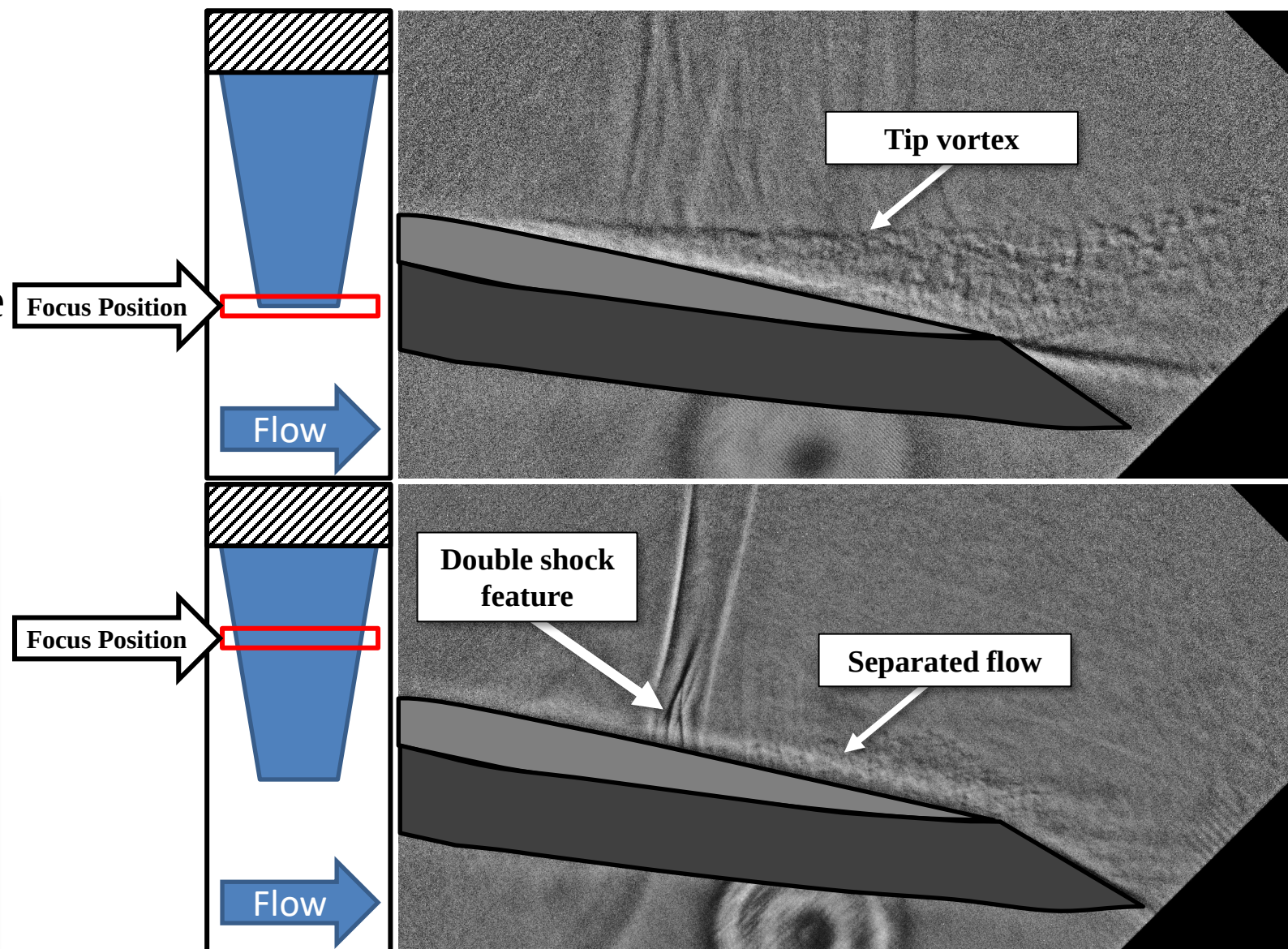
SAFS



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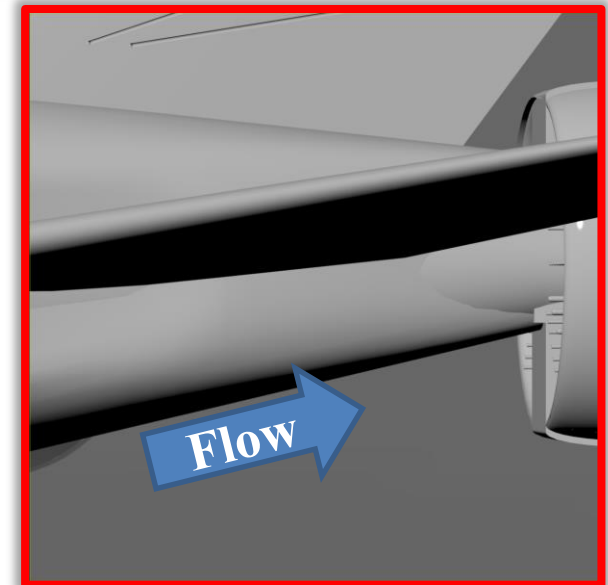
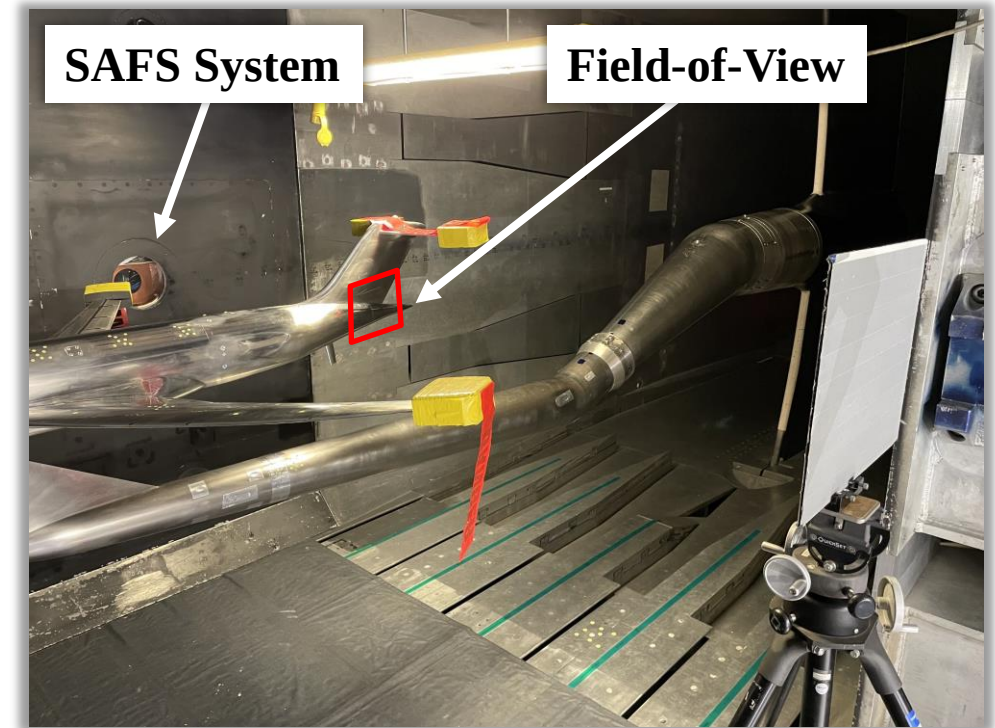
- ✓ **Ability to reject flow artifacts in plenum**
- ✓ **Sensitivity exceeded shadowgraph**
- ✓ **Ability to scan camera and observe flow three-dimensionality**



Recent Applications of SAFS at NASA

- Transonic Flow – National Transonic Facility (NTF)
 - Visualization of the tail cone of a common wide-body jet model with and without a tail cone thruster
 - Tunnel was run in both air and cryogenic modes
 - Depth of focus ± 30 cm
 - LED pulse width of $30\ \mu\text{s}$

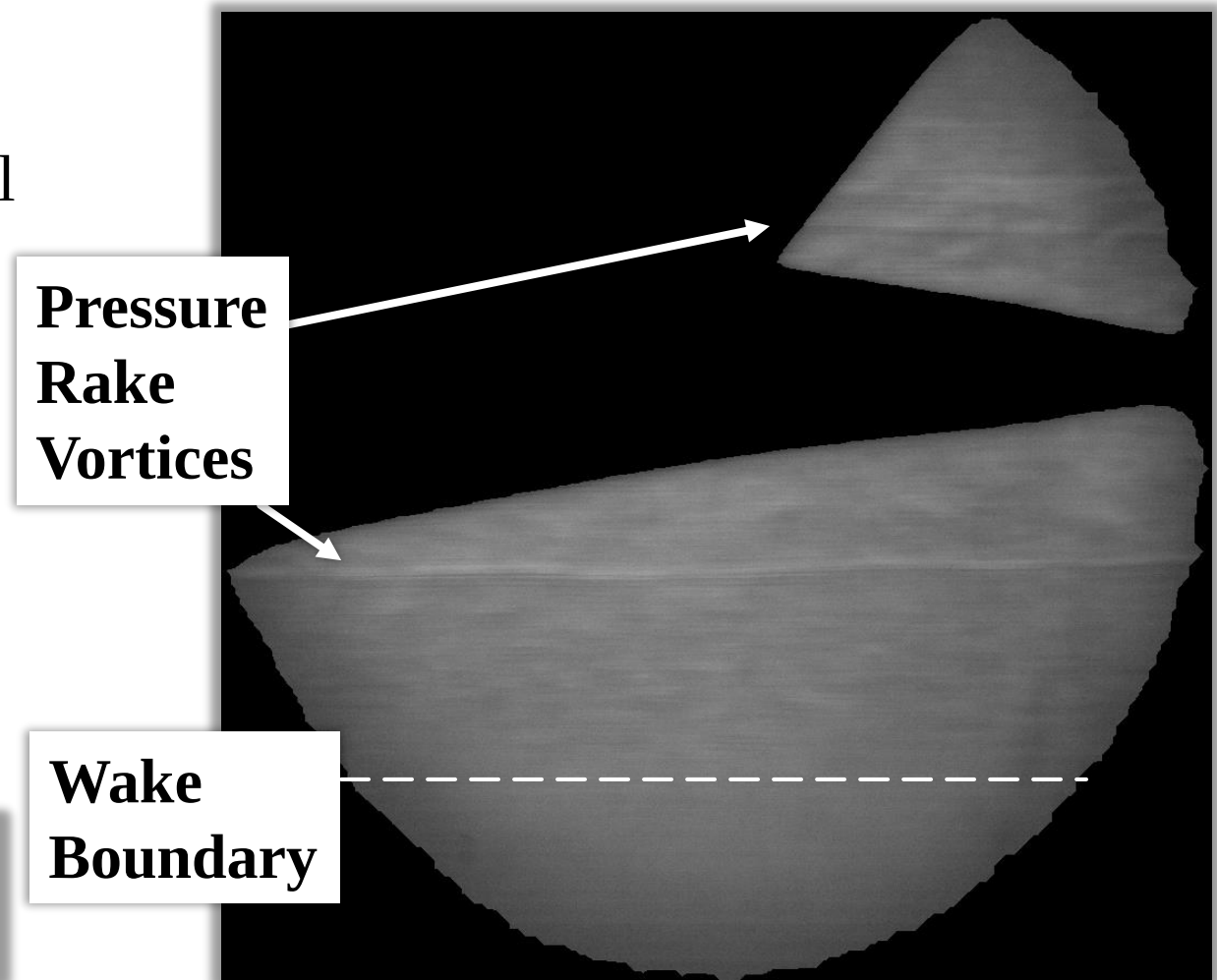
✓ **Successful demonstration of SAFS in the NTF in both air and cryo modes**



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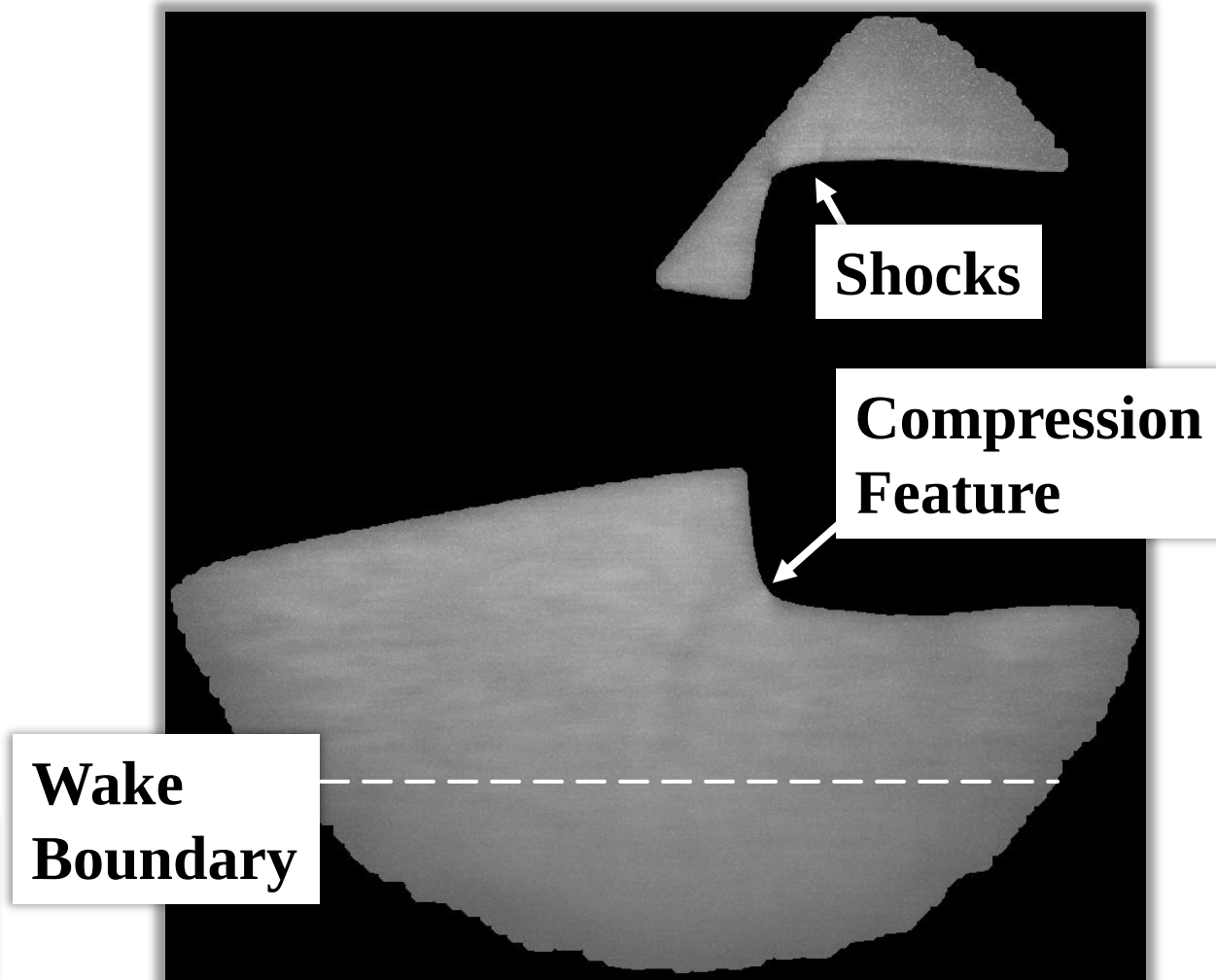
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✓ **Successful demonstration of SAFS in the NTF in both air and cryo modes**



Concluding Remarks

- Developed a new inherently self-aligned focusing schlieren (SAFS) system:
 - Dramatically reduces setup time
 - Vibration insensitive
 - Requires only single-sided optical access
 - Compact
 - Polarized nature of instrument can aid in rejection of glare/reflections from windows
- Presented flow visualization data acquired with SAFS instruments implemented in several NASA ground test facilities
 - 20-Inch Mach 6 and 31-Inch Mach 10 Hypersonic Wind Tunnels at NASA Langley
 - National Full-Scale Aerodynamics Complex at NASA Ames
 - 0.3-m Transonic Cryogenic Tunnel and National Transonic Facility
- Acknowledgements
 - This work was supported by NASA's Transformational Tools & Technologies (T³) project