



# **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 2<sup>nd</sup> 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)

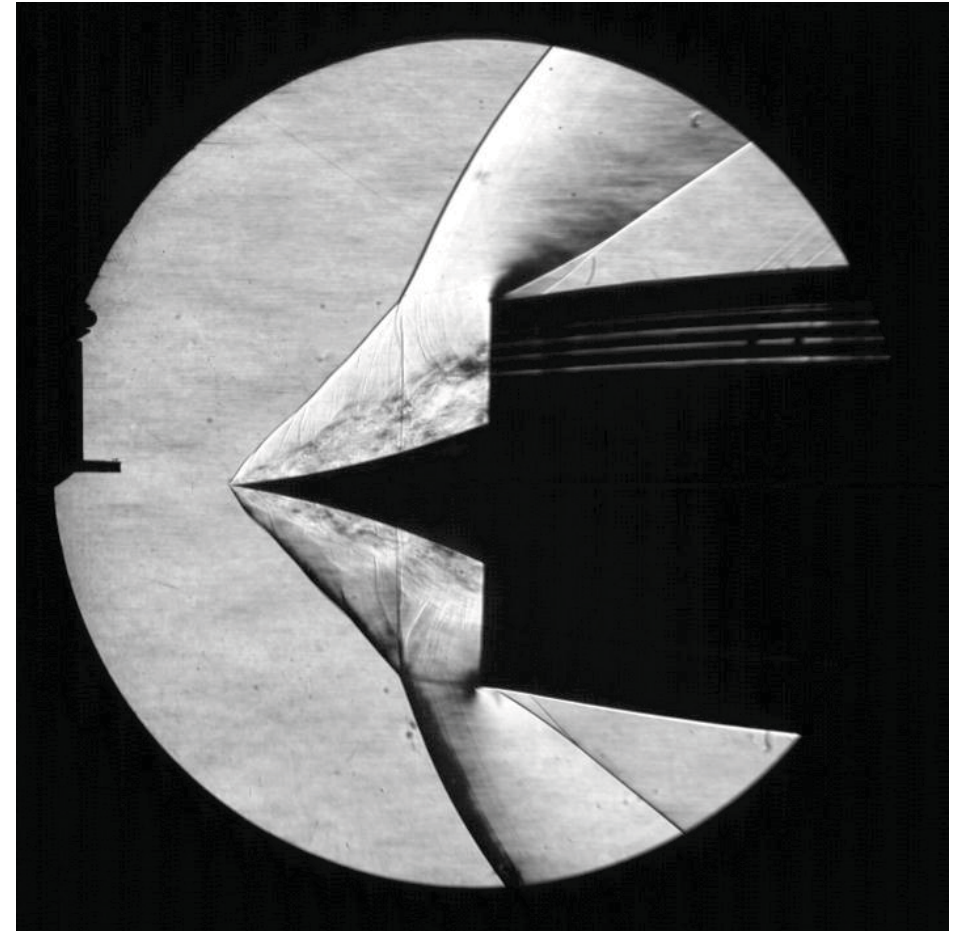
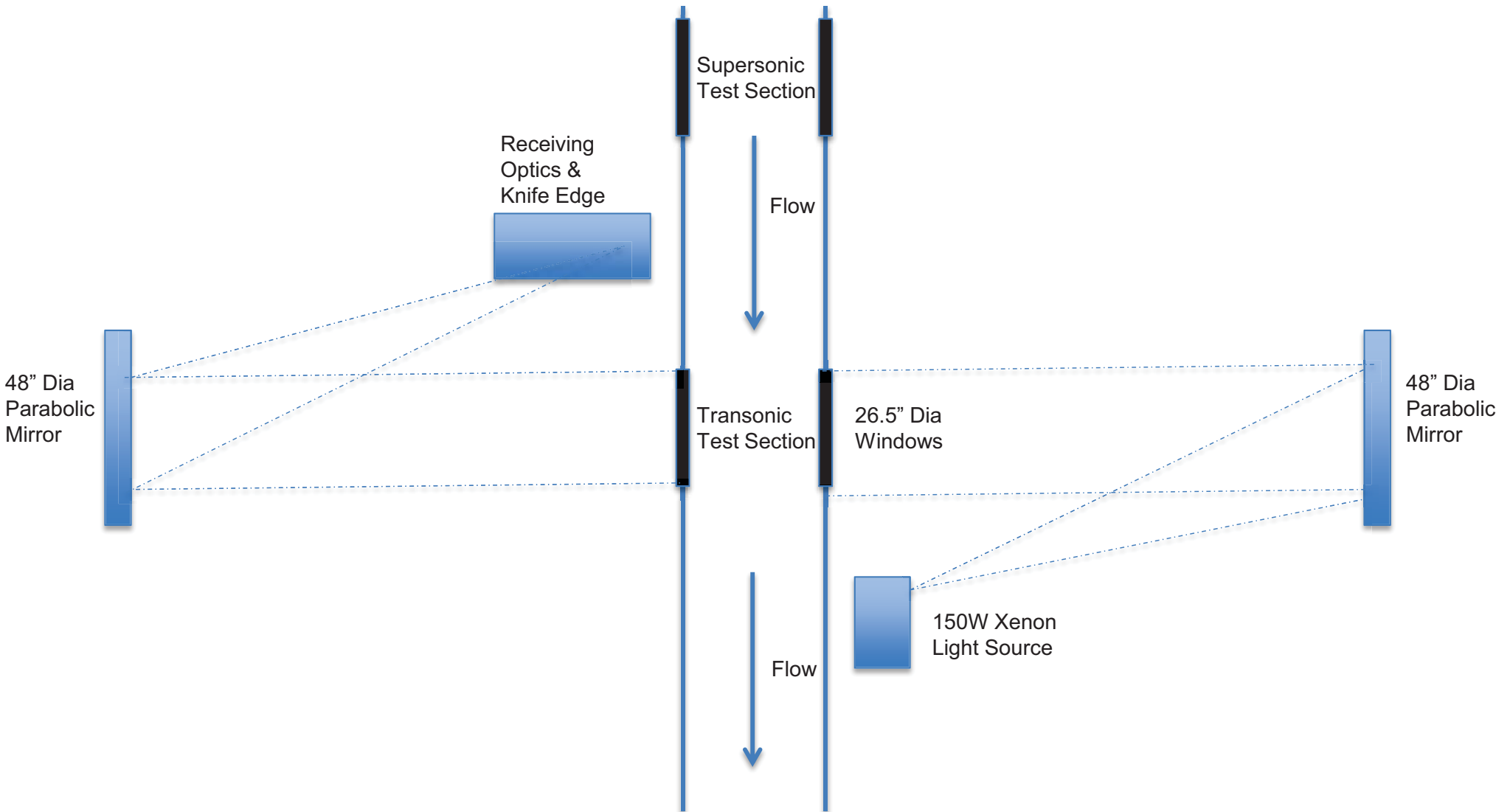


Image acquired from 8x6 Schlieren System " on Large Scale Low Boom Inlet test (Oct. – Nov. 2010) - Showing Inlet at "Buzz" condition.

# 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



Receiving Optics,  
Knife Edge & Camera  
Station

Supersonic  
Test Section

Flow



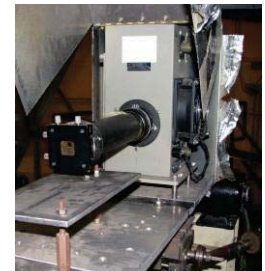
Transonic  
Test Section

26.5" Dia  
Windows

48" Dia  
Parabolic  
Mirror

Flow

150W Xenon  
Light Source

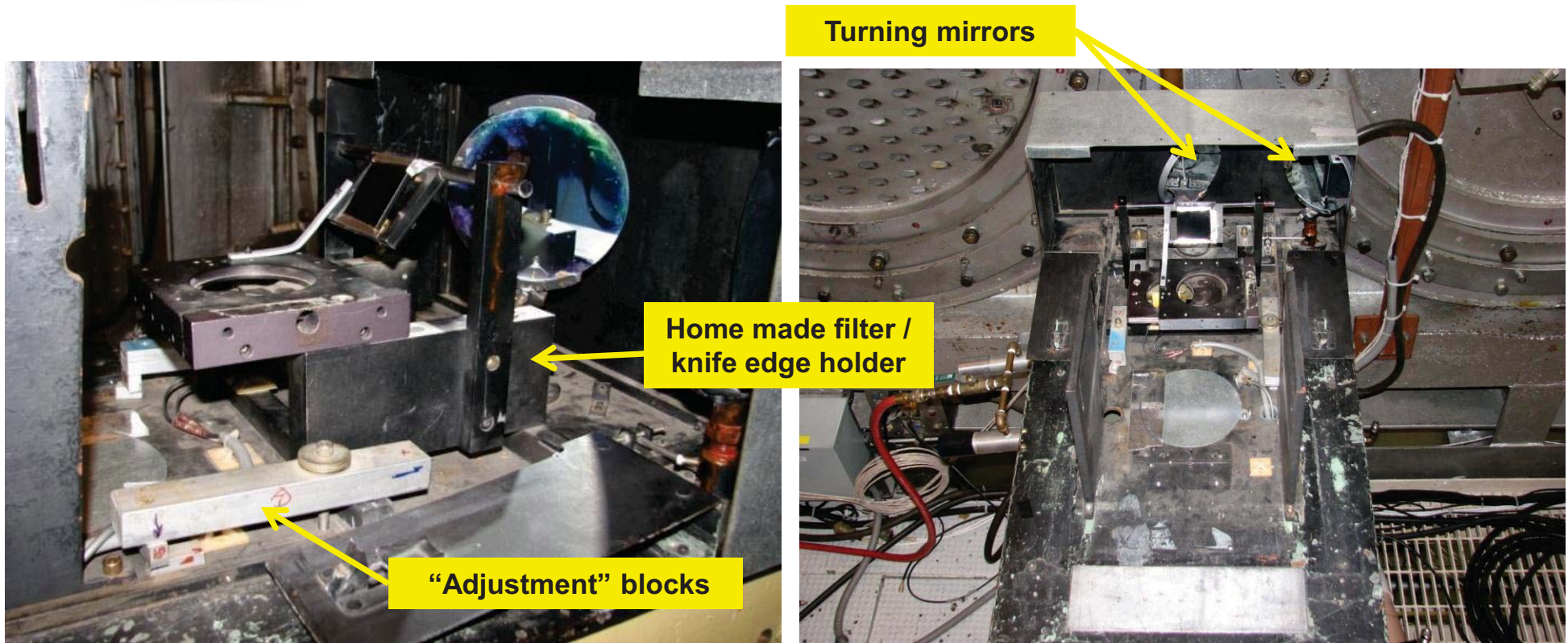


48" Dia  
Parabolic  
Mirror





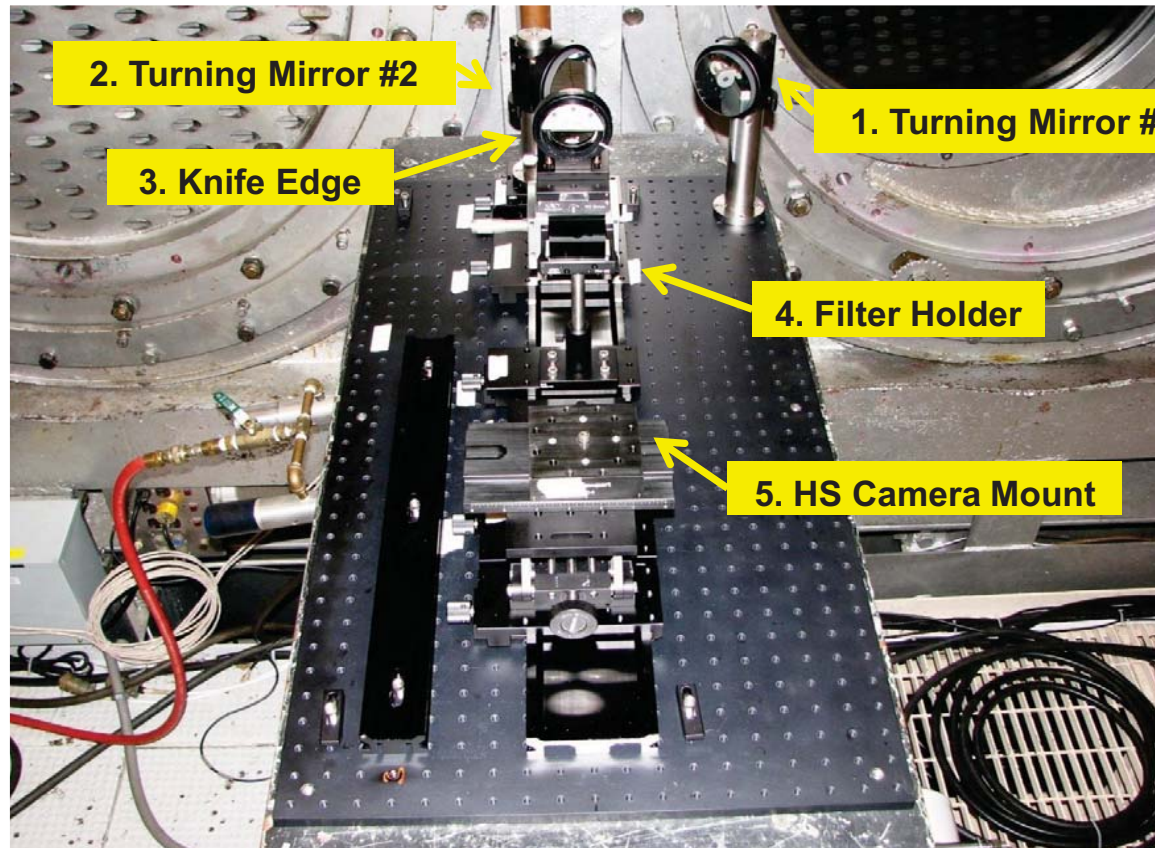
# 1. Receiving Optics – Pre Upgrade



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

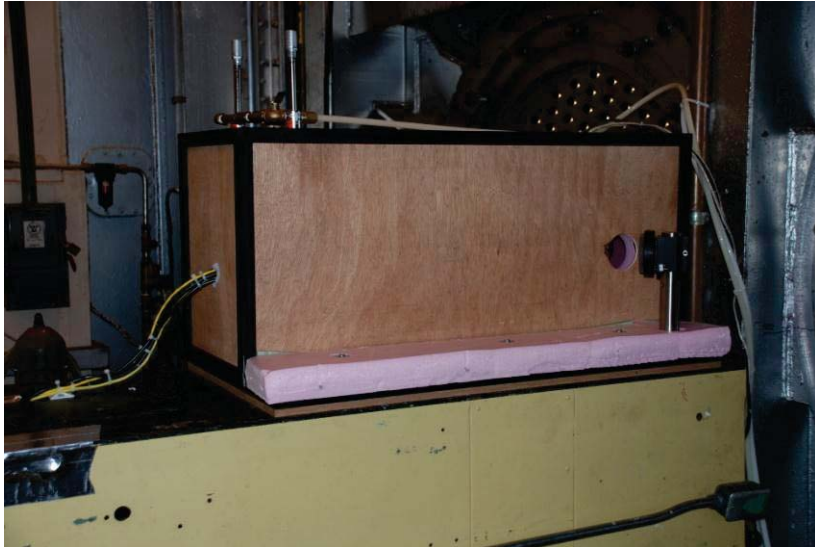


**New 8x6  
Schlieren  
Receiving  
Optics**

- 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

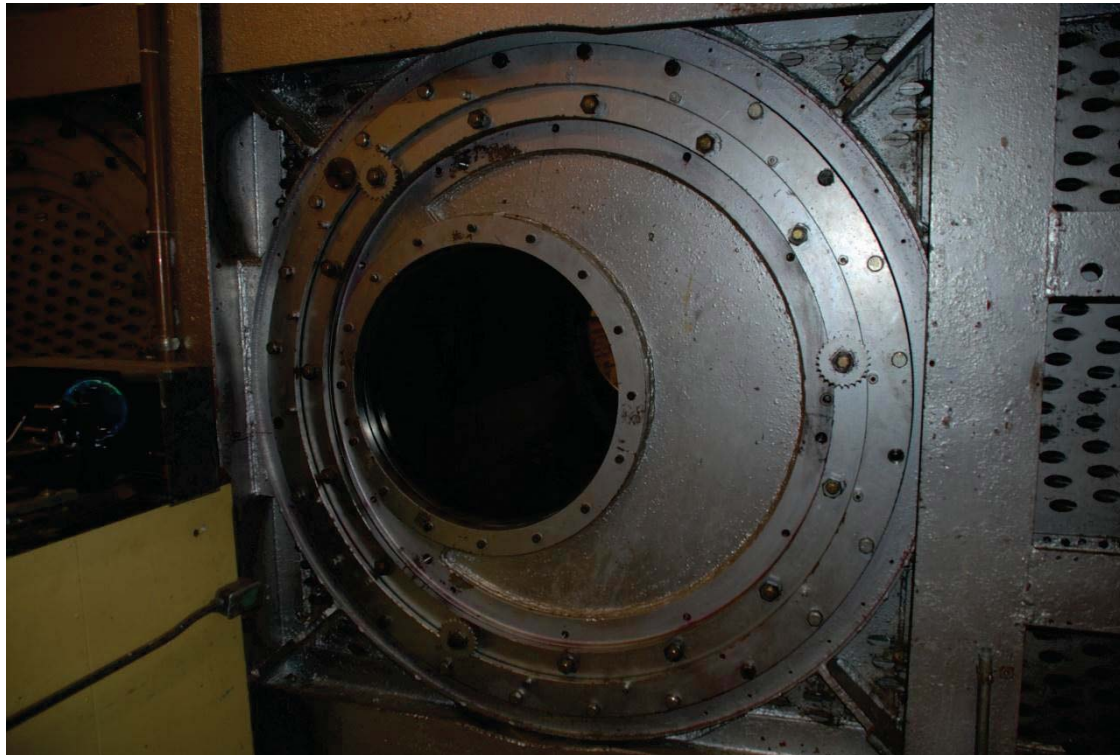
Phantom V310  
Installed in  
Schlieren  
System



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 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

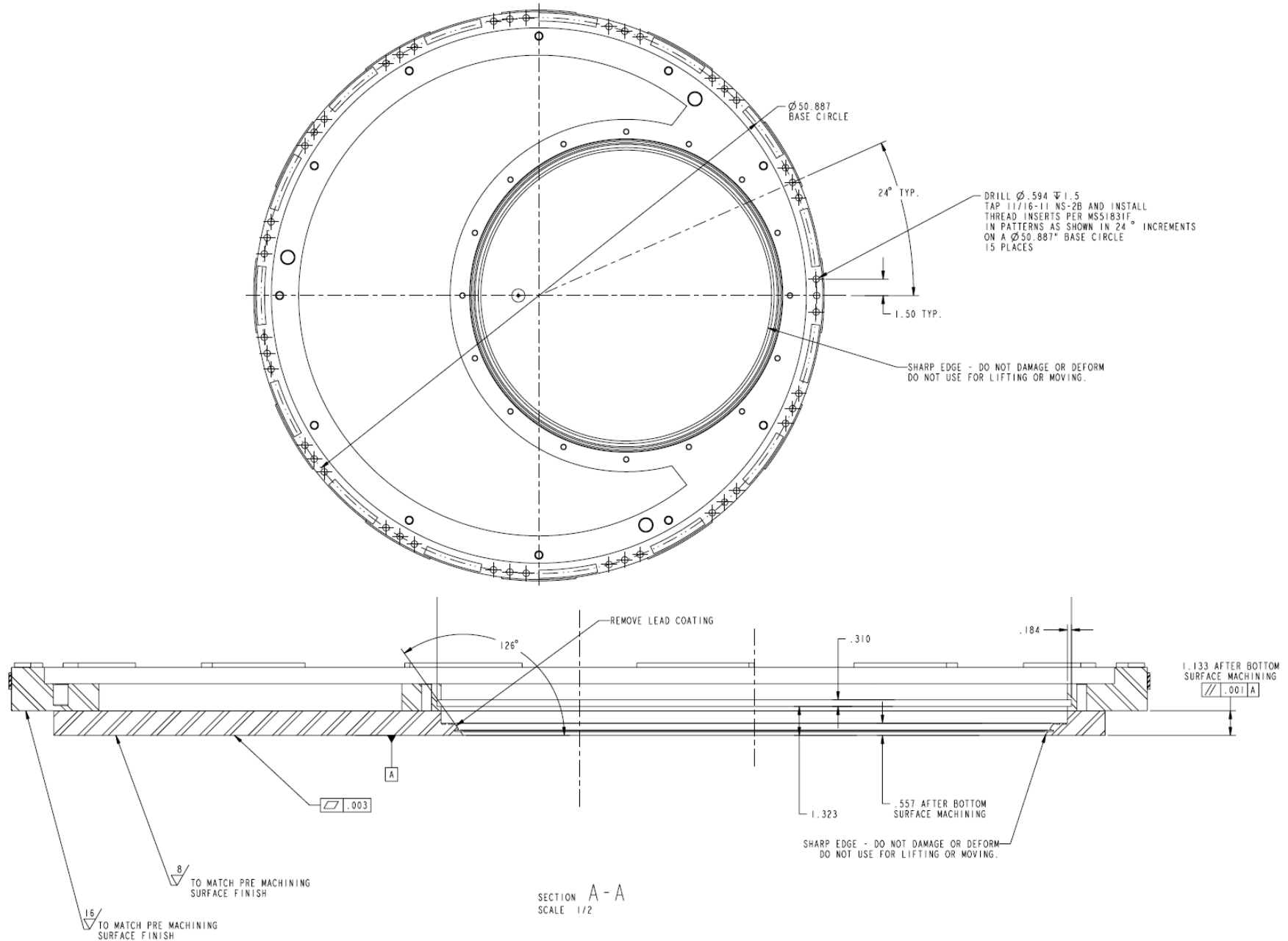


Existing Window Frame After Being Resurfaced

- 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



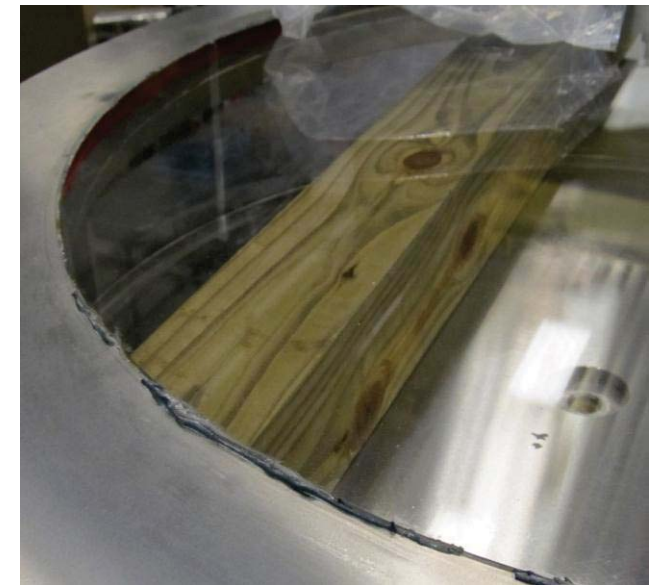


# 3. Window Installation - First Attempt and Results

- **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 cast 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. **...not trivial, spent some time evaluating candidate materials**
  - 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

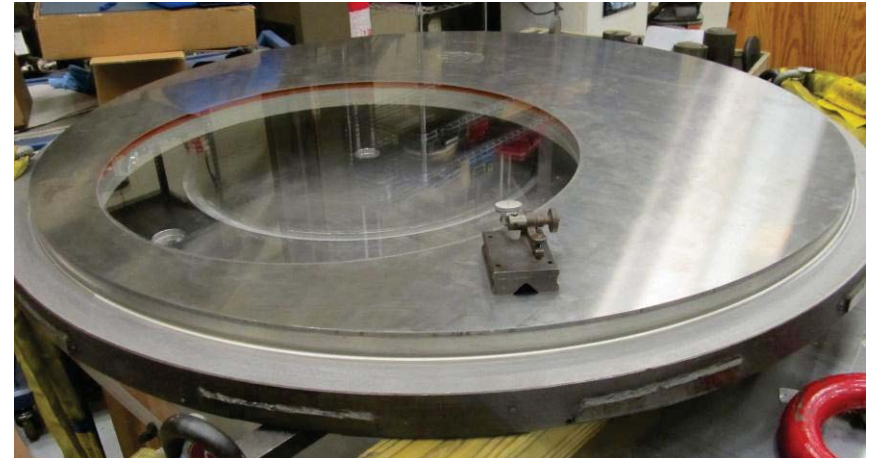


Seal Material Samples for Environmental Load Testing



# 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

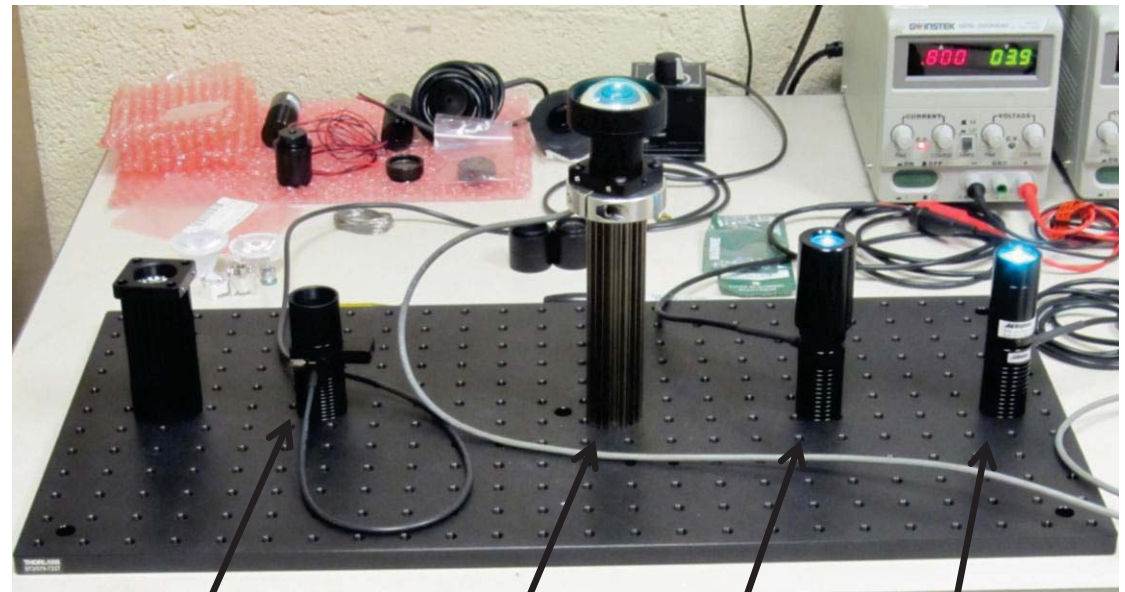
- Replaced 150W Xenon Light Source
  - Required large 48V, 6A power supply, needed to be co-located in test chamber with light source
  - Bulbs & 150W Xenon light source parts very expensive to replace.
- Implemented new LED technology
  - Provides ample lighting, relatively inexpensive
  - Requires 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



Thorlabs Mounted LED

“NASA Built” Unit using a Luxeon High Power LED

Mightex LED Precision Spot Light Source

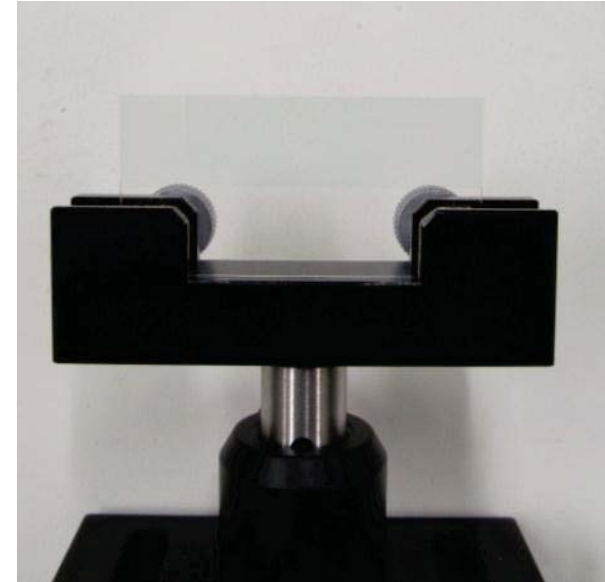
Mightex LED Collimator Light Source

## 5. New Knife Edges Technologies – Optical Phase Knives



**Standard Razor Blade Knife Edge**

- Investigating  $\frac{1}{2}$  wavelength phase knives
- Instead of blocking diffracted light, passes it through and shifts it  $\frac{1}{2}\lambda$ .....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**

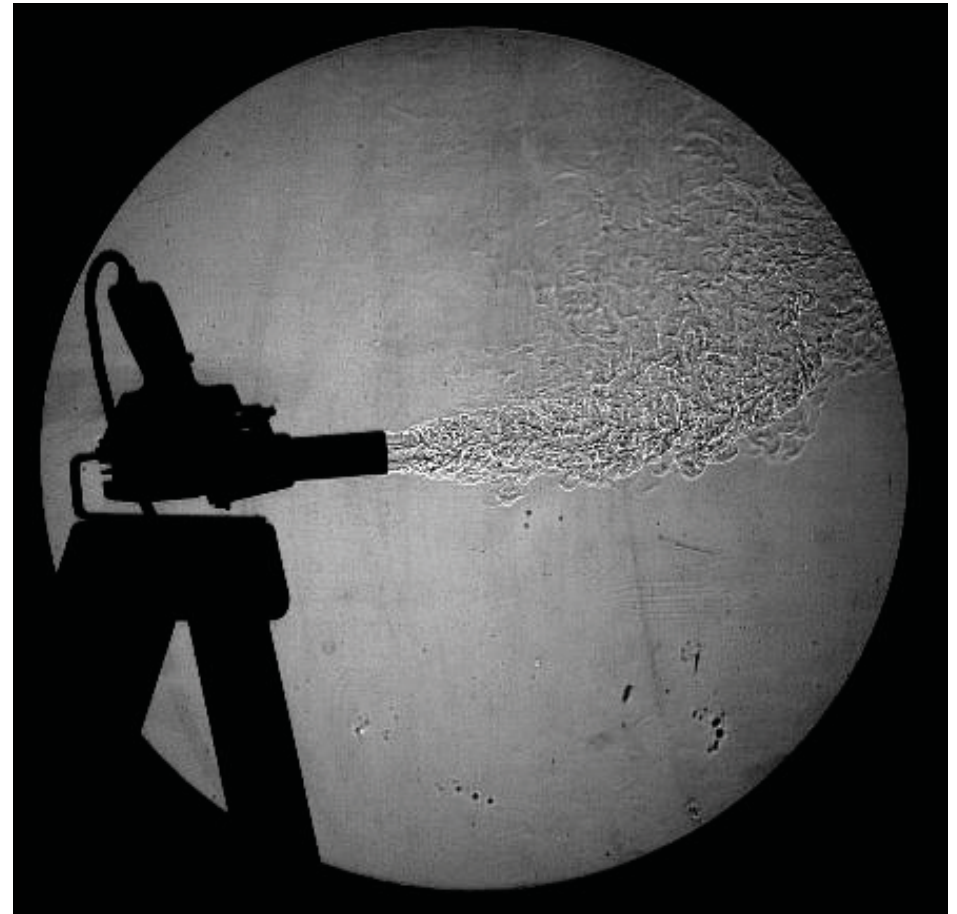
**Deposition Sciences Inc.  
3300 Coffey Lane  
Santa Rosa, CA 95403**

## 5. New Knife Edges Technologies – Optical Phase Knives

Standard “razor” knife edge



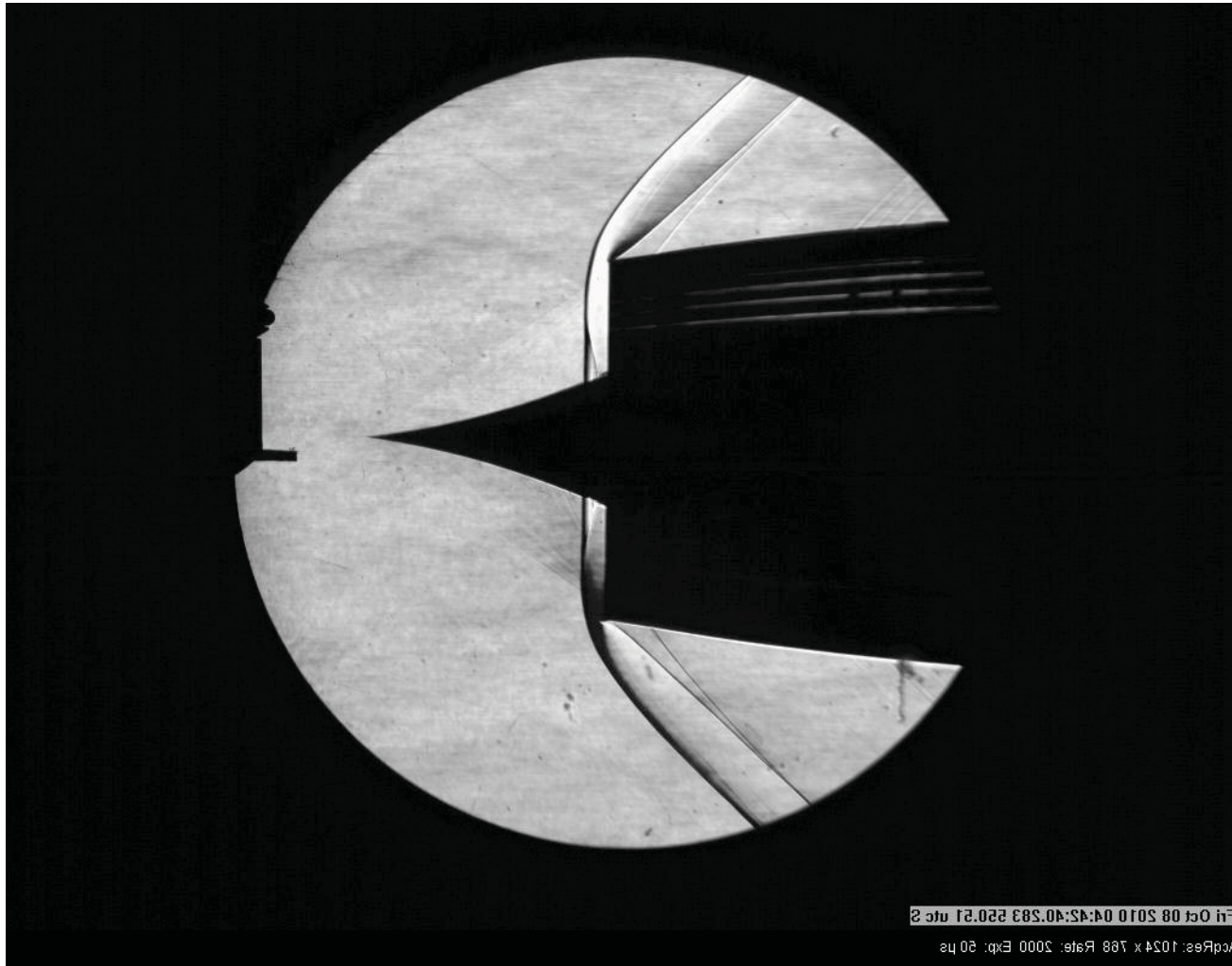
Optical phase knife edge



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



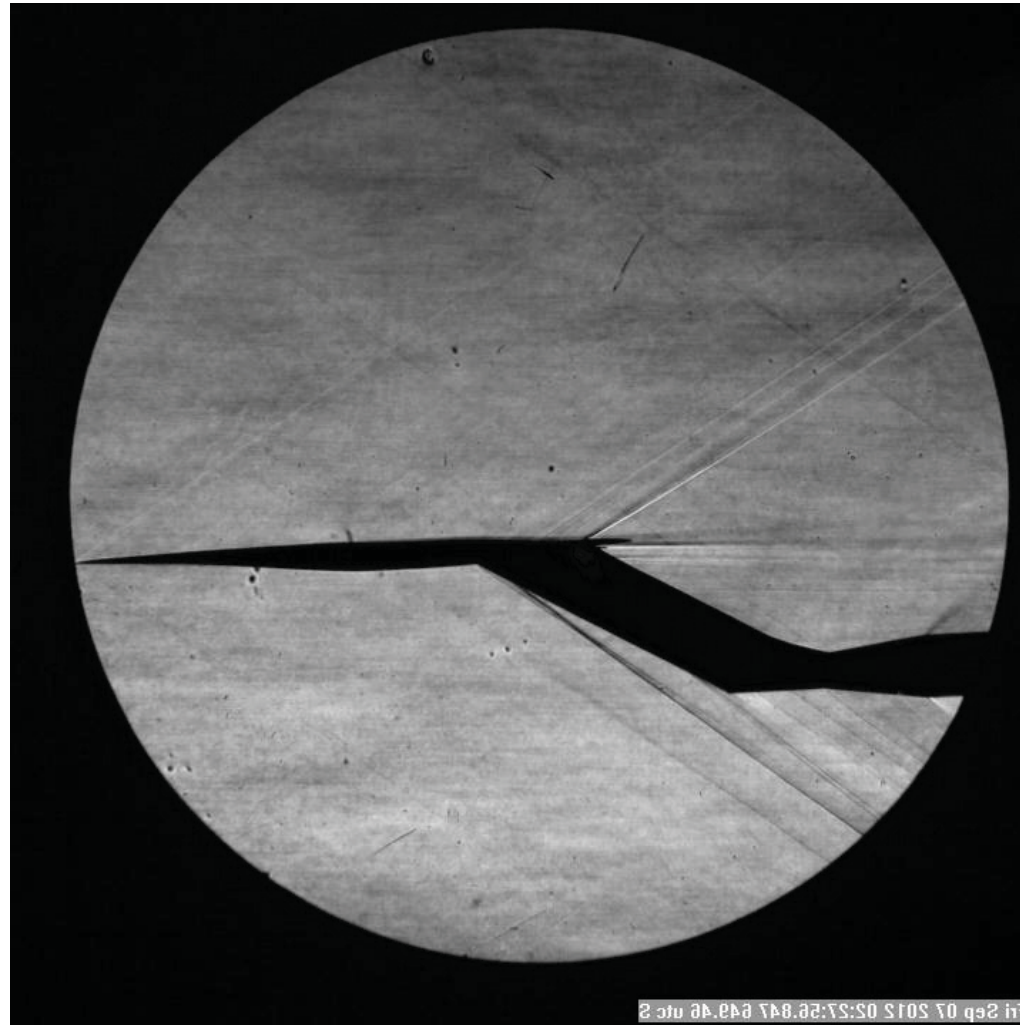
# Large Scale Low Boom Test, Fall 2010



- 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

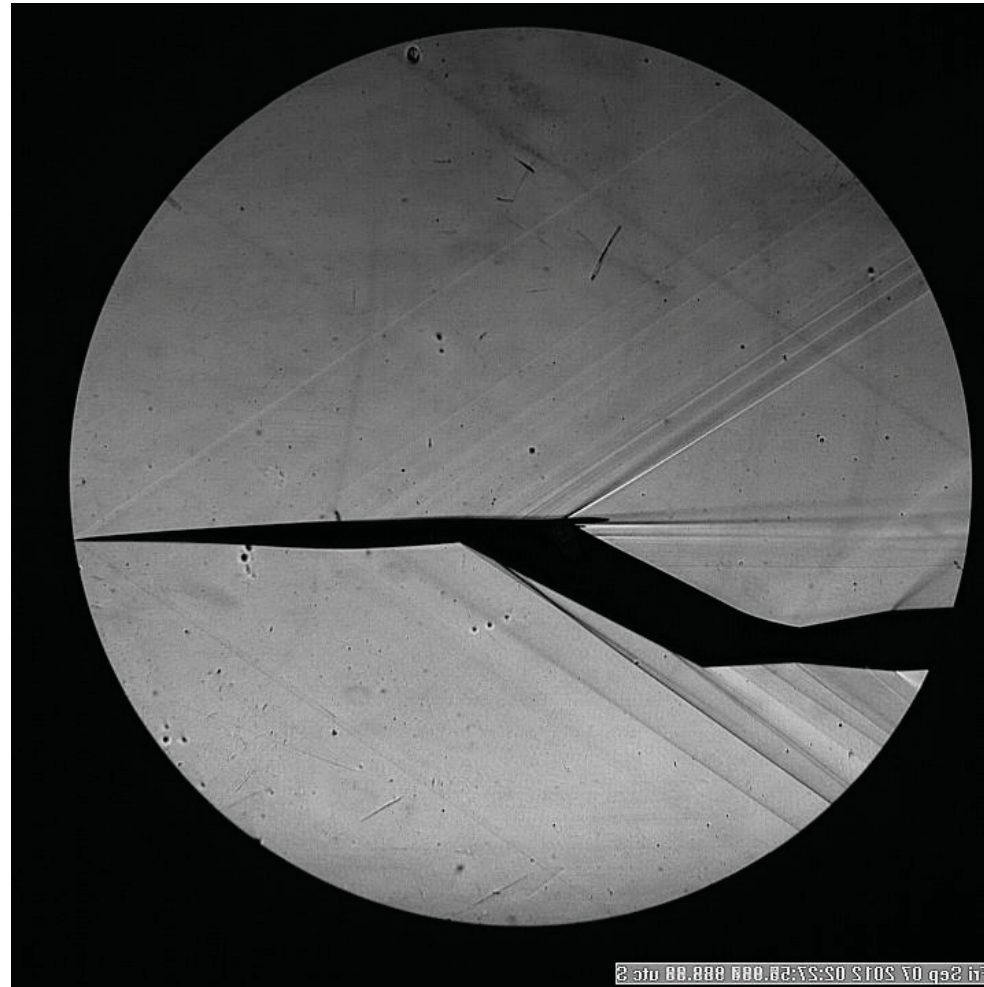


# NASA Boeing Low Sonic Boom Test, Fall 2012

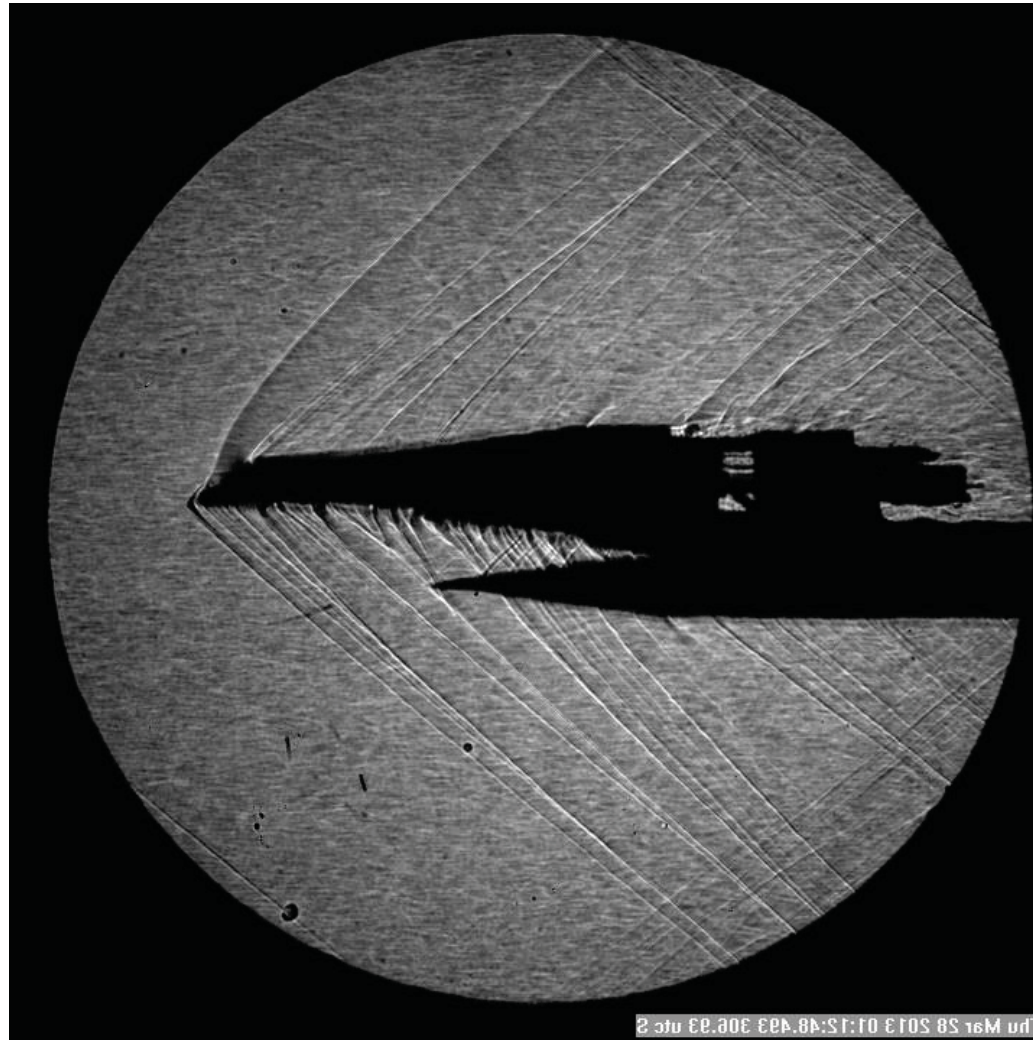


- Acoustic signature testing of a new low boom vehicle concept up to  $M=1.8$
- Used high speed Schlieren data to visualize shock structures from vehicle
- 200 image bursts were averaged to provide “average” test condition image....eliminated background noise and enable low shock structures to stand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

**Averaged  
Image**



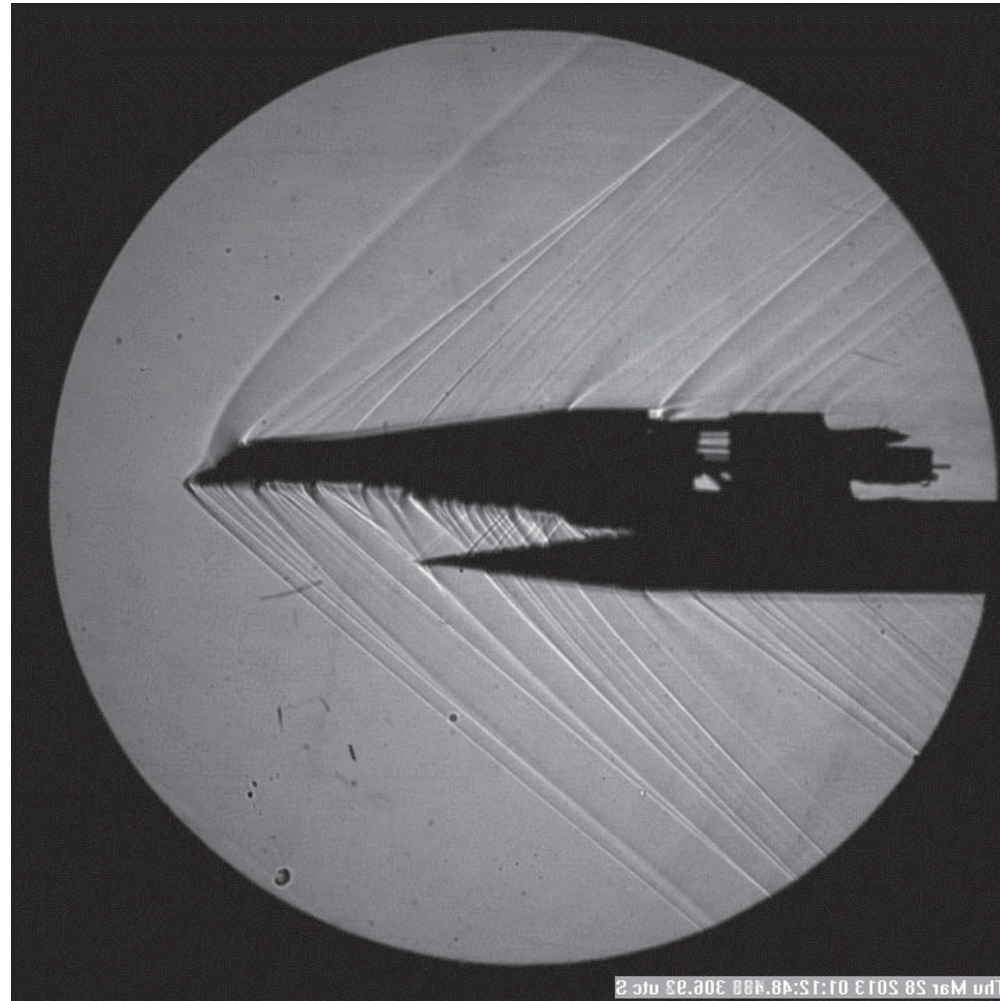
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- Performance testing of a new low boom inlet concept up to  $M=1.8$
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- Capture several inlet “unstart” conditions



**Averaged  
Image**



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# 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