Institutional Schlieren:

A Production-Level Wind Tunnel Test Measurement

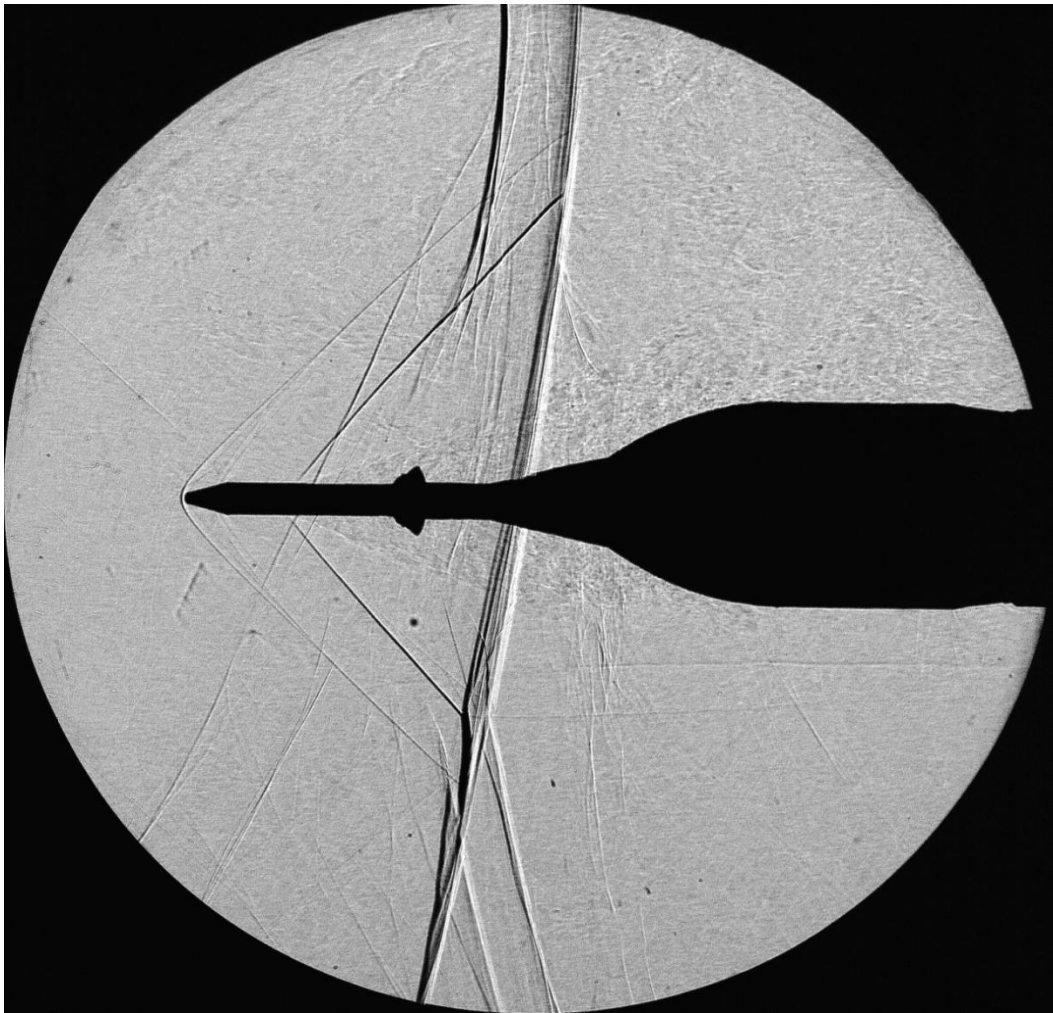
01/08/2015

Ted Garbeff
NASA Ames AOI
Theodore.J.Garbeff@nasa.gov

James T. Heineck
NASA Ames AOX
James.T.Heineck@nasa.gov

T. Kevin McDevitt
NASA Ames AOI
Kevin.McDevitt@nasa.gov

Laura Kushner
Aerospace Computing Inc.
Laura.K.Kushner@nasa.gov



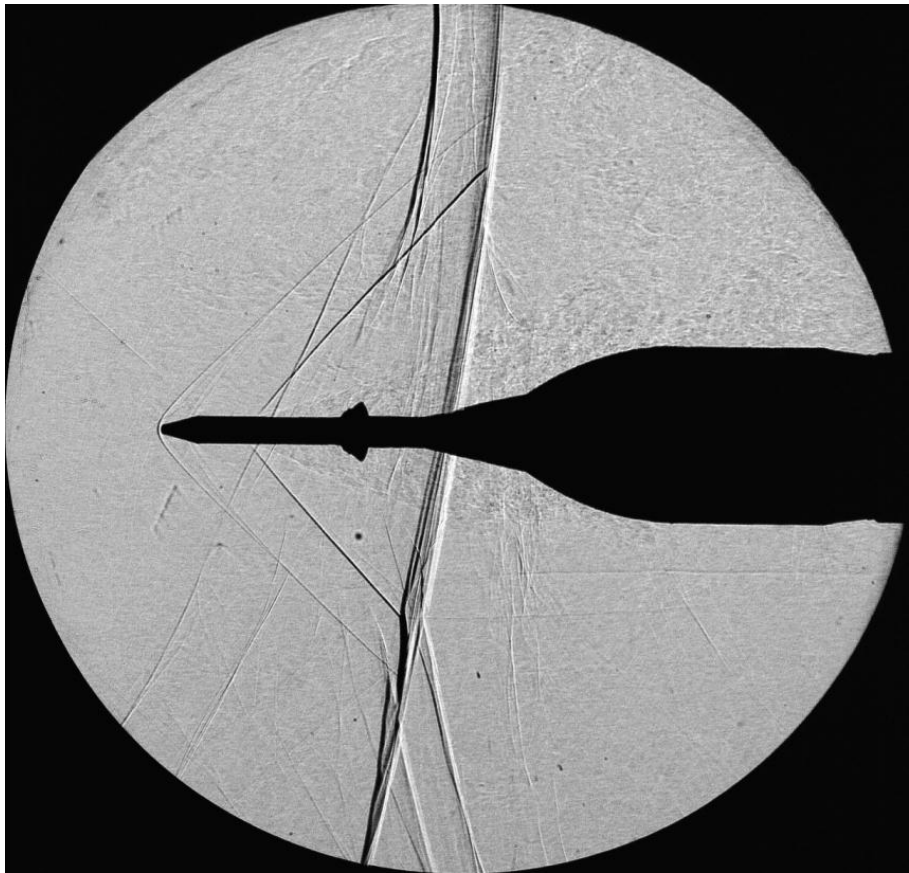
Outline

- Use of schlieren/shadowgraph at NASA Ames Unitary Plan Wind Tunnel (UPWT).

- Institutional schlieren/shadowgraph data systems modernization project.
  - Hardware selection.
  - Software methodology.

- Overview of completed data systems.
  - High-level system components.
  - Image acquisition and processing.
  - Current system capabilities.

- Future target capabilities/improvements.



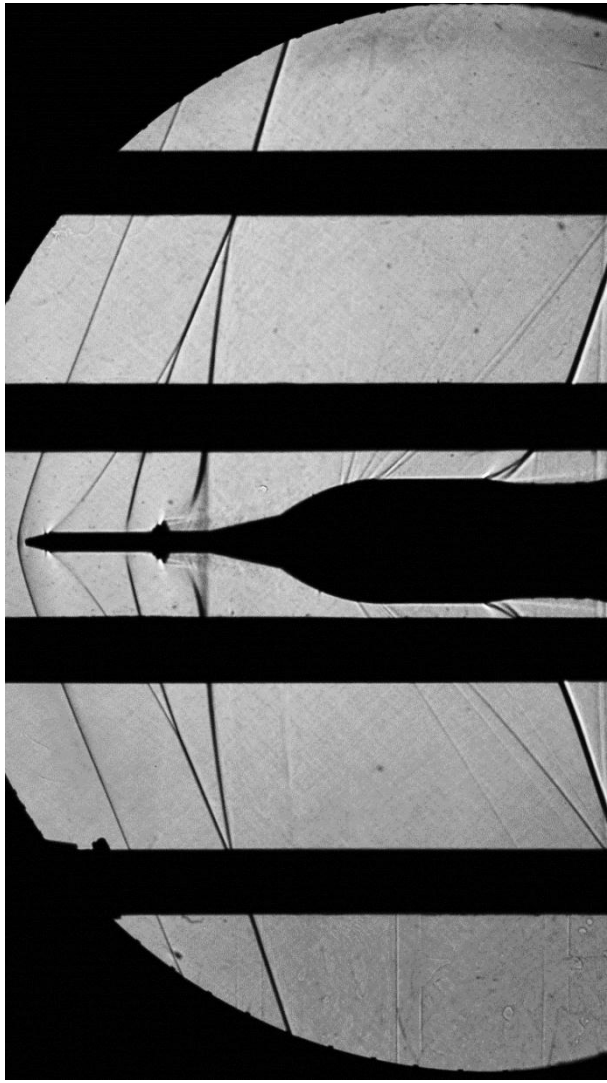
Overview of Schlieren/Shadowgraph

- Technique often deployed as a test dependent facility measurement.

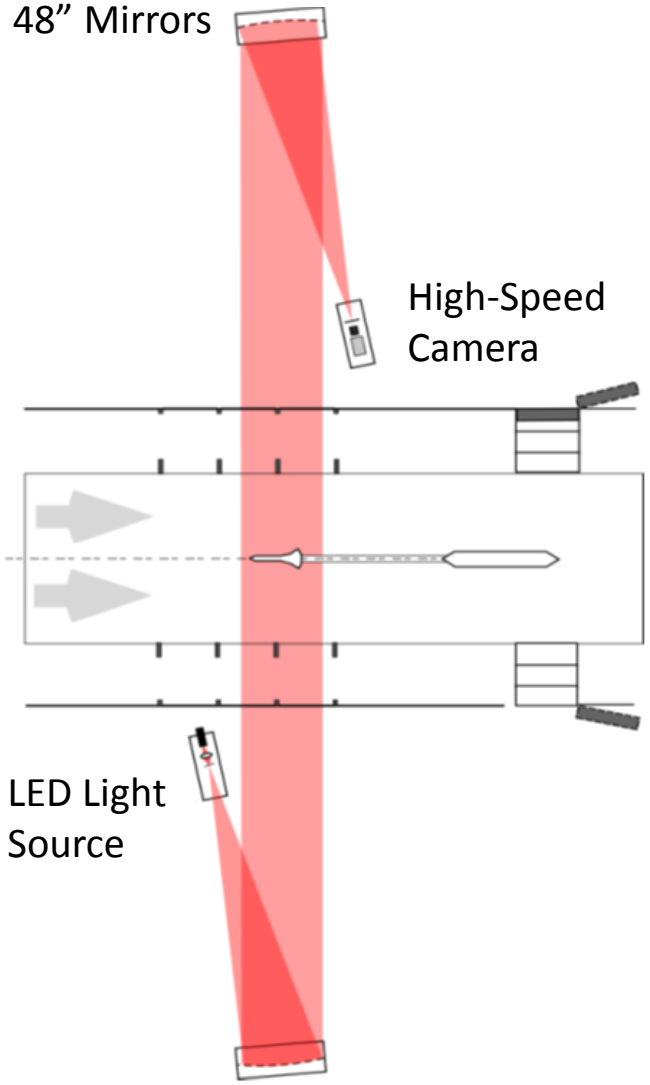
- Technique used to observe phenomena that are not visible to the unaided eye. Allows observation of aerodynamic flow features:
  - Model shockwave formation and interaction.
  - Flow separation.
  - Mach wave radiation.

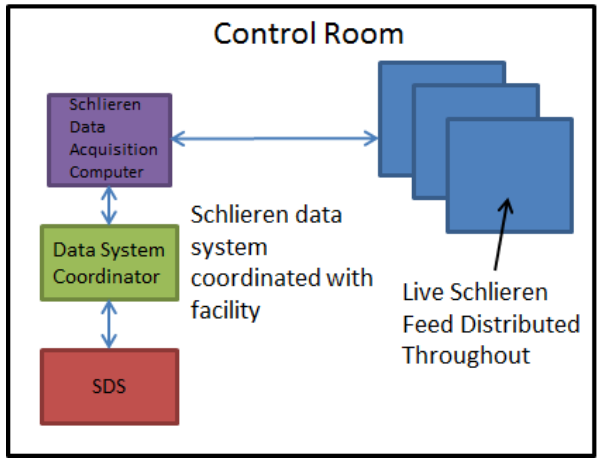
- Caused by density gradients created by flow phenomena. Technique exploits index of refraction changes in test section.

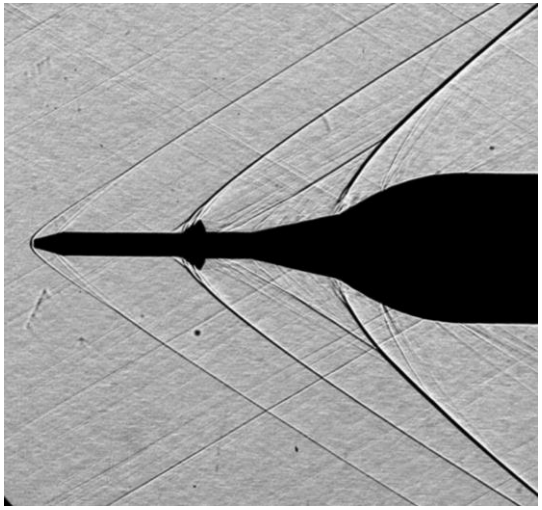
- Optical technique,
  - Point light source collimated on one side of test section using large concave mirror.
  - Collimated light passed through test section.
  - Light collected by a large concave mirror and imaged onto camera on other side of test section.



NASA Ames Unitary Plan Wind Tunnel Schlieren/ Shadowgraph







Motivation

- Historically Ames Unitary Plan Wind Tunnel (UPWT) provided customers optical data services on a per test basis.

- These optical data services typically consist of Schlieren, Shadowgraph, infrared thermography, and pressure sensitive paint (PSP).

- Hardware/personnel furnished by Experimental Aero-Physics branch.

"Institutionalize optical data services" projects focusing on Schlieren, Shadowgraph, IR thermography, and pressure sensitive paint with the goals of:

- Purchasing state of the art, dedicated facility instruments.
- Improving data productivity by developing new data systems controls tools.
- Improving data product quality.
- Reducing data product delivery times.

Objective: Institutionalize/modernize UPWT Schlieren/Shadowgraph systems with an emphasis on test productivity and data quality.

- Purchasing/deploy dedicated hardware in both 11-by-11 and 9-by-7 foot test areas.
  - State of the art cameras and acquisition/control equipment.
  - Light sources, optics, mounts, remote controls.
- Develop improved software architecture.
  - Reduce labor intensive aspect of optical services.
  - Improve near-time delivery of data products to customers.

Requirements:

- Minimize impact to test productivity.
  - Automate data collection process.
  - Improve camera throughput.
- Capture unsteady flow field phenomena when needed.
  - Camera used must be capable of high frame rates, but of sufficient resolution.
- Improve delivery rate of data products.
  - Camera used must have fast download rates.
- Develop a group of standardized data products.
  - Pixel averaged image.
  - Low-speed video.
  - High-speed video.

Hardware Down Select Criteria

Selecting a Camera
- Frame rate versus resolution
- Sensitivity
- Stability/Reliability
- Data transfer
- Workflow
- Auxiliary outputs

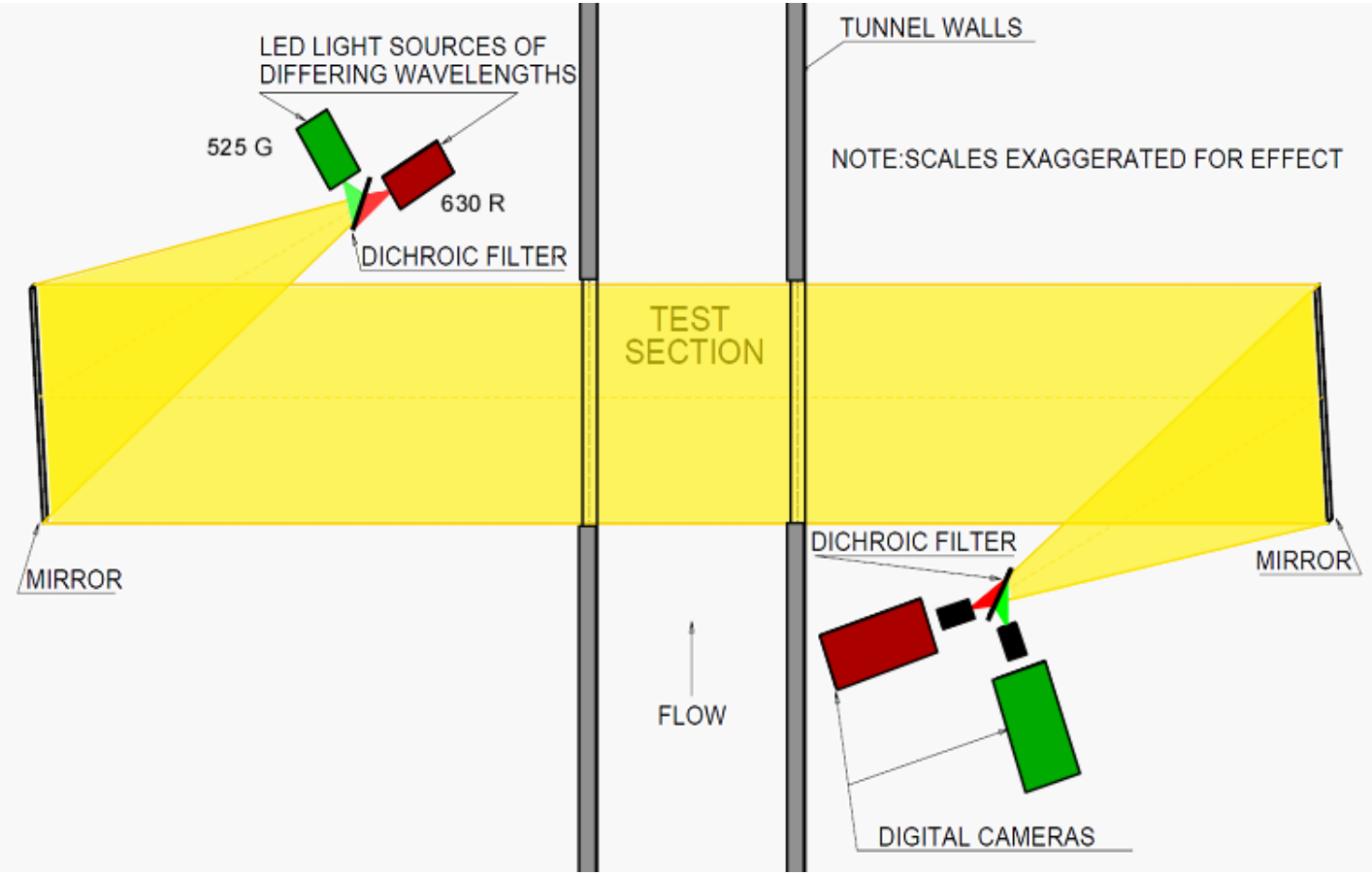
Selecting a Light Source
- Power output
- Stability/Reliability
- Point size
- Configurability

Selecting Image Acquisition/Processing
- Reliability
- Ease of use
- Redundancy
- Expandability

Testing in Production Wind Tunnel Environment

Dual-Color Shadowgraph

- A dual-color shadowgraph configuration was used to evaluate multiple makes and models of cameras in the wind tunnel during production testing.



Cameras and Light Sources

- Evaluated several high-speed camera manufacturers in facility.
- The Vision Research Phantom v2010 best fit unique needs of Ames UPWT.
- Selected new high-powered pulsed LED light sources.

Phantom v2010

- 22,500 FPS at 1280x800 pixels.
- ISO 64,000.
- 10 Gigabit Ethernet (~350 MB/sec)
- HD-SDI Auxiliary Output

ISSI LMS-520/LMS-620

- High-powered (2-3W) pulsed LED.
- Operated continuous or pulsed.
- Green and red wavelengths.

Image Acquisition and Processing

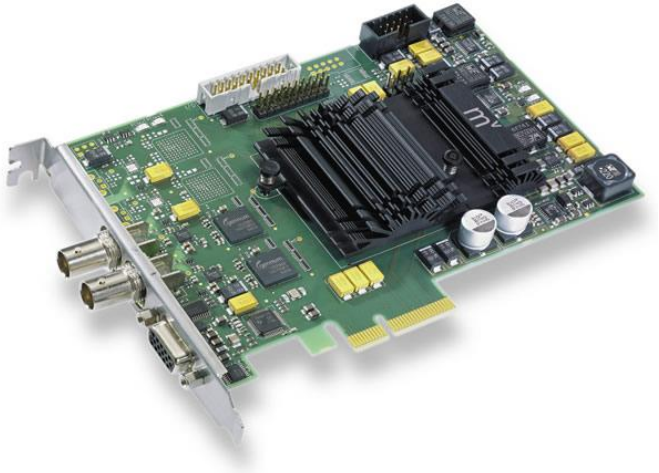
- A single server-class, rack-mount PC for both image acquisition and processing.

Server-class SuperMicro

- Dual six-core 2.4 GHz Xeon processors
- 24 GB RAM
- 64-bit Windows 7
- LabVIEW Developers Suite 2013 SP1
- LabVIEW Vision Development Module
- 4TB Raid 1

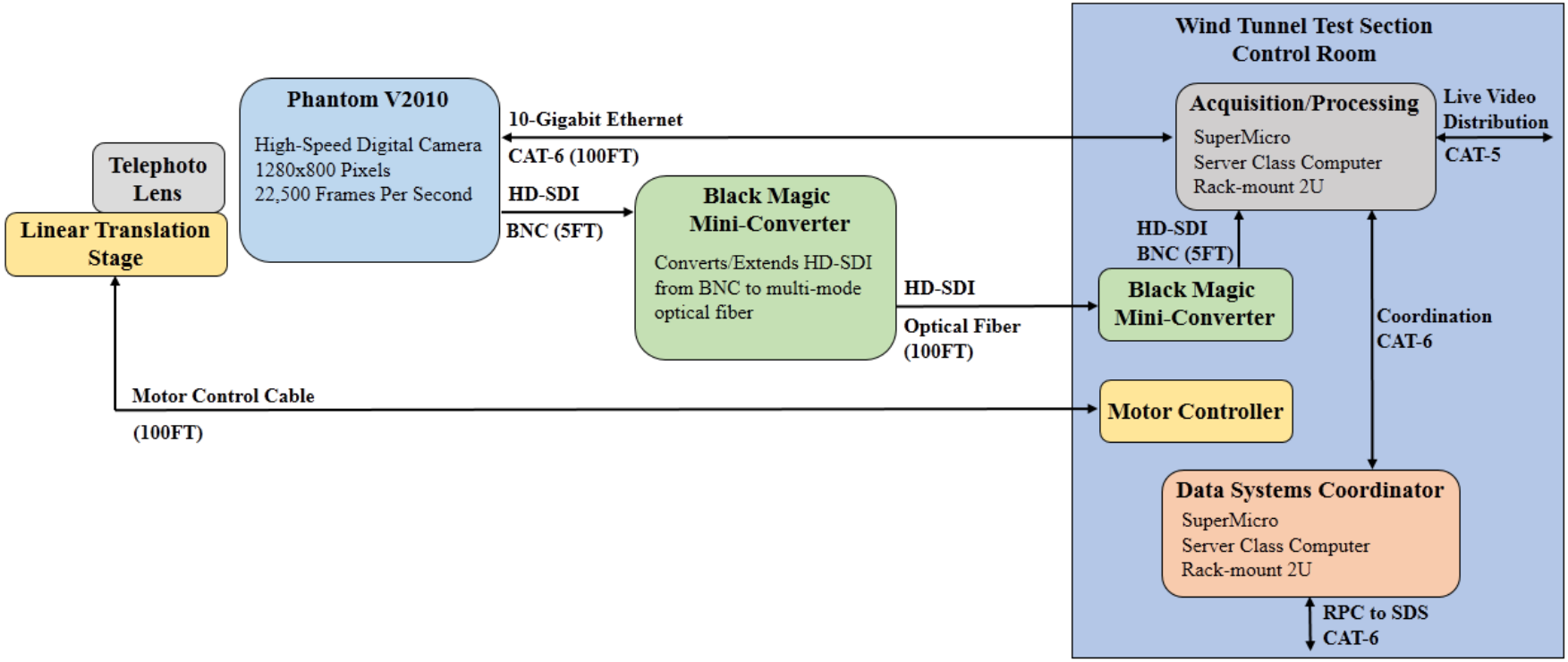
Intel AT2 10 Gigabit Server Adapter

MatrixVision HD-SDI Framegrabber



High-Level Data System Schematic

- Two complete data systems deployed in both 11-by-11 foot and 9-by-7 foot test areas.



UPWT Data Systems Architecture

- Data systems coordinator (DSC) interfaces any number of “test dependent” data services.
- Network published “shared variables” and remote procedure calls allows information flow to and from schlieren/shadowgraph data system.

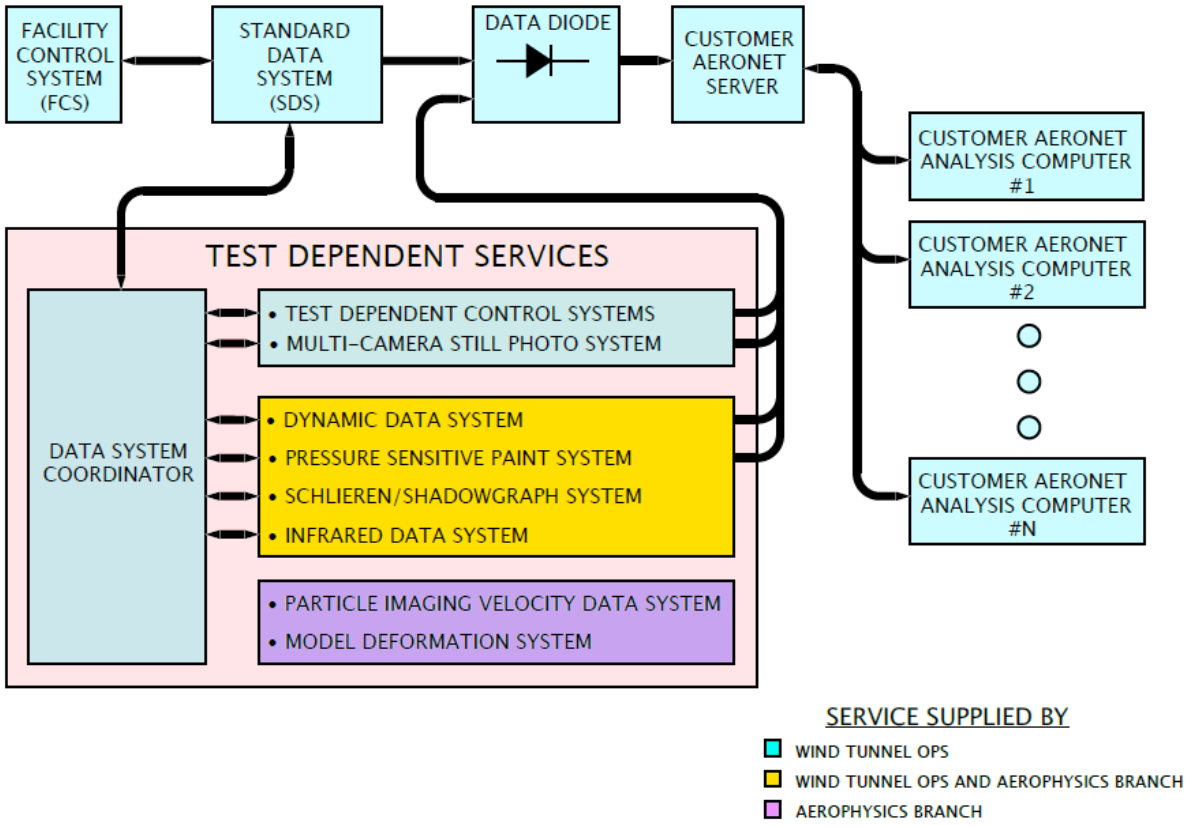
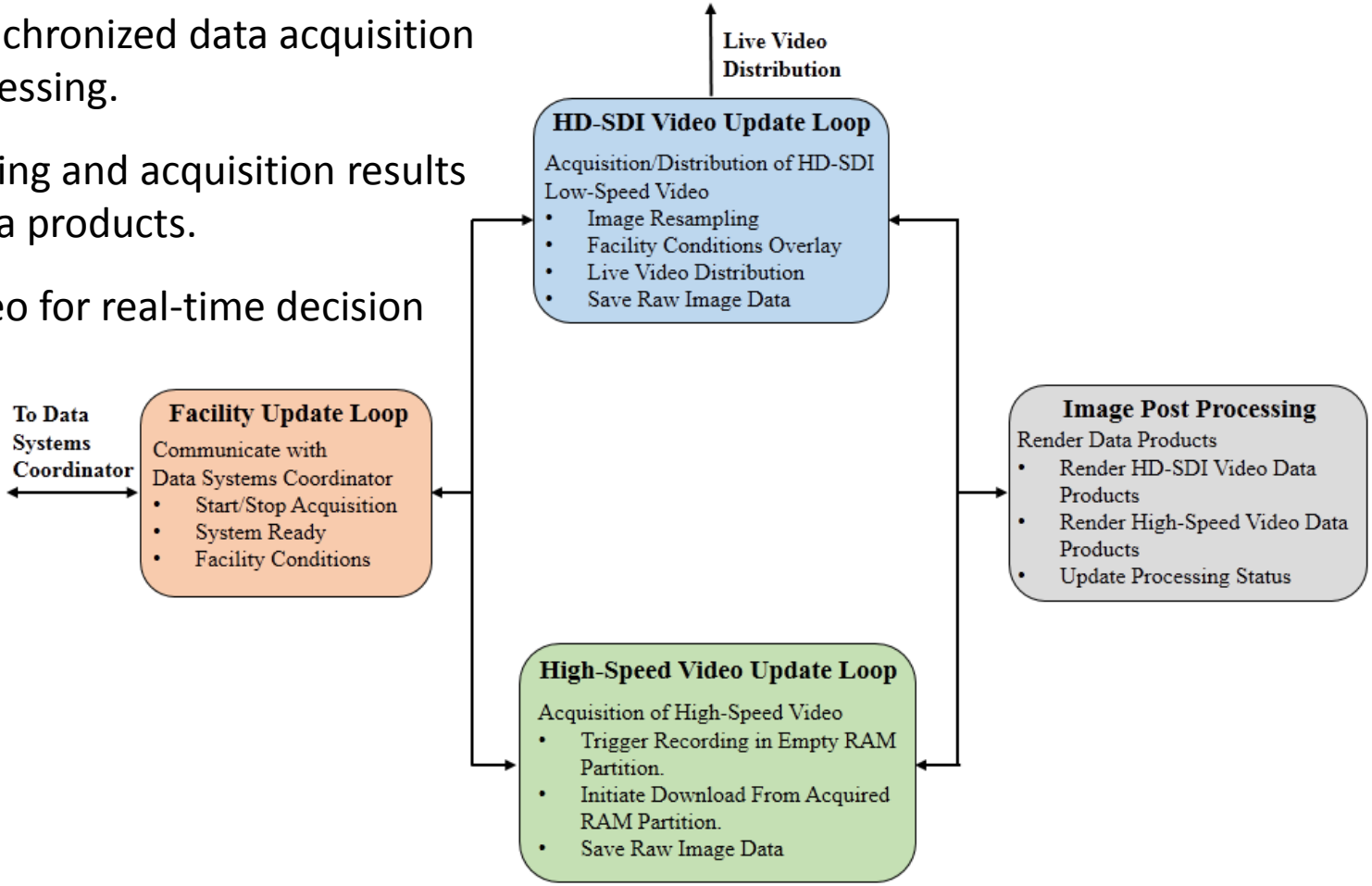


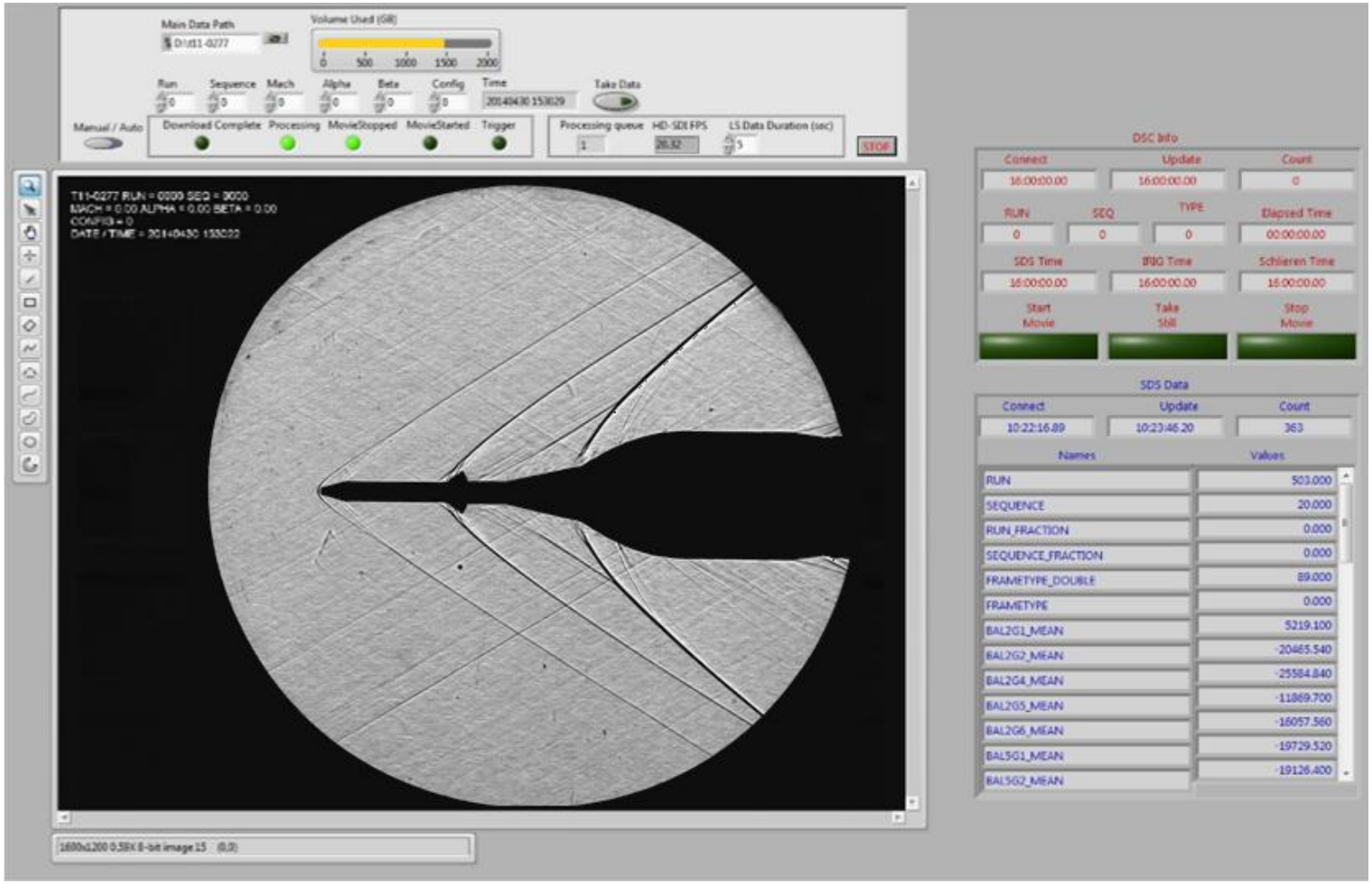
Image Acquisition and Processing Architecture

- LabVIEW based data system developed in-house.
- Automated, synchronized data acquisition and image processing.
- Parallel processing and acquisition results in real-time data products.
- Distributed video for real-time decision making.



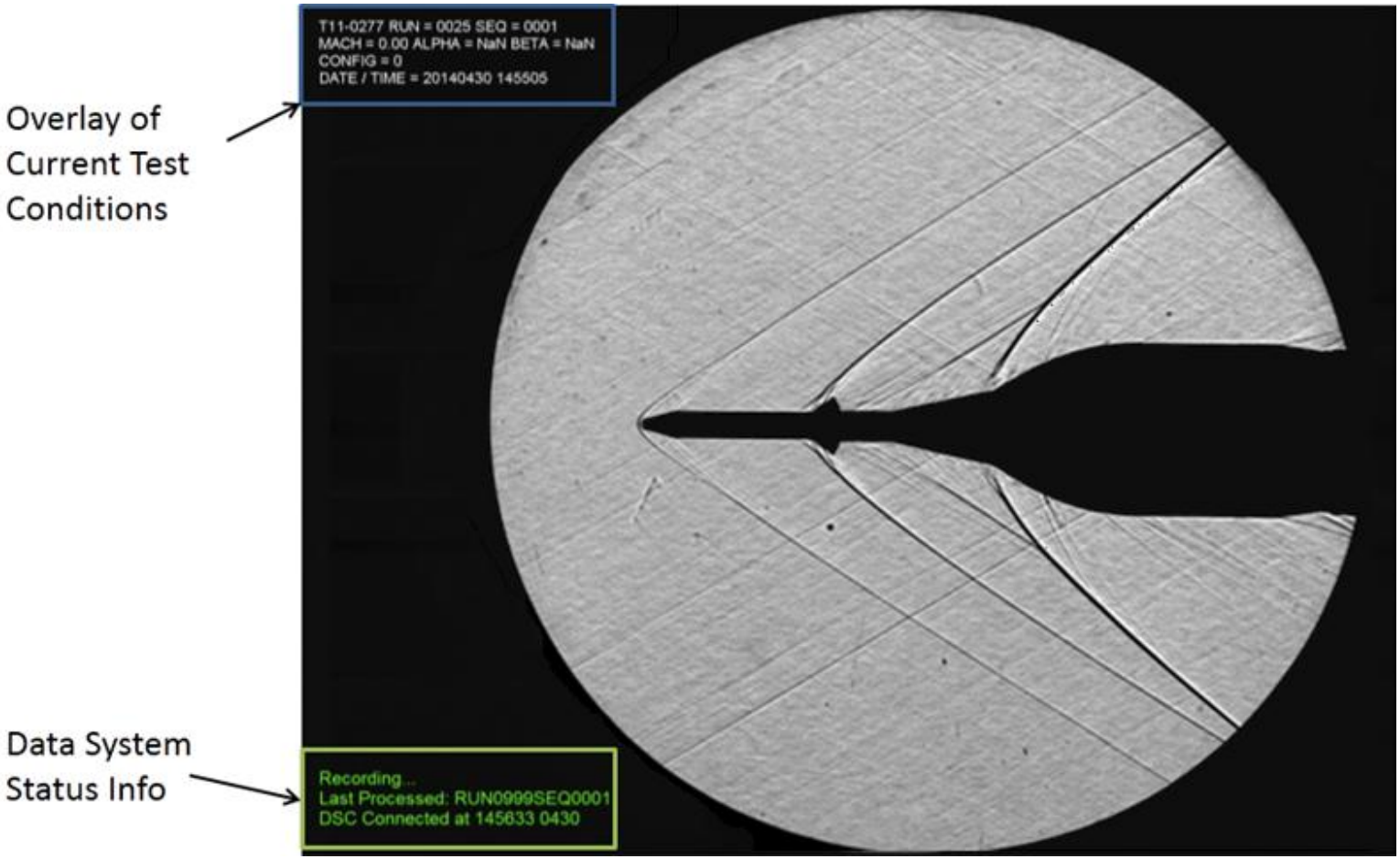
Data System Graphical User Interface

- In-house developed camera acquisition/processing software utility.



Live Distributed Video Feed

- Permanent overlay displays test conditions as communicated from the facility.
- Non-destructive overlay indicates acquisition system health and status.

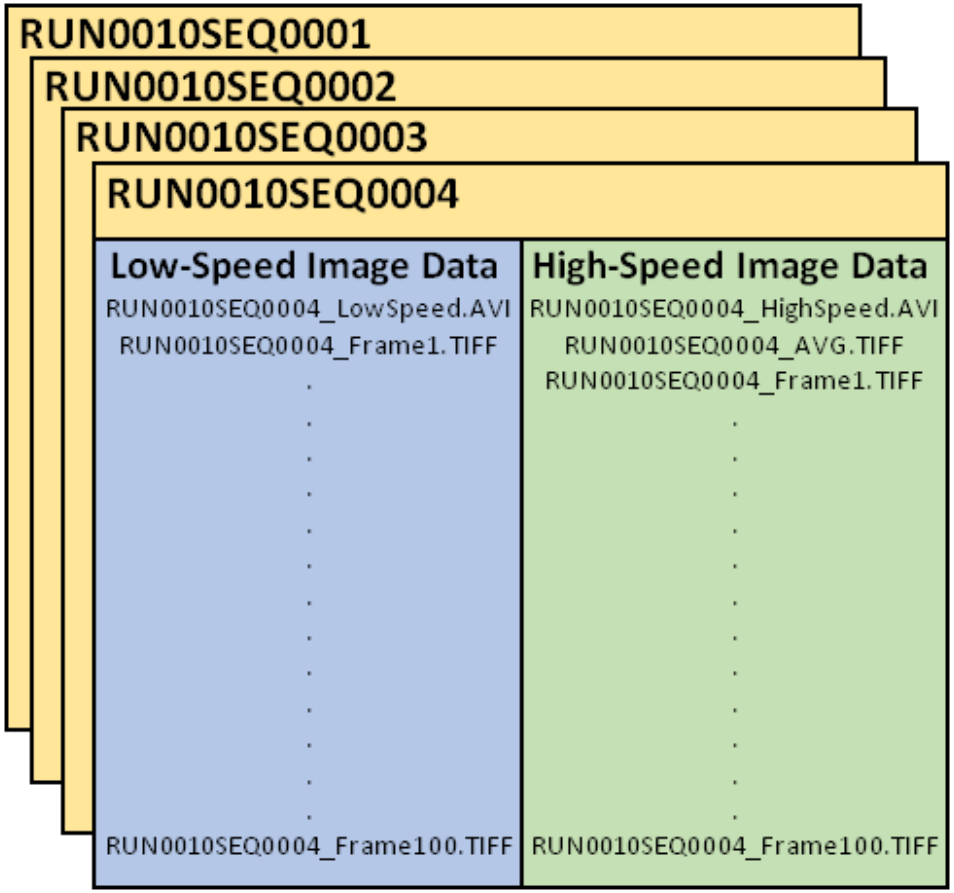


Overview of Data Products

Data Products/Data Point =

- Low-Speed Video (HD-SDI), 1080p acquired up to 30 FPS
- High-Speed Video (Digital), 550 frames @ 26010 FPS
- Stills
- Averaged Still (pixel average of all stills)

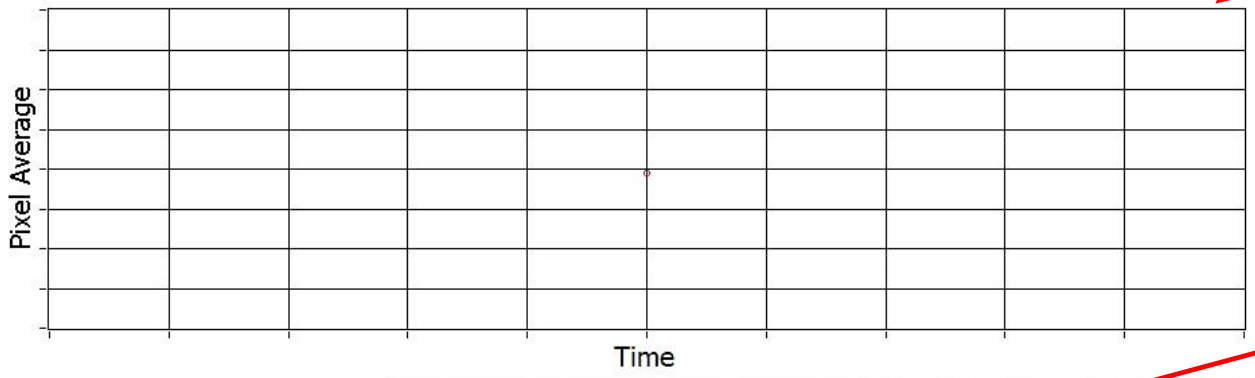
All processed automatically and in parallel with acquisition.



Spectral Shadowgraphy

- High frame-rates make dynamic analysis possible.

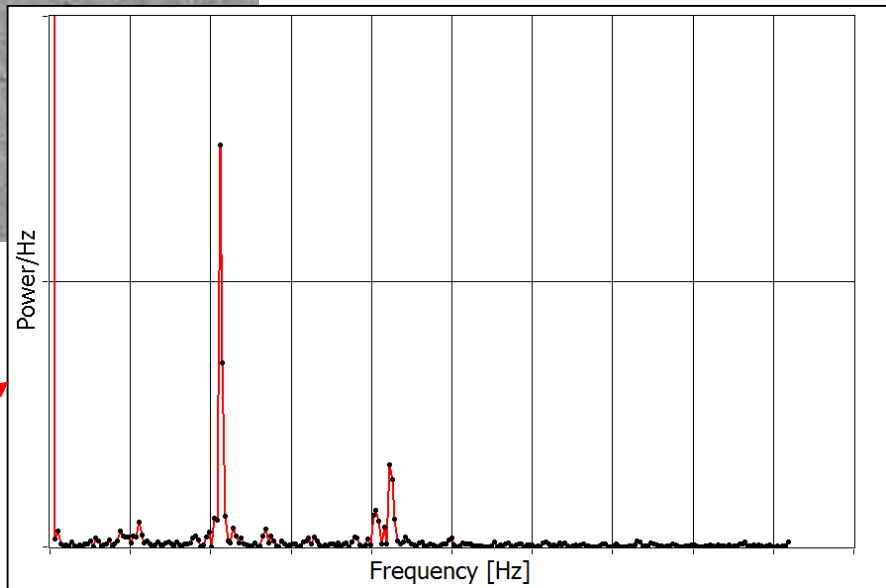
Pixel Average Time History



Region of Interest

Zoomed ROI

PSD
Computed from
image data



Future Capabilities

Dual Schlieren/Shadowgraph

- Augment dual imaging concept with addition of high-resolution, wide-field camera.

Remote Optomechanics

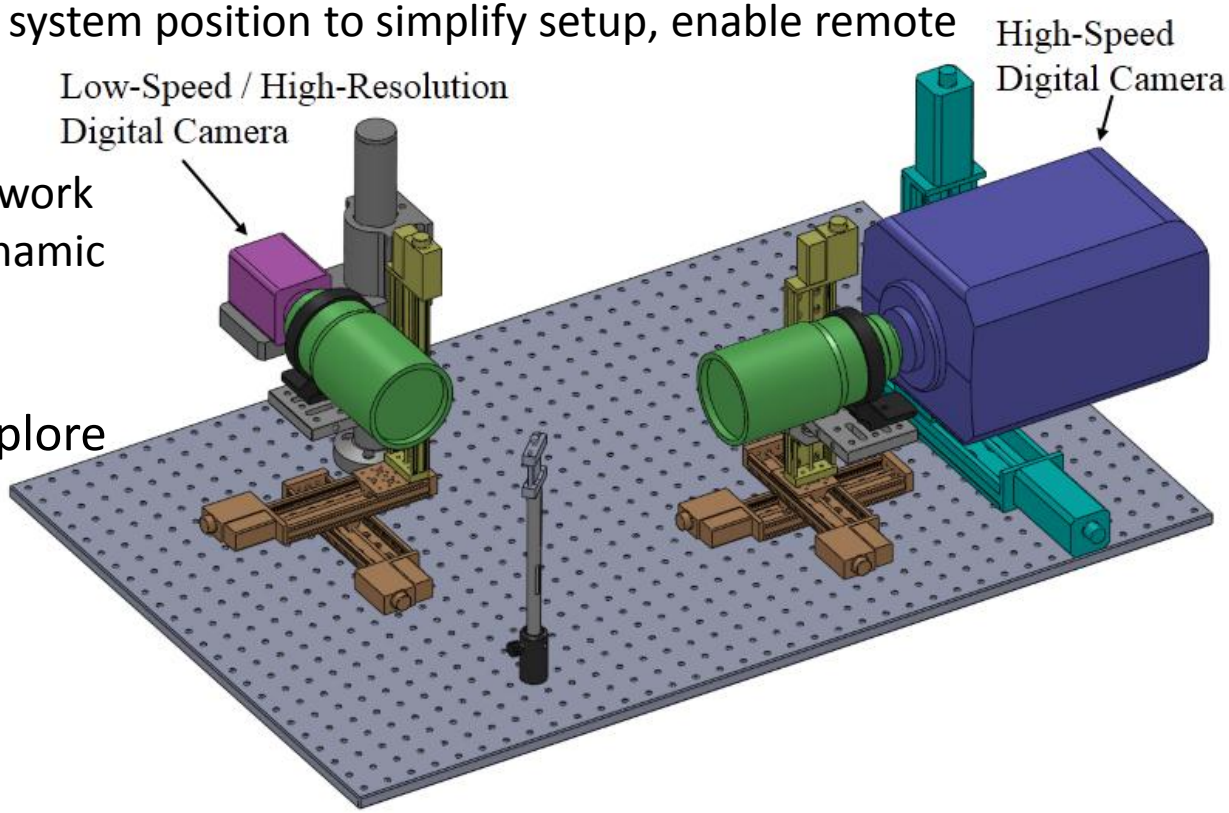
- Ability to traverse in three axes and rotate in two.
- Remote control of camera/lens system position to simplify setup, enable remote panning.

Advanced Processing

- GPU accelerated processing to work large data sets and perform dynamic analysis.

Advanced Optics

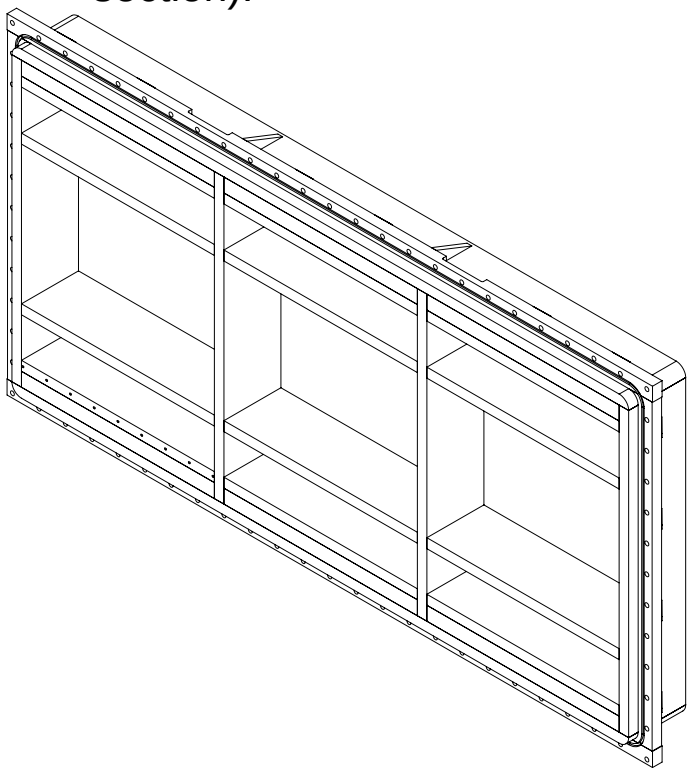
- Correct astigmatism and explore stereoscopic techniques.



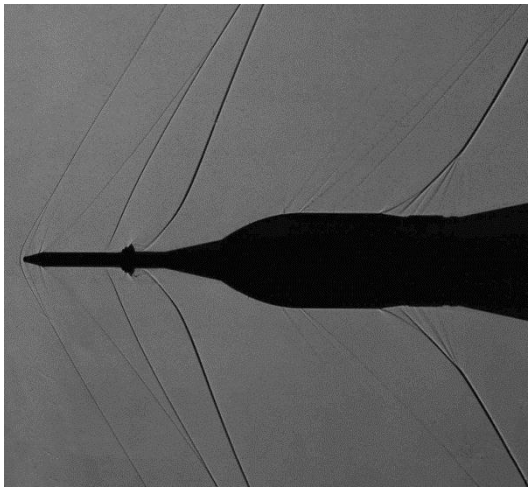
Optical Test Section of the Future

Improved viewing for Schlieren/Shadowgraph

- New larger windows to replace the 3 center rows allow for unobstructed Schlieren viewing.
- Removal of two wall slots between rows may affect tunnel calibration and test section airflow:
  - Flow measurements are being taken to quantify the effects.
  - Options for eliminating flow effects are being developed (i.e. interchangeable window section).



New Larger Window Concept

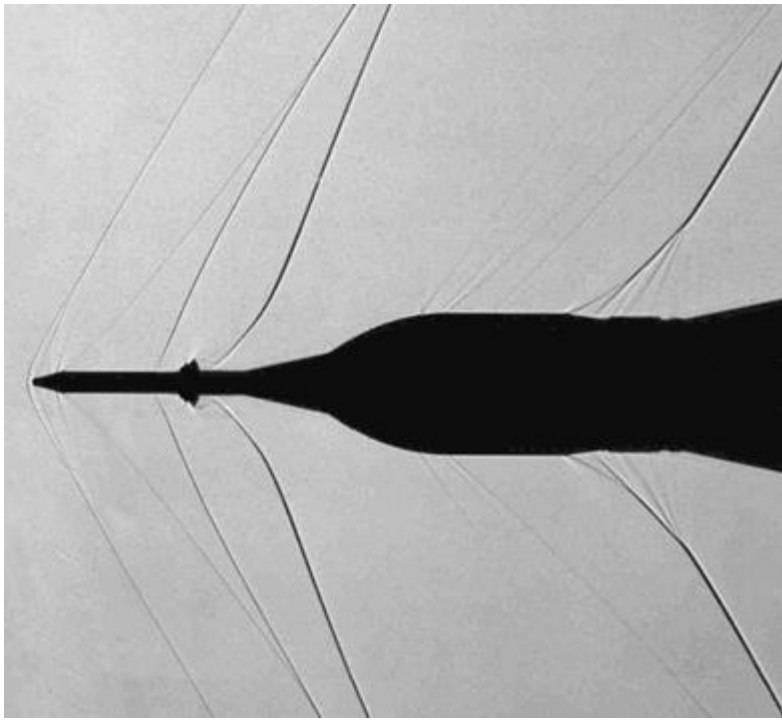


Resulting improved imaging from larger window

Conclusions

Advanced, institutional, production-level schlieren/shadowgraph systems at Ames UPWT 11-by-11 and 9-by-7 foot test sections.

- Hardware down-select:
  - High-speed digital cameras.
  - High-powered LED light sources.
  - Server-class computing for acquisition and processing.
- New software:
  - LabVIEW based acquisition and processing.
  - Data system synchronized to facility through data systems coordinator.
  - Processing done in parallel with acquisition.
  - Data products standardized and available real-time.
- New capabilities:
  - High frame-rates allow for off-body spectral analysis of flow field for correlation with on-body acoustic measurements.
- Future capabilities:
  - Leverage dual imaging and electro-mechanical actuation.
  - Advanced processing and optics.



Questions?