Schlieren System Enhancements at GRC

Advanced Schlieren Working Group Meeting
November 21 & 22, 2013

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Scope of Work and Relationship to Other Projects

- **8x6 SWT Schlieren System Upgrade**
  - Partnership with Advanced Optical Diagnostics & Schlieren Tasks
    - ***Started under Supersonics-Cruise Efficiency Propulsion (SCEP)***
    - ***Continued under Aeronautical Sciences Project (ASP), Innovative Measurements (IM) Advanced Schlieren Task***
    - ***Partnered with Aeronautical Test Program (ATP) for facility upgrade tasks (new windows)***
  - An incremental approach was taken with this upgrade task
    - Allowed earlier achievements to be utilized in supporting tests in the 8x6 Wind Tunnel

- **Continuing development work**
  - New light source & knife edge technologies that were implemented at the 8x6 and are currently being investigated under ASP IM
  - ***Michelle Clem's presentation gets into more detail on newer Schlieren Techniques being investigated under ASP IM (i.e. BOS).***
  - ***Goal of Advanced Schlieren Task under ASP IM***
    - ***Develop & advance Schlieren techniques to a quantitative measurement technique (density & velocity)***

- **Upgraded system has been successfully used to support customer tests in the 8x6**
  - NASA Supersonics Project, Large Scale Low Boom Inlet Test, Fall 2010
  - NASA-Boeing Low Sonic Boom Test, Fall 2012
  - NASA-Boeing QEVC Propulsion Rig Test, March 2013

Customer satisfaction was very high for the Schlieren data acquired for these three tests.

Scope of Work and Relationship to Other Projects

- **Scope of work in upgrade of 8x6 Schlieren System**

  1. Receiving Optics Upgrade:
     - Replaced the receiving optics with new off-the-shelf SOA optical components (2010 to 2011)
  2. High Speed Digital Imaging Capability:
     - Added 1st HS cam in 2010
     - Added 2nd HS cam in 2011
  3. Two new Schlieren windows:
     - Involves a new seal design and modifying existing window frames (2011 to present)
     - ***Some lessons learned here!***
  4. Light source:
     - Replaced existing antiquated 150W Xenon light source utilizing newer LED technology (2012 to 2013)
  5. Knife Edge Technologies:
     - Implemented state-of-the-art knife edge technologies – Optical phase knife edges (2012 to 2013)

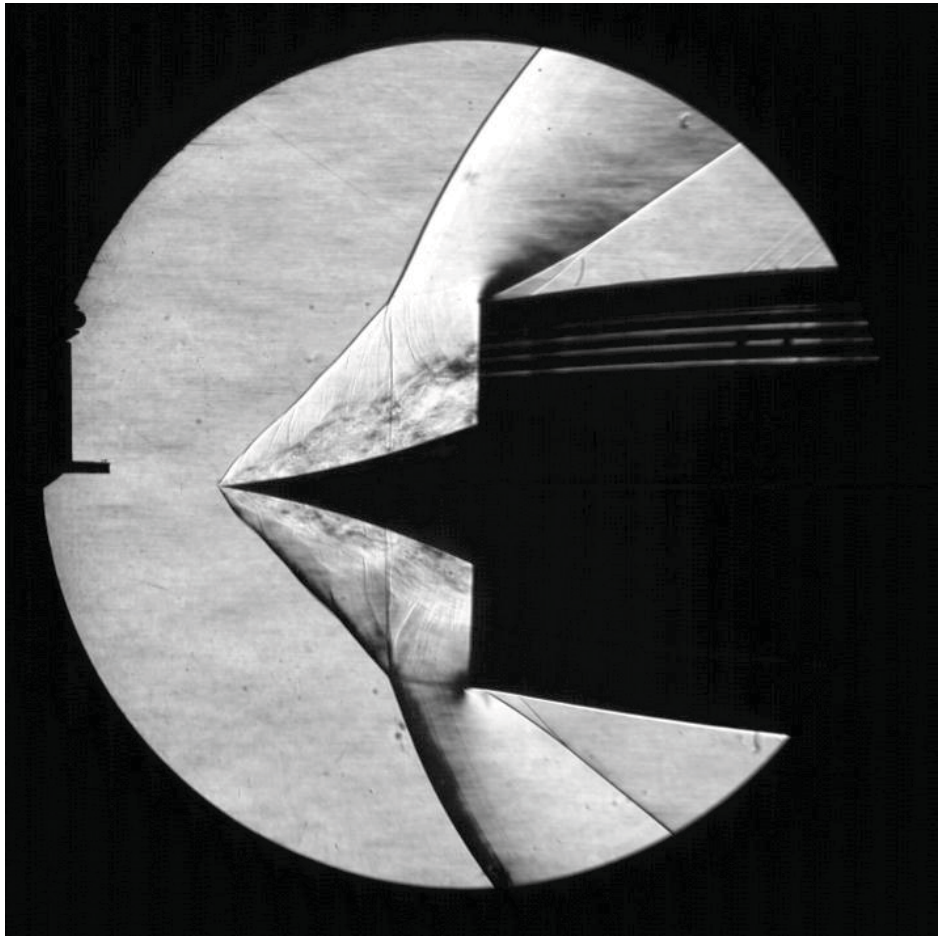
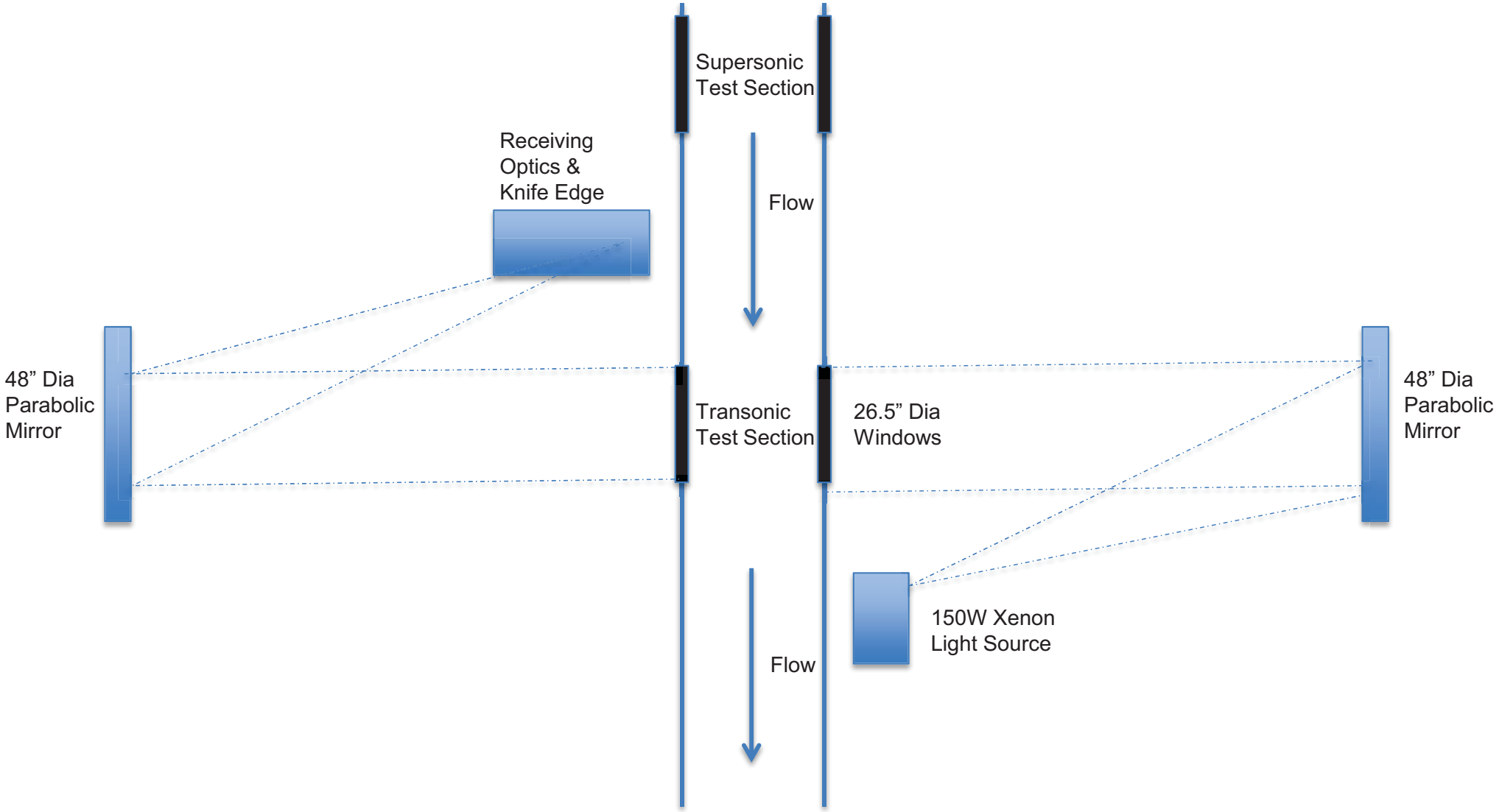


Image acquired from 8x6 Schlieren System ” on Large Scale Low Boom Inlet test (Oct. – Nov. 2010) - Showing Inlet at “Buzz” condition.

Existing System (Pre-Upgrades) at the 8x6

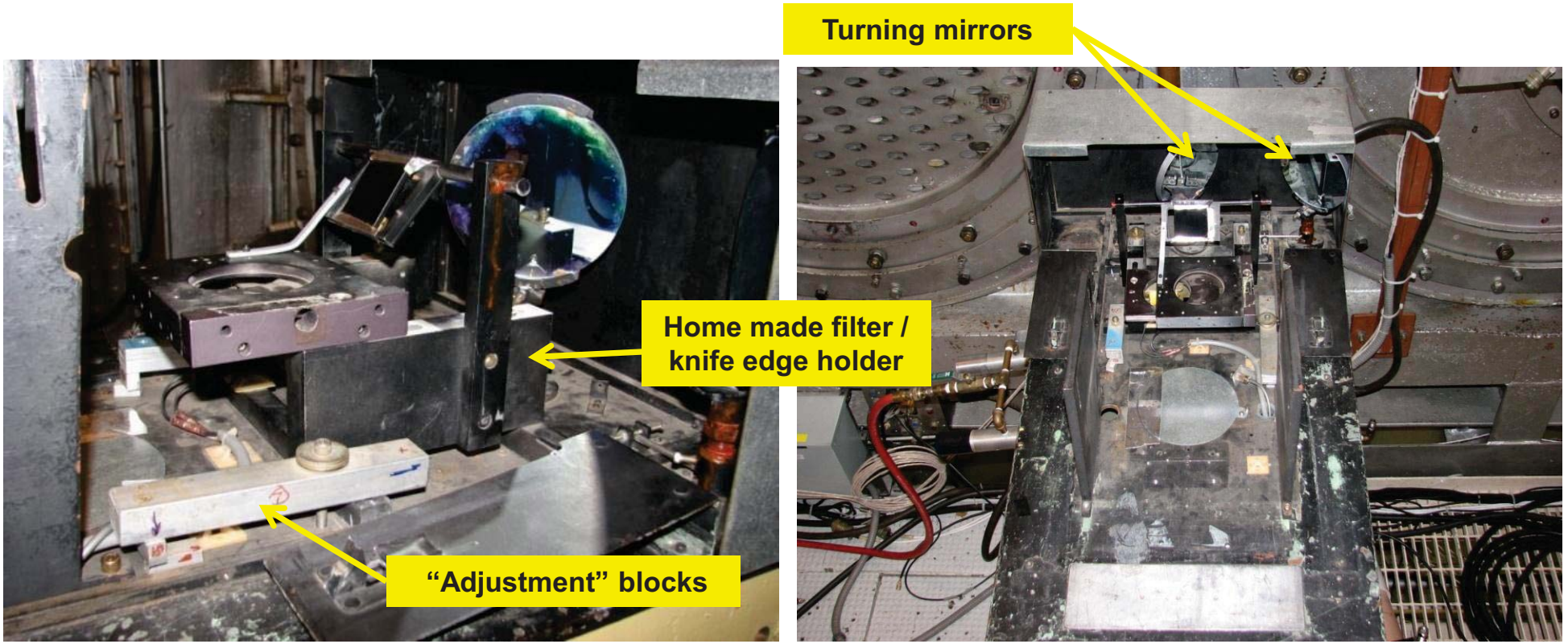
- **Conventional Knife Edge Schlieren System - Horizontal Z-Configuration**



Existing System (Pre-Upgrades) at the 8x6

- **Conventional Knife Edge Schlieren System - Horizontal Z-Configuration**

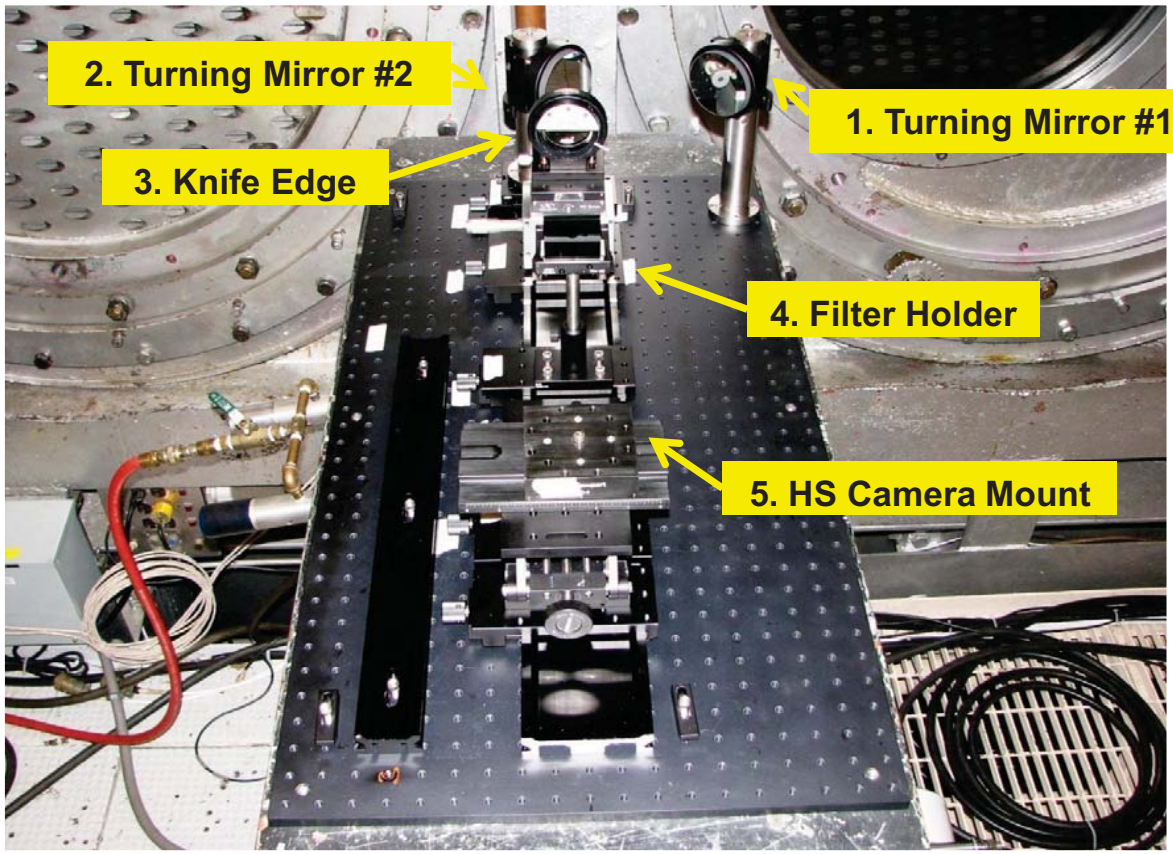
1. Receiving Optics – Pre Upgrade



Original 8x6 Schlieren Receiving Optics

- The system used “home made” and very antiquated components
- Very hard to adjust
  - No remote adjustment capability on knife edge
- No provisions for adjustable camera mounts
  - Cameras installed as needed and attached to fixed plate
- The system was extremely difficult to set-up and very sensitive to vibration

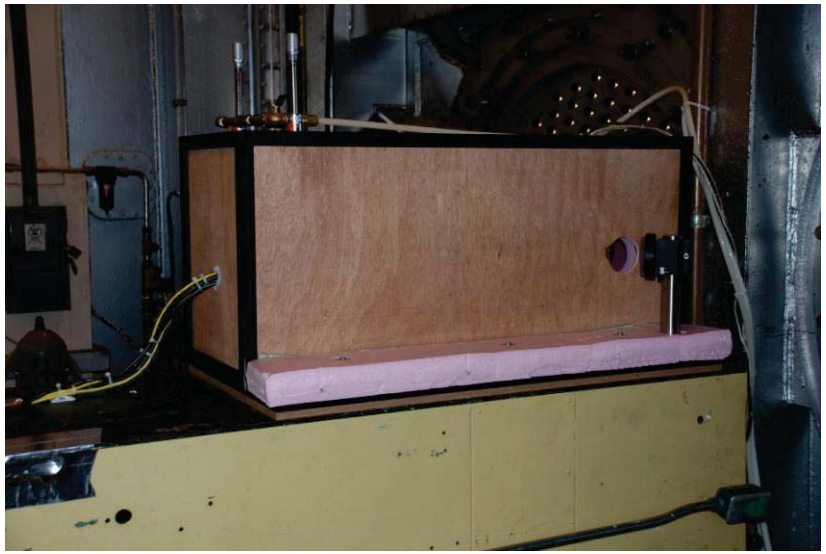
1. Receiving Optics – Upgrade



New 8x6 Schlieren Receiving Optics

- Installed optical breadboard & rails to facilitate component installation & adjustment
- Replaced all old components with new adjustable “optical” quality components
- Remote adjustment capability on knife edge in both
  - Focal point (z-axis)
  - Sensitivity (y-axis)
- Made provisions for mounting cameras (primary & secondary cameras)
- Developed procedures and trained facility personnel on the set-up of the system

1. Receiving Optics – Other Issues That Needed Fixed

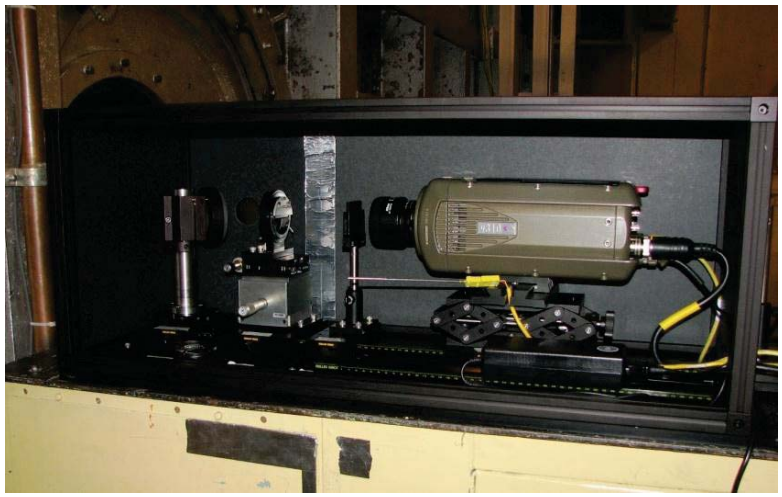


Receiving Optics Enclosed in an Environmental Enclosure

- System is located in the balance chamber…….tough environment for optics.
  - 200 deg F in temperature
  - ~3 psia
- Enclosed receiving optics station in an insulated environmental box with cooling to protect the high speed camera and associated optics
- Worked well for all of the tests to date.
  - Even at highest temp conditions, box conditions have been kept under 90 degrees F.
- Definite plans are to improve box or at least make it look better! (but it has worked!!)

2. High Speed Digital Imaging Capability

Phantom V310 Installed in Schlieren System



Phantom V611 installed at the 10x10 for the ExoMars Tests

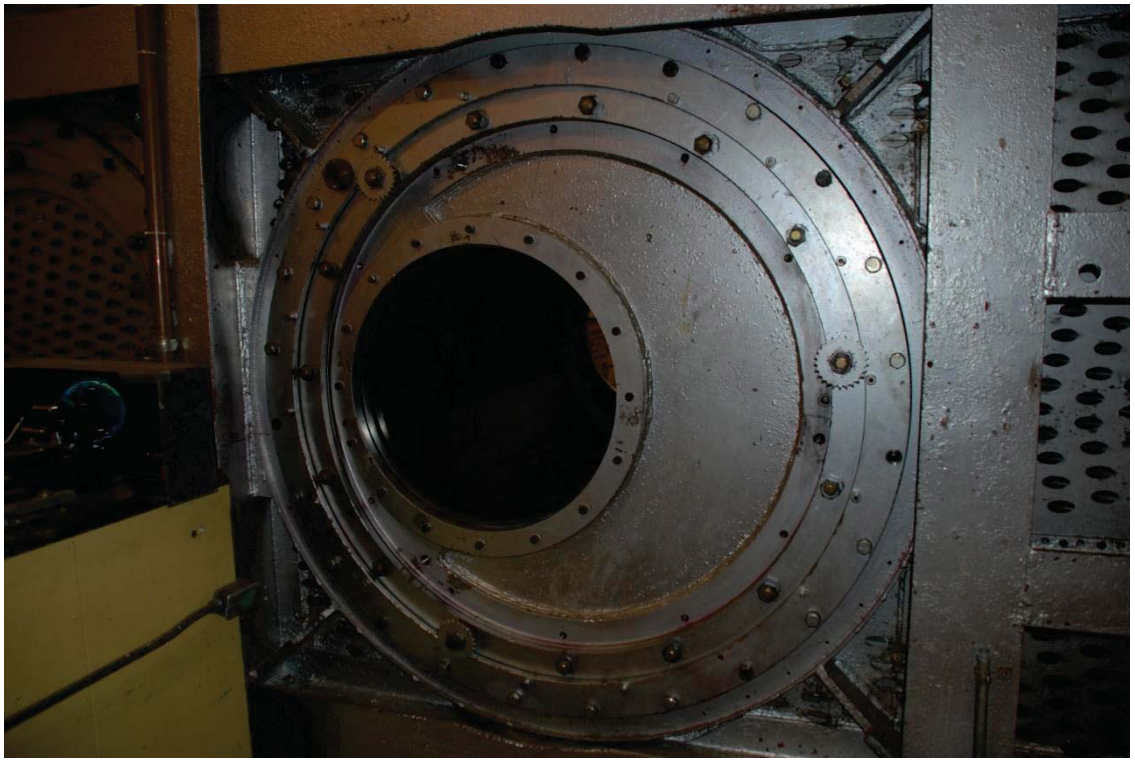
- The original system only had provisions for standard video & still cameras. Other cameras were borrowed and installed on an as-needed basis. Presented some limitation on the use of the system.

- Phantom V310
  - 3250fps at 1200x800, 500,000 fps max at reduced resolution, 8GB memory, 8 and 12-bit depth.
  - Acquired for 8x6 Schlieren as part of an Optical Diagnostics Task under Supersonics for LSLB Inlet Test.
  - Under ATP a 128GB "Cinemag" online storage cartridge was added.
  - Successfully used to provide Schlieren imaging on Large Scale Low Boom Inlet Test 2010 (~2TB data), Boeing Low Sonic Boom Test 2012 (~1TB data), Boeing QEVC Propulsion Rig Test 2013 (~500 GB data).

- Phantom V611
  - 6242fps at 1200x800, 1Mfps at reduced resolution, 8GB memory, 8 and 12-bit depth w/ 128 GB storage cartridge
  - Acquired under ATP in 2011 to support further high speed imaging needs
  - Successfully used along with the V310 and a borrowed V12 to a acquire high speed digital video for the ExoMars Supersonic Parachute deployment tests conducted in the 10x10 SWT, Fall 2012.
  - Was the primary data for the ExoMars Test, Customer satisfaction was high.

- ***High Speed imaging is now a capability that we can now offer to our test customers***

3. Schlieren Window Replacement



Schlieren Window at 8x6 Wind Tunnel

- The existing windows (4 total) have developed numerous nicks and flaws in them due to years of usage and wear.
- The existing windows were installed into the frames using lead seals using a very laborious process…..The windows had not been replaced in several decades.
  - Two windows had become damaged to a point where they were not usable.
- Frames were becoming difficult to align and get flush due to wear and previous installation processes.

3. Schlieren Window Replacement – Scope of Work

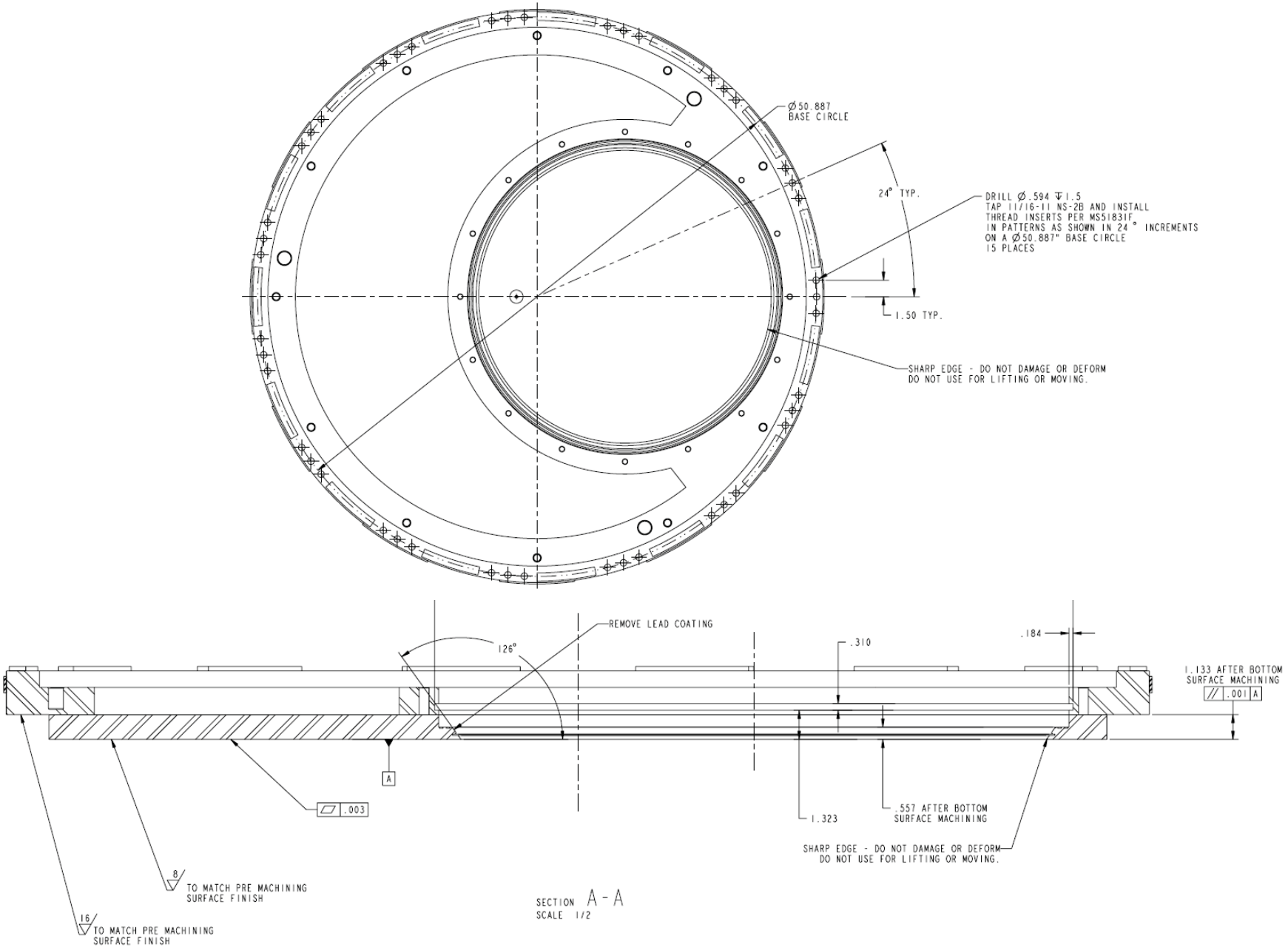
Existing Window Frame

New Windows to be Installed

Existing Window Frame After Being Resurfaced

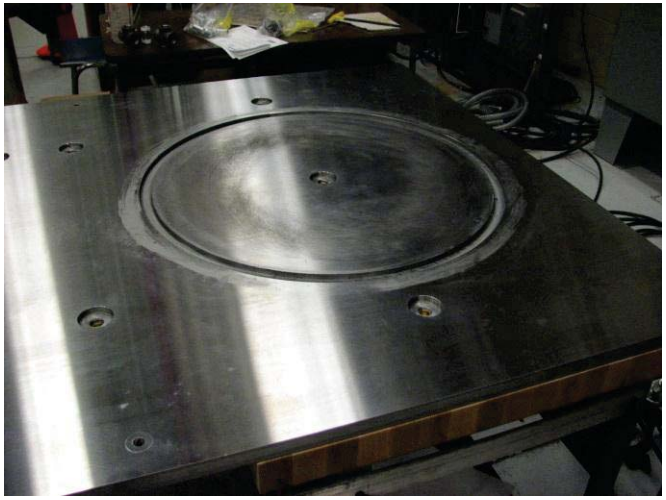
- Design a new seal and have window frames re-machined to remove old seal and incorporate new "epoxy based" seal design.
- Re-surface & polish frames to make flat again so they are flush to the inside of the tunnel when installed.
- Design, fabricate and/or procure
  - Fixtures required for the re-machining
  - Surface table and fixtures required for the window installation
- Identify sealant material that will have low viscosity for application but cure to have minimal deflection, 100 mil thick, no more than 2 mil at tunnel test conditions, 250 deg F, 81 psi load.

3. Schlieren Window Frames

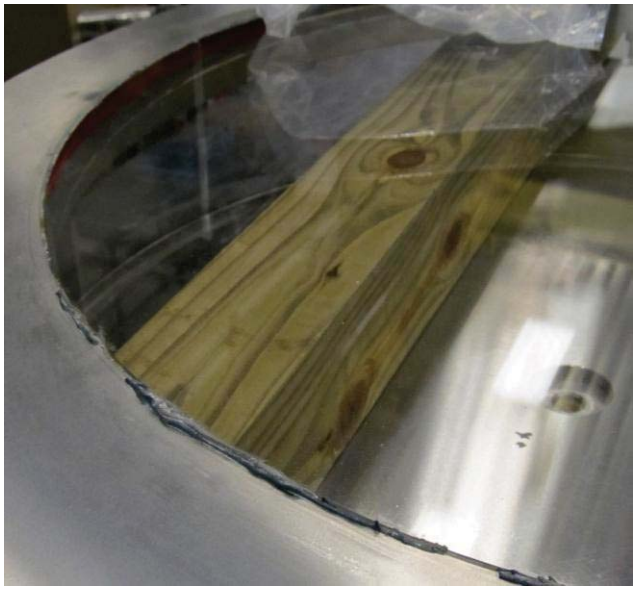


3. Window Installation - First Attempt and Results

- **Window frames were successfully machined for the new seal design and resurfaced (2011)**
  - Did have some issues with finding a company that could handle the size of frames on their machines
  - “Standard Jig & Bore”, Akron Ohio
  - Several attempts were made to get the correct surface finish
- **Installation Method - First Attempt (end 2011, beg 2012)**
  - Place frame on steel surface table
  - Apply Belzona (4151) sealant material to window seal area in frame
  - Install window into frame, allowing excess material to run into groove on table.
  - Vacuum applied through holes in table surface used to hold window in place during curing
- **First Attempt Results**
  - Material did not flow evenly as required, excess material in some areas voids in others.
  - Window was not flush, protruded into the flow side by 3 mils causing forward facing step. Exceeds our requirements of ~1 mil, (2 mils allowable at most).
- **Causes**
  - Steel table not providing stable, flat surface as required. Determined it was deflecting
  - Belzona material was not of low enough viscosity for our application



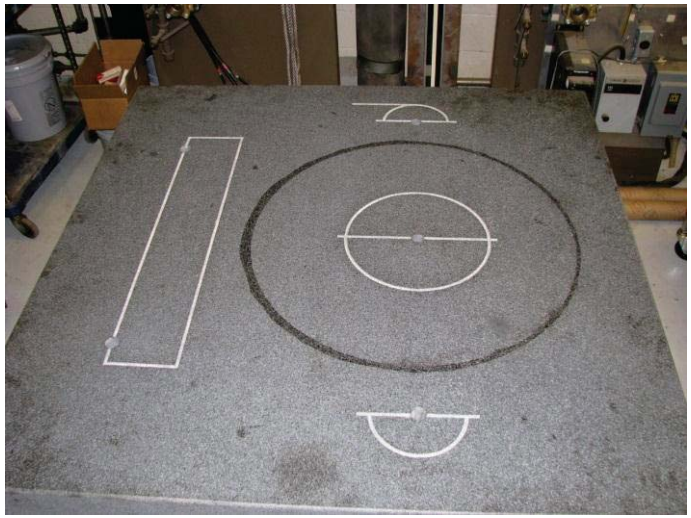
Steel Schlieren Window Installation Table



First Window Installation Attempt

3. Window Installation - Revised Installation Method

- **Trouble shooting (Jan - July 2012)**
  - Able to recreate first attempt scenario using the steel table
  - At fab shop utilized granite table for mock up of installation, verified granite table would work for installation
  - Determined it would be better to caste seal in place around window once installed in frame
- **Revised Installation Procedure (~June 2012)**
  - Install frame on granite surface table
  - Install window into frame and center using dowel pins
  - Pour sealant material into area between window and frame
  - Vacuum was again applied through holes in table to hold frame & window in place during cure
- **New granite surface table (~June 2012)**
- **New sealant materials identified & tested (June-Dec 2012)**
  - Needed a material that was of low viscosity to flow during the installation, but cures strong enough to experience minimal loading during operation at tunnel conditions**<u>….not trivial, spent some time evaluating candidate materials</u>**
  - Materials identified and tested using external testing lab (2 rounds of testing)
  - **Ended up testing internally to verify performance**
  - **Master Bond EP42HT-2 selected, Master Bond EP42HT-2AO, close second.**

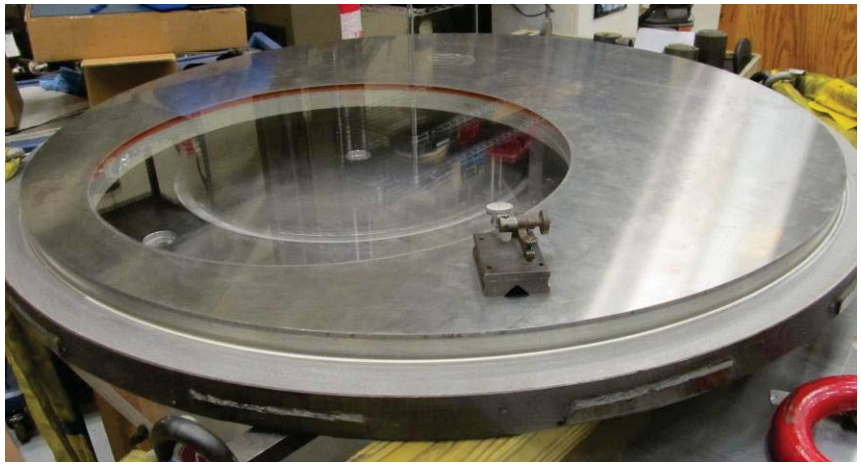


Granite Schlieren Window Installation Table

Seal Material Samples for Environmental Load Testing

3. Window Installation – Latest Results

- **Completed two "test" installations on plexiglass windows to validate the process (Dec-Jan 2013)**
  - Cotronics material 4461S
  - Master Bond EP42HT-2
  - Both with in +/-1 mil tolerance
- **First window successfully installed into frame March 2013**
  - Master Bond EP42HT-2
  - With in +/- ½ mil of being flush
- **Second window successfully installed in July 2013**
- **Two new windows have been completed**
  - Design, fixtures, materials and procedure on-hand for follow on installations
- **Lessons learned**
  - For next time will use 20 to 50 mil gap for seal instead of 100 mils
  - **Others lessons to be documented….**



First window successfully installed using revised procedure March 2013

Second window in process of being installed into frame July 2013

4. Replacement of Light Source

Existing 150W Xenon Light Source

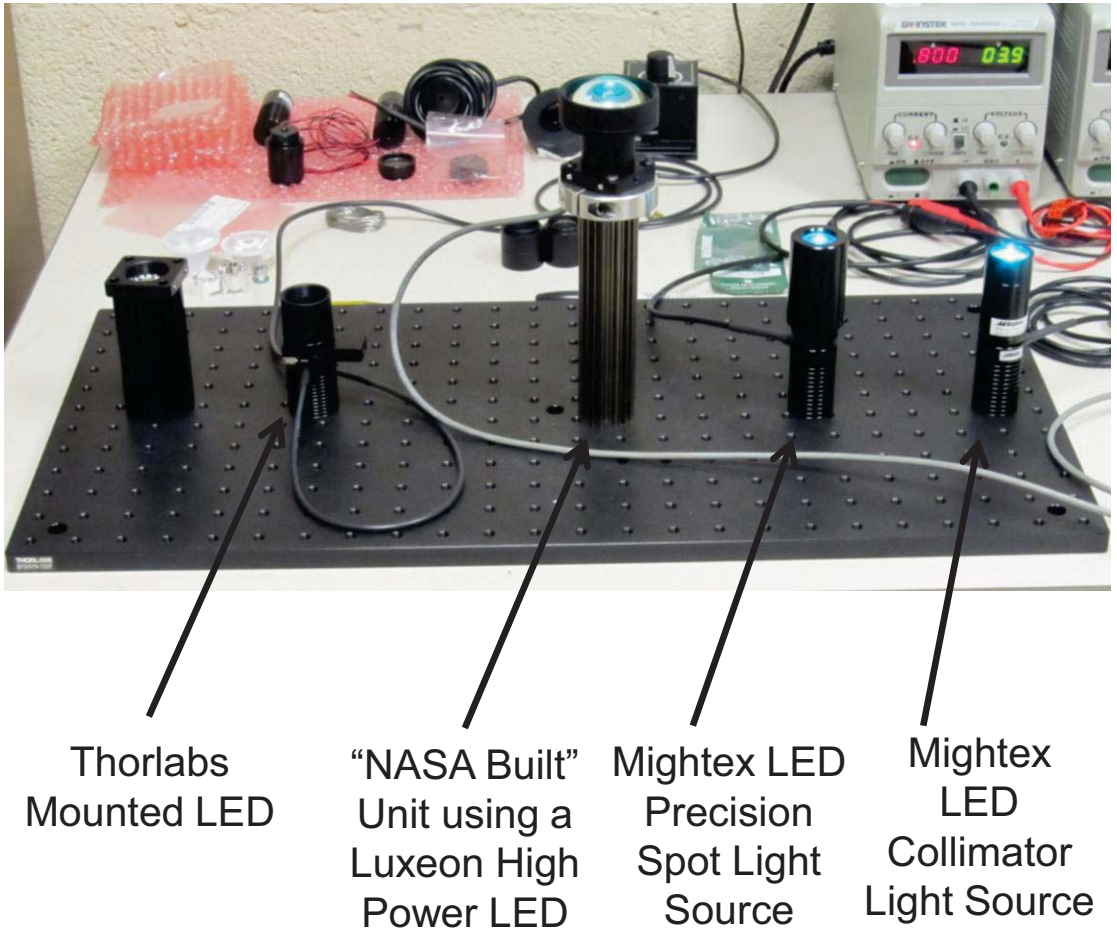
New LED Light Source installed in 8x6

- Replaced 150W Xenon Light Source
  - Required large 48V, 6A power supply, needed to be co-located in test chamber with light source
  - Bulbs & 150W Xenon light source parts very expensive to replace.
- Implemented new LED technology
  - Provides ample lighting, relatively inexpensive
  - Requires relatively low power (700ma @ 3.2V)
- Used monochromatic light (505nm) to take advantage of new knife edge technologies.
- Evaluated several NASA built and commercial LED light sources
- Installed NASA built LED units in 8x6 and used for two Boeing Sonic Boom Test (2012-13)

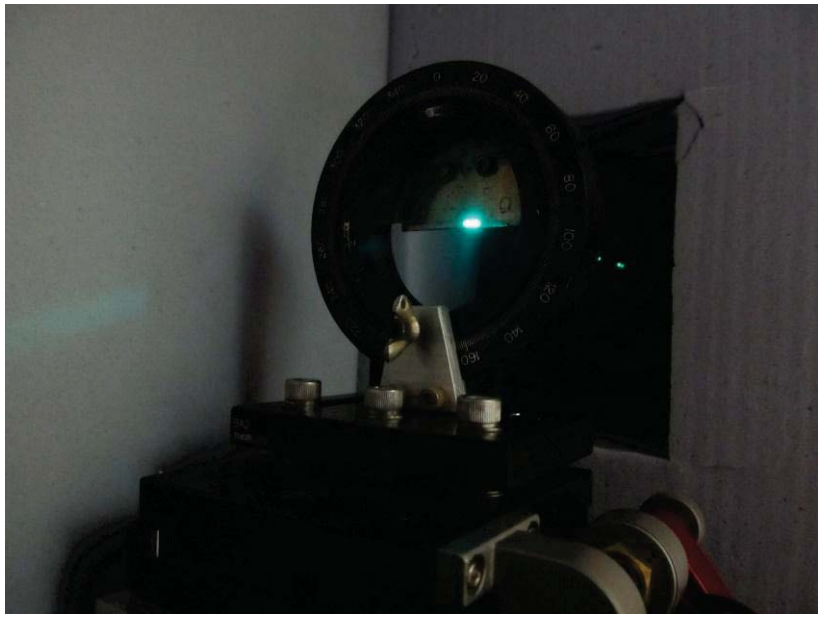
4. Replacement of Light Source

- Evaluated several LED light sources
  - Off-the-shelf systems
  - NASA built system using commercial parts
- Selected NASA built unit
- Yielded the most illumination required for HS imaging
- Best survivability in the environment of the 8x6 balance chamber
- This type of unit has also been installed on the Schlieren system at the 10x10
  - Used on the ExoMars test.

Alternative Light Source Technologies

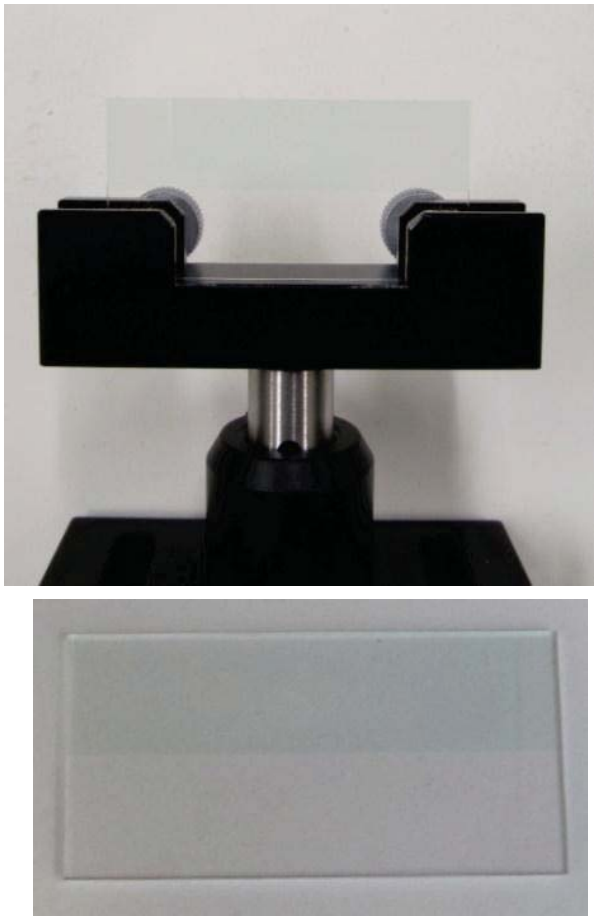


5. New Knife Edges Technologies – Optical Phase Knifes



Standard Razor Blade Knife Edge

- Investigating ½ wavelength phase knifes
- Instead of blocking diffracted light, passes it through and shifts it ½-λ…..in effect it lets more light through
- Provides greater contrast and detail in “dark areas” and provides better system sensitivity
- A batch of 12 optical phase knife edges have been fabricated and delivered to NASA GRC
- Installed and used in the 8x6 in 2013
- Parametric Studies underway to evaluate knife edge and its increased sensitivity

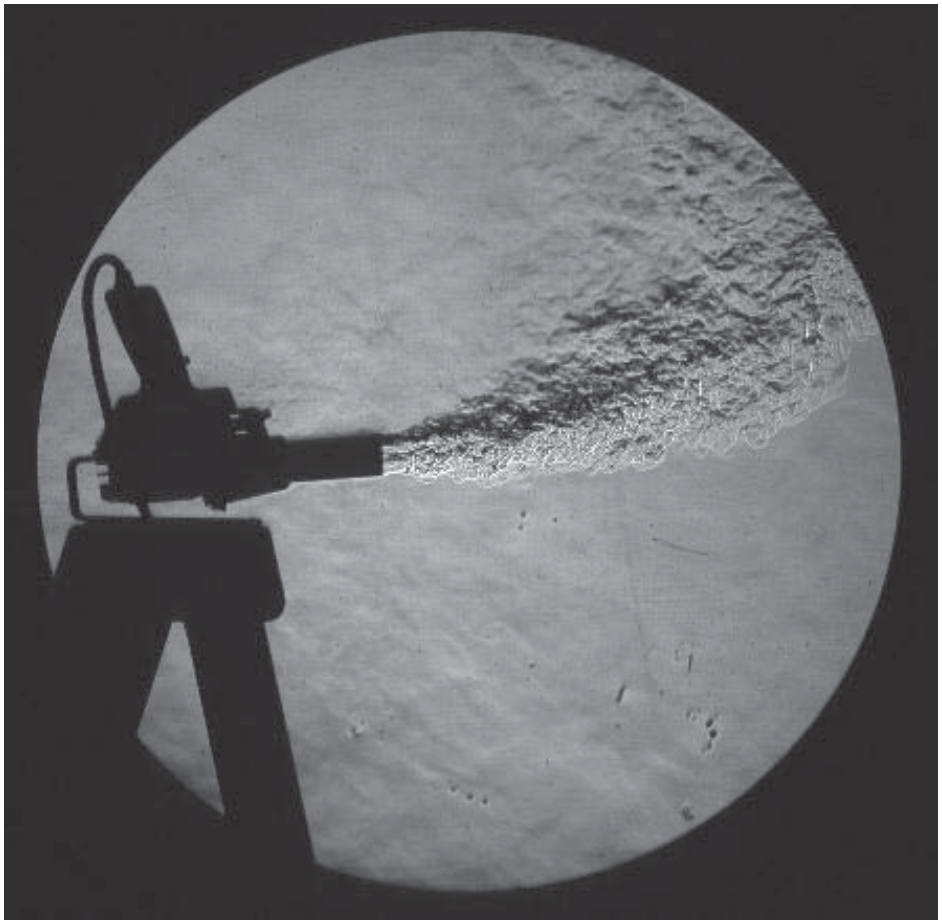


Optical Phase Knife Edge under evaluation in the lab. Set up for 505nm Cyan light source use

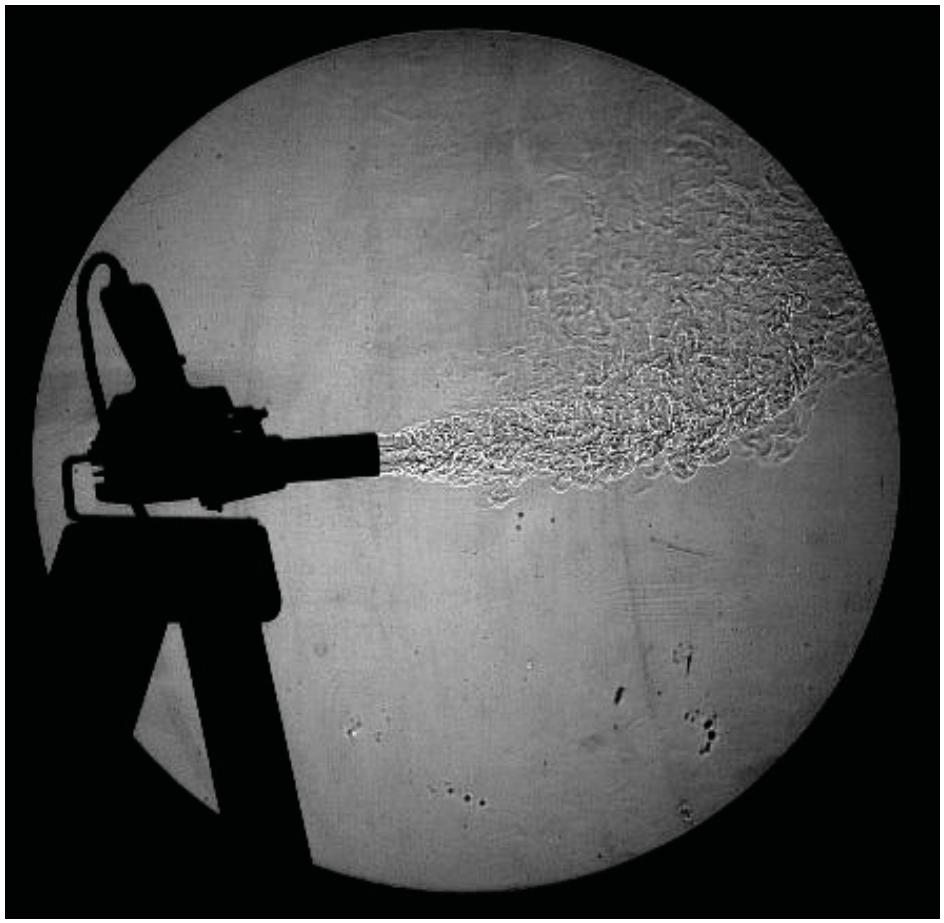
Deposition Sciences Inc.
3300 Coffey Lane
Santa Rosa, CA 95403

5. New Knife Edges Technologies – Optical Phase Knifes

Standard “razor” knife edge

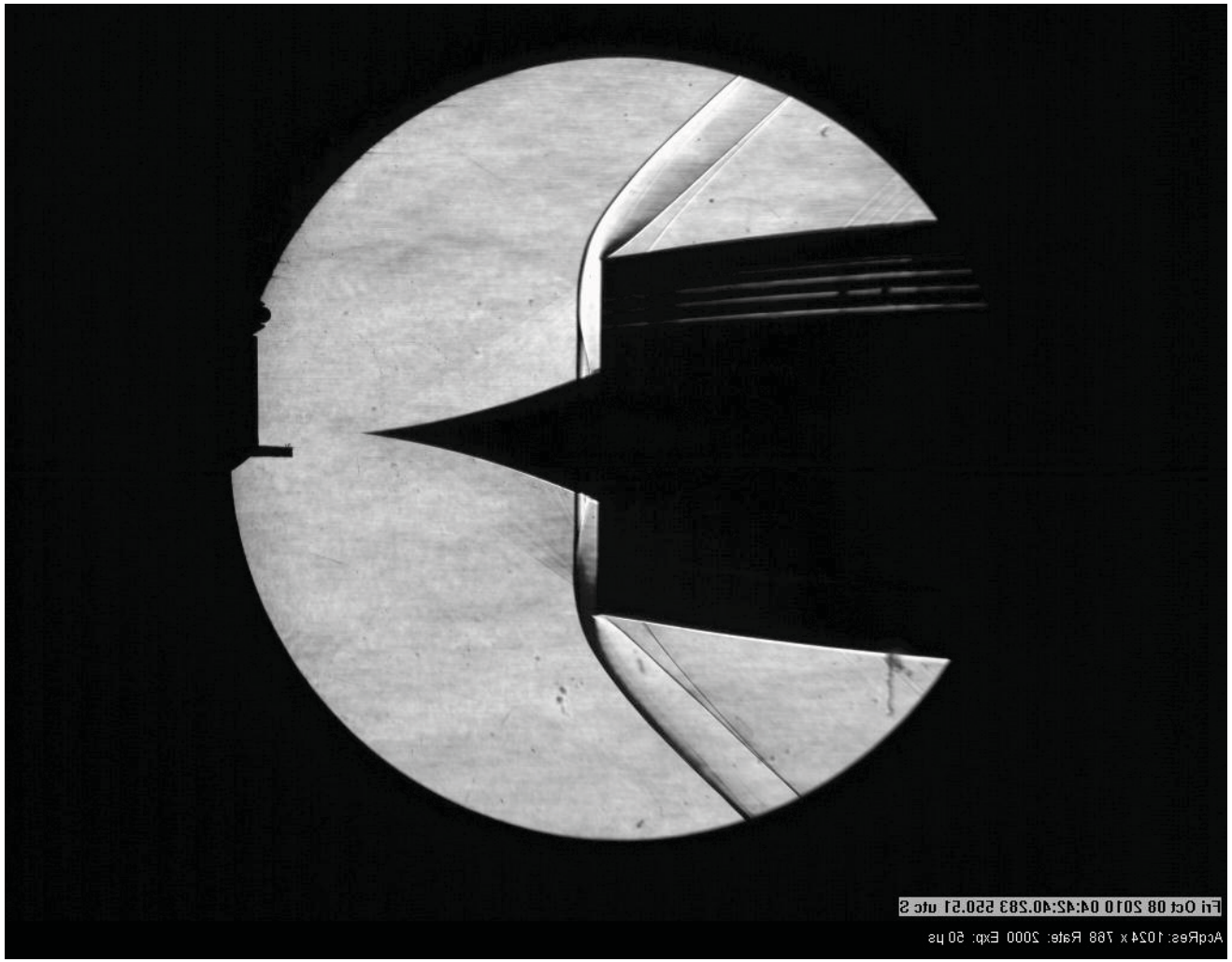


Optical phase knife edge



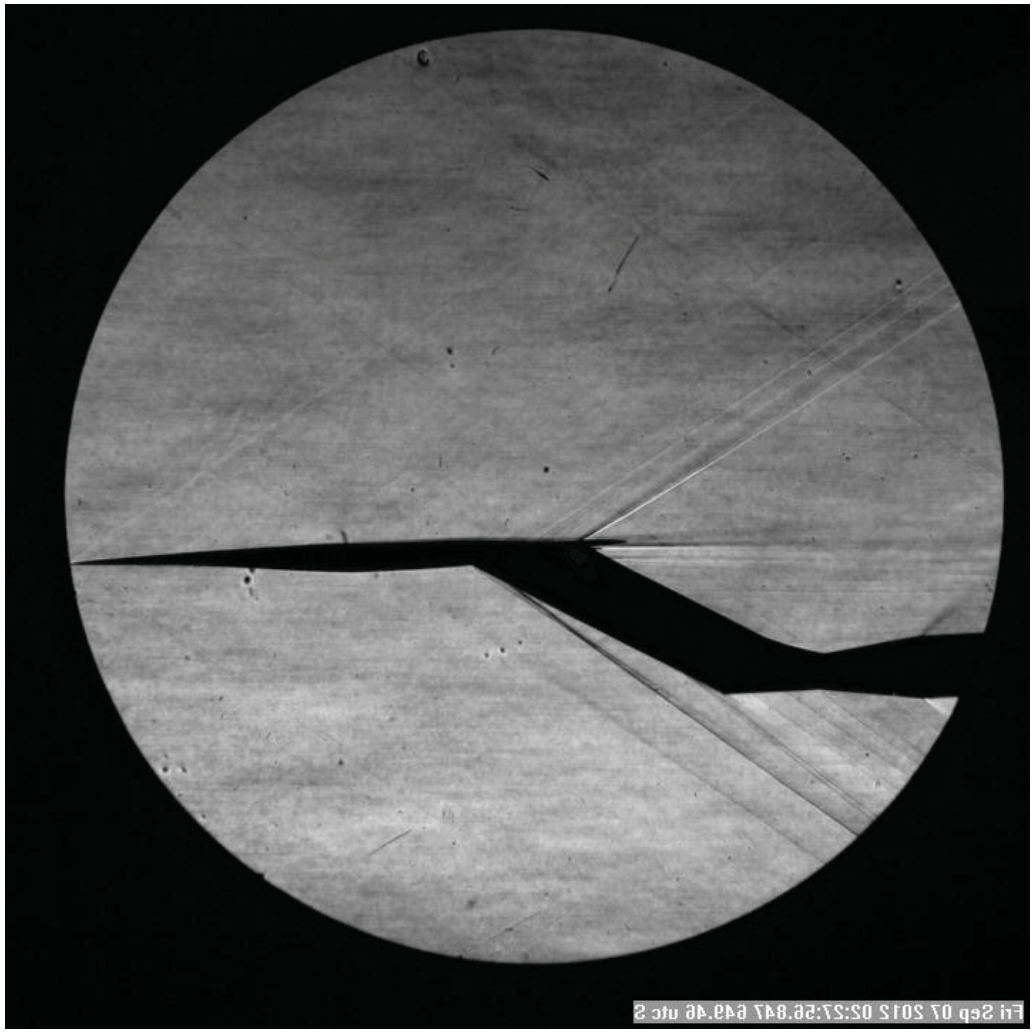
- Can see more detail in structure of flow on optical phase knife system
- Shows up as dark areas using conventional knife edge

Large Scale Low Boom Test, Fall 2010



- Performance testing of a new low boom inlet concept up to M=1.8
- Used high speed Schlieren data to validate their CFD code
- Capture several inlet “unstart” conditions

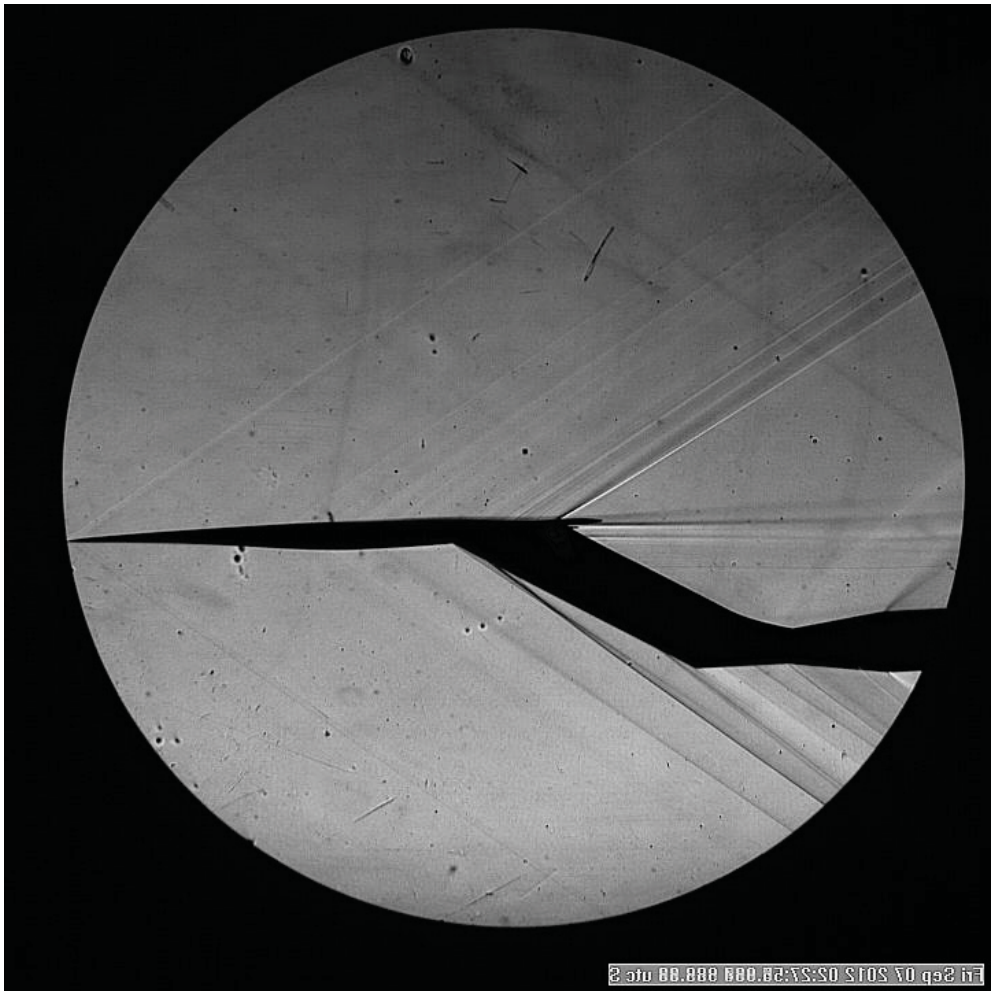
NASA Boeing Low Sonic Boom Test, Fall 2012



- Acoustic signature testing of a new low boom vehicle concept up to M=1.8
- Used high speed Schlieren data to visualize shock structures from vehicle
- 200 image bursts were averaged to provide “average” test condition image….eliminated background noise and enable low shock structures to stand out.

NASA Boeing Low Sonic Boom Test, Fall 2012

Averaged Image



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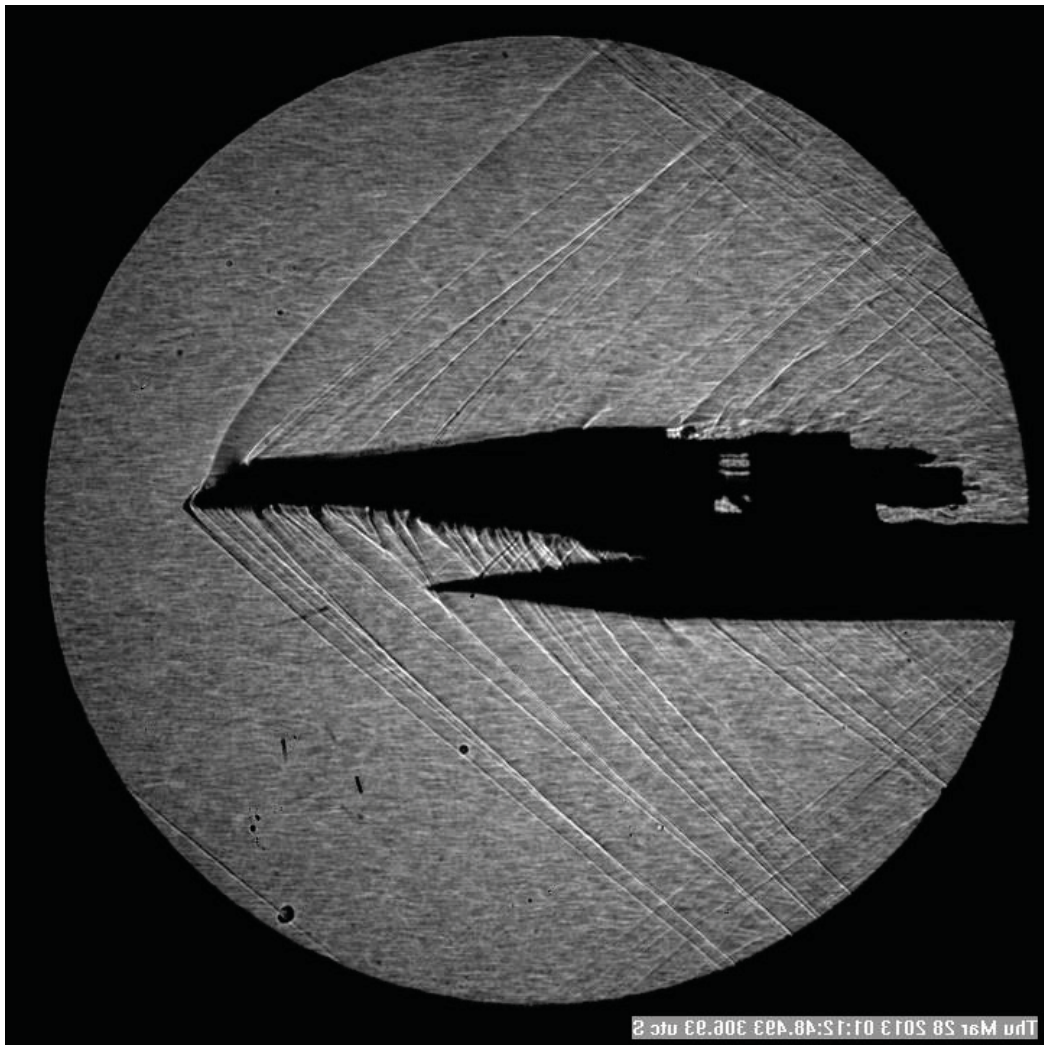
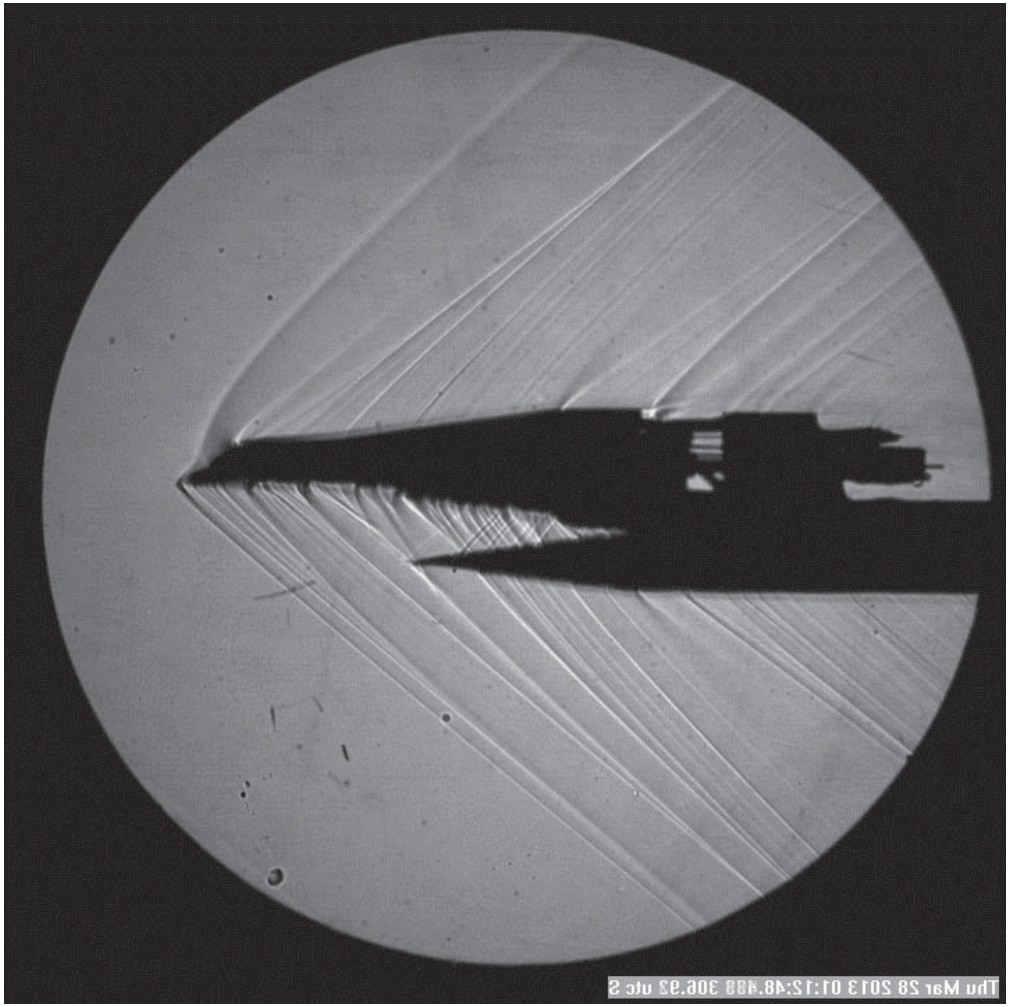
Boeing QEVC Propulsion Rig Test, March 2013



- Performance testing of a new low boom inlet concept up to M=1.8
- Used high speed Schlieren data to visualize shock structures and inlet unstart.
- Capture several inlet “unstart” conditions

Boeing QEVC Propulsion Rig Test, March 2013

Averaged Image



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- Used high speed Schlieren data to visualize shock structures and inlet unstart.
- Capture several inlet “unstart” conditions

Summary & Next Steps

- **8x6 Schlieren System has been upgraded**
  - Receiving optics
  - LED light source
  - New Knife Edge Technologies, Optical phase knife
  - High Speed Digital Video
- **Upgrade system successfully used to provide Schlieren imaging on 3 tests in the 8x6**
- **New window installation completed…finally!!**
- **Will continue work on turning Schlieren into a Quantitative measurement tool**
  - ASP IM Advanced Schlieren Task - Michelle Clem & Mark Woike