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Development of a Large Field of View Shadowgraph System for a 16 Ft. Transonic Wind Tunnel

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September 2000

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Contents

List of Figures

ABSTRACT

A large field of view shadowgraph flow visualization system for the Langley 16 ft. Transonic Tunnel (16 ft.TT) has been developed to provide fast, low cost, aerodynamic design concept evaluation capability to support the development of the next generation of commercial and military aircraft and space launch vehicles. Key features of the 16 ft. TT shadowgraph system are: 1)high resolution (1280 X 1024) digital snap shots and sequences; 2) video recording of shadowgraph at 30 frames per second; 3) pan, tilt, & zoom to find and observe flow features; 4) one microsecond flash for freeze frame images; 5) large field of view approximately 12' X 6'; and 6) a low maintenance, high signal/noise ratio, retro-reflective screen to allow shadowgraph imaging while test section lights are on.

1.0 INTRODUCTION

This paper discusses the development of a large field of view shadowgraph flow visualization system for the Langley 16 ft. Transonic Tunnel (16 ft.TT). Topics discussed include: needs analysis; description of the shadowgraph system; and tests & results.

This work was funded by the Wind Tunnel Enterprise primarily to provide fast, low cost, aerodynamic design concept evaluation capability to support the development of the next generation of commercial and military aircraft and space launch vehicles. This may include research and development with passive porosity, synthetic jets, blowing, integrated sensor/actuator/controller surfaces, designer materials for noise control, and other techniques where novel control approaches are used.

2.0 NEEDS ANALYSIS

2.1 Features Needed

The main features desired by users are visualization of flow structure and spatial distribution of flow features within a field of view up to 9 ft. wide by 5 ft. high. To obtain adequate detail for a field of view this large, high resolution and high contrast images will be needed. Additional desired features include: a) ability to take digital snap shots and sequences and continuously record video to VHS tape from the 16 ft.TT control room; b) ability to include test parameters with images such as test title, time & date, Mach number, temperature, dynamic pressure, etc.; c) non-intrusive to the flow; d) cost effectiveness; e) little or no impact on productivity, f) easy maintenance; and g) ability to accommodate other test techniques.

2.2 Constraints on the Shadowgraph System

The shadowgraph cameras and light source packages must be installed outside of the test section plenum to avoid excessive vibrations and temperatures that occur while the tunnel is running. Optical access must be through the plenum and test section windows. A low maintenance, high signal/noise ratio retro-reflective screen will need to be applied to the far side test section wall approximately 30 ft. from the camera. A field of view of approximately 9 ft. by 5 ft. at the center of the test section will require the screen to be 12 ft. wide by 6.5 ft. high. The computer used for digital image acquisition, VHS tape recorder, and all system controls must be located in the control room. A generic shadowgraph configuration that meets these constraints is shown in **Figure 1**.

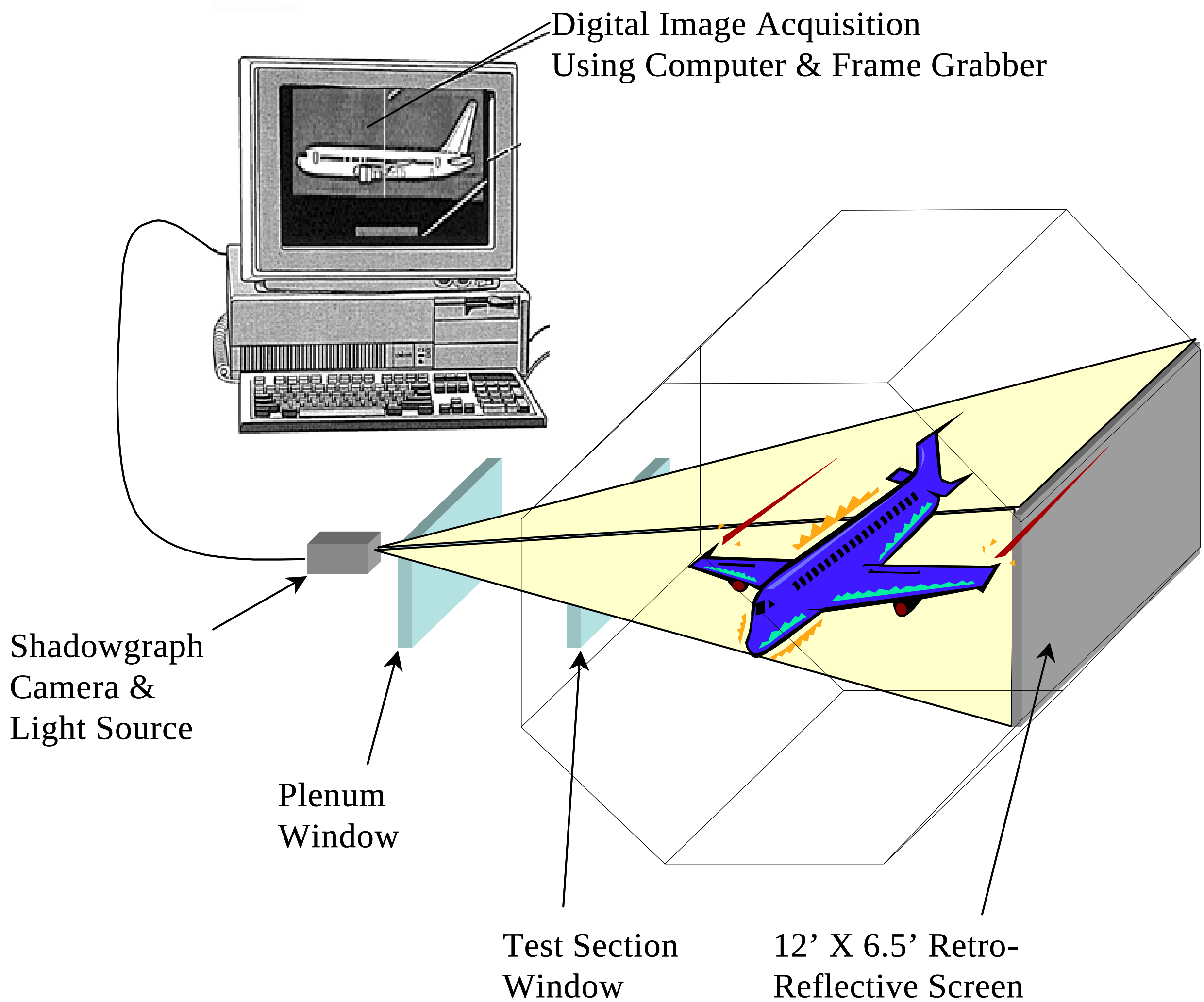

Figure 1. Shadowgraph configuration at 16 ft. TT.

4.0 DESCRIPTION OF SHADOWGRAPH SYSTEM

Key features of the 16 ft. TT shadowgraph system are: 1)high resolution (1280 X 1024) digital snap shots and sequences[1]; 2) video recording of shadowgraph at 30 frames per second; 3) pan, tilt, & zoom for scanning flow features; 4) one microsecond flash[2] for freeze frame images;

5) large field of view approximately 12' X 6'; and 6) a low maintenance, high signal/noise ratio, retro-reflective[3] screen to allow shadowgraph imaging while test section lights are on. The optical layout of the system is shown in **Figure 2** and the layout of the light source and camera is shown in **Figure 3**.

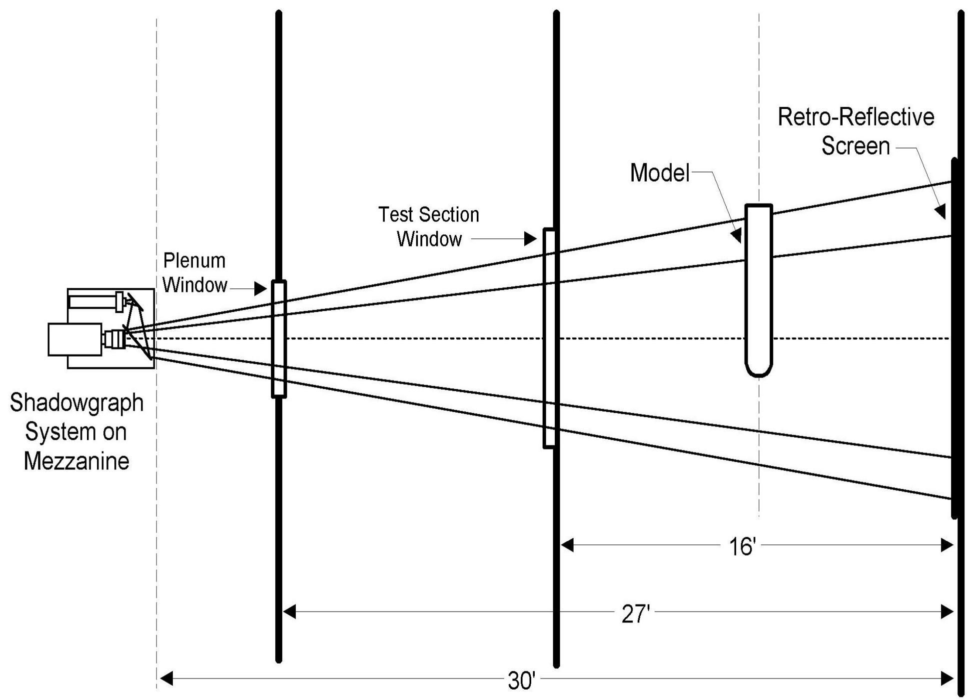

Figure 2. Optical Layout of shadowgraph system at 16 ft. TT.

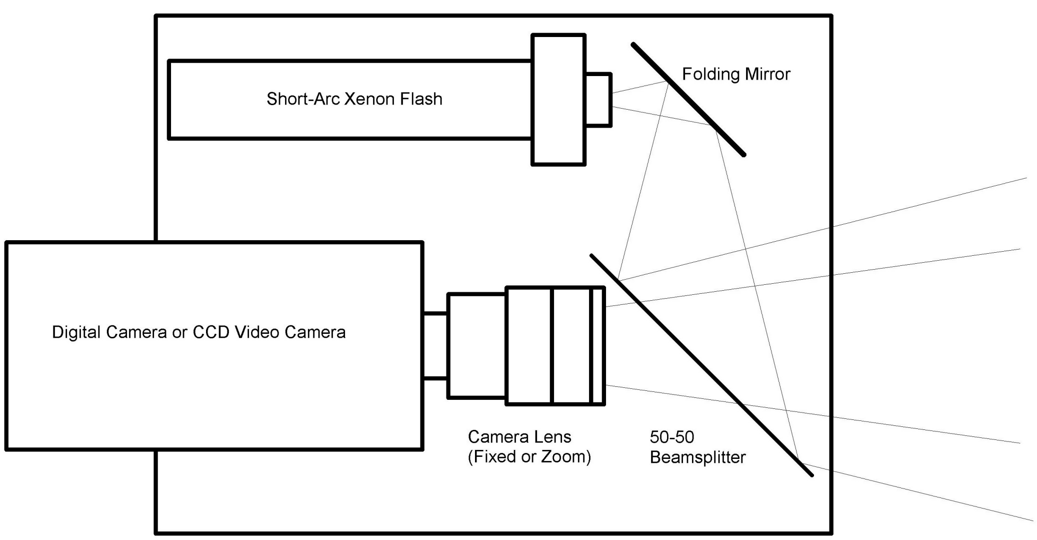

Figure 3. Layout of light source and camera.

Block diagrams showing components of the digital and 30 frame per second video systems are shown in **Figure 4** and **Figure 5** respectively.

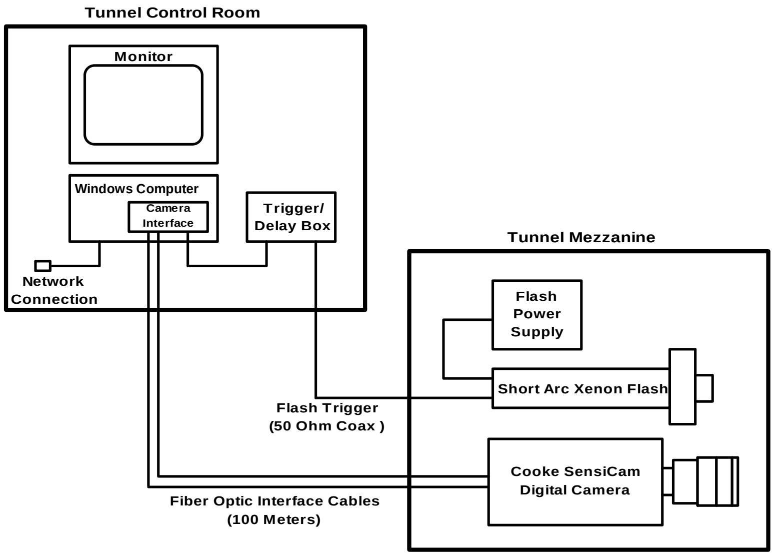

Figure 4. Digital shadowgraph system.

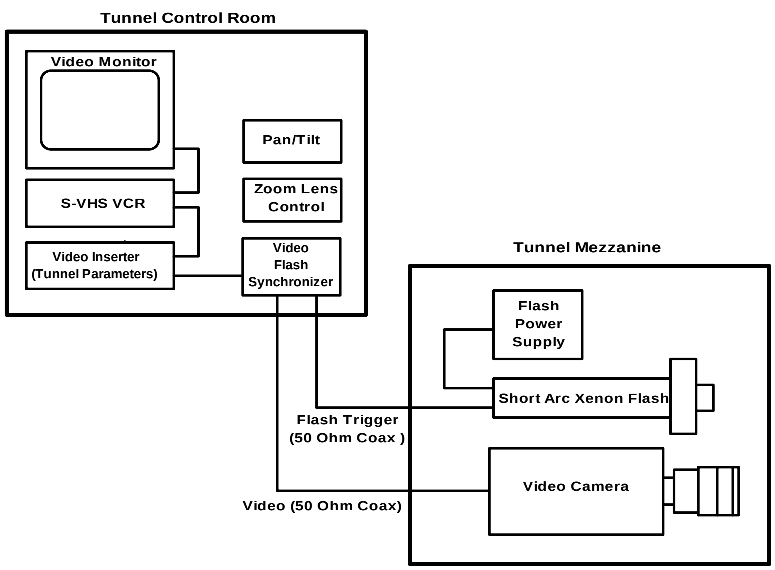

Figure 5. 30 frame pers second video system.

A picture of the image acquisition station in the control room is shown in **Figure 6**.

Figure 6. Control room image acquisition station.

A rear view of the camera and light source setups looking through the plenum and test section windows is shown in **Figure 7**. A close-up picture of the high resolution digital camera and light source setup is shown in **Figure 8**.

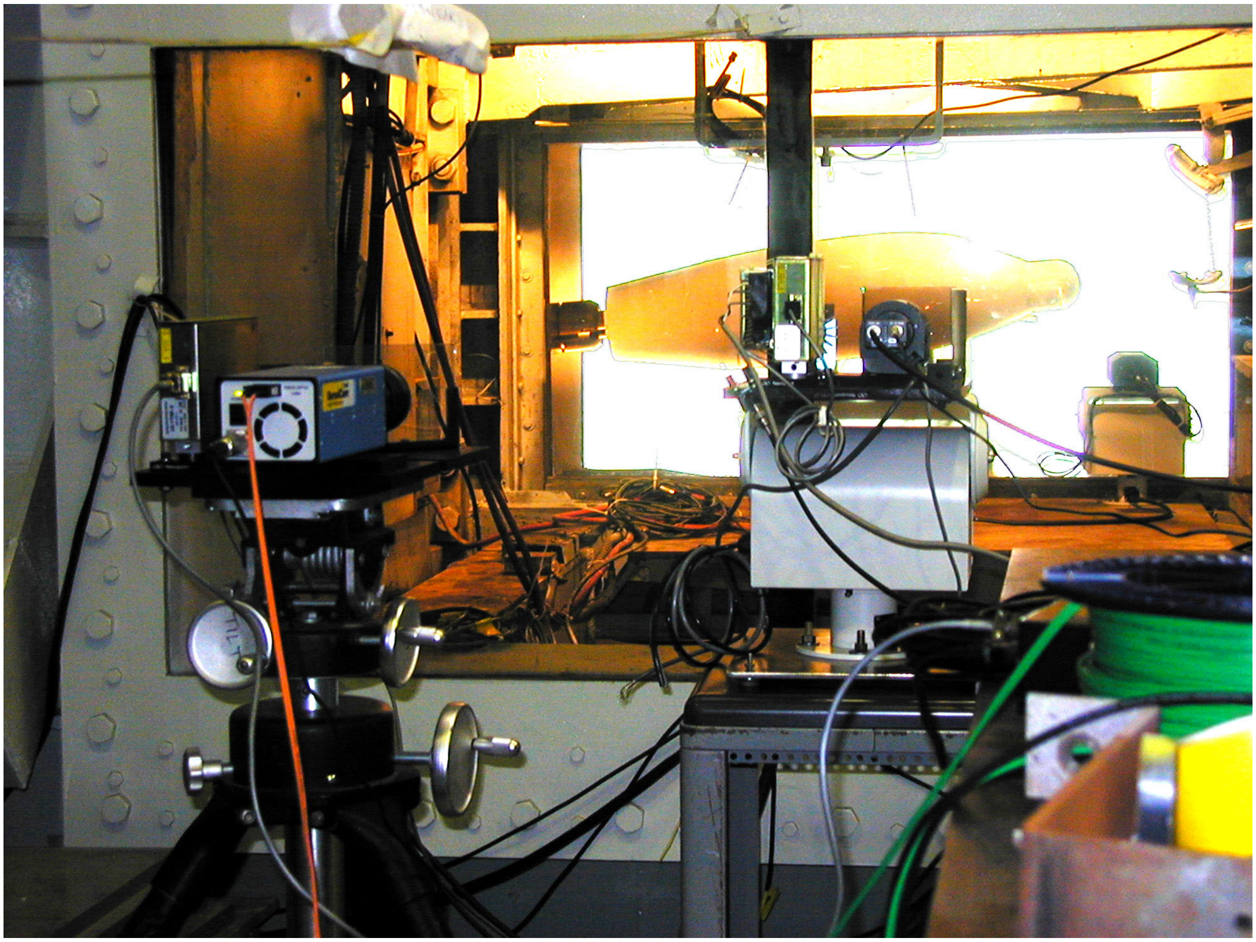

Figure 7. Rear view of cameras and light sources looking into test section.

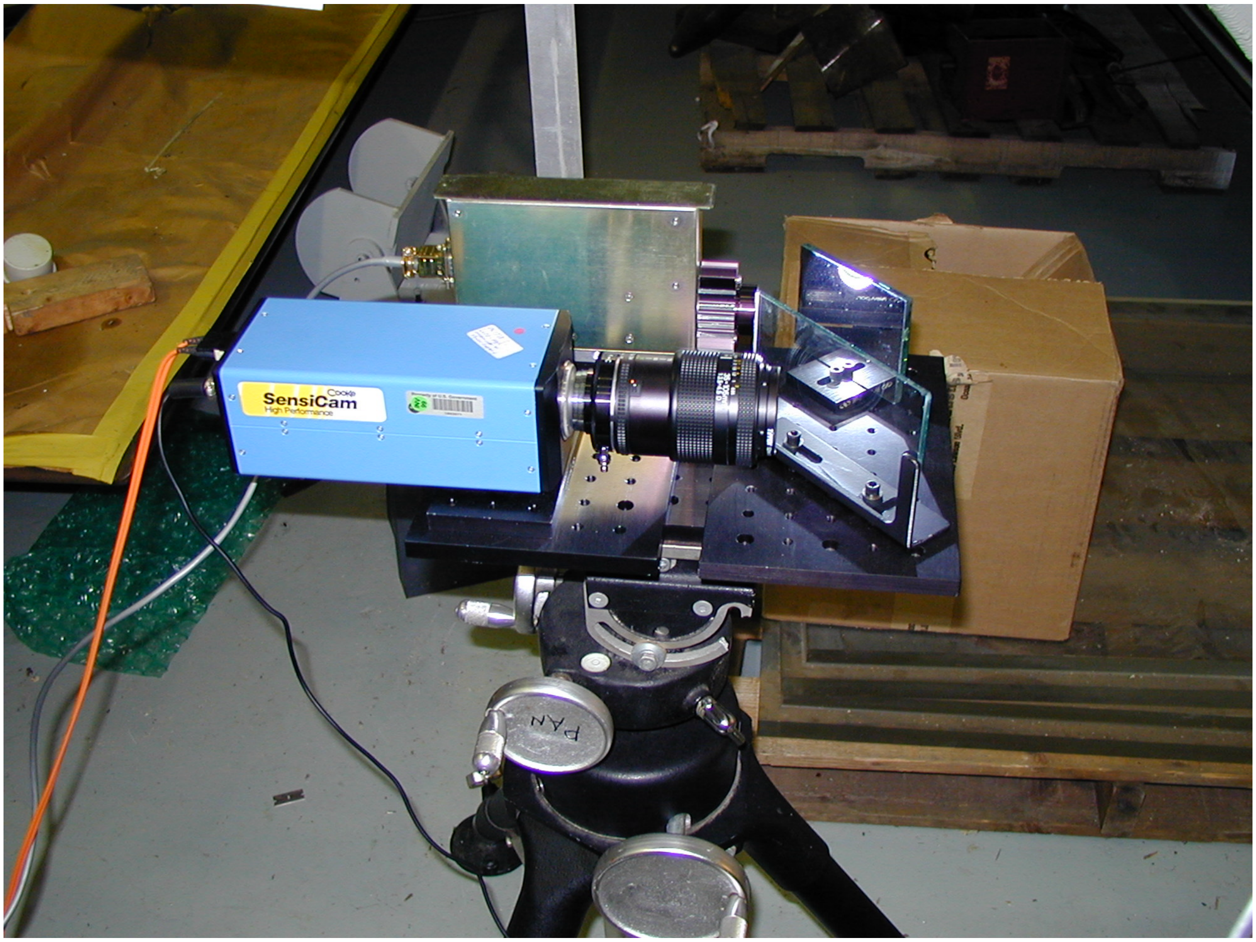

Figure 8. High resolution digital camera and light source setup.

5.0 TESTS & RESULTS

5.1 Lab Tests

The digital and video shadowgraph systems were tested in the lab using a complete mock-up of the 16 ft. TT optical layout. **Figure 9** shows a shadowgraph image of flow from a heat gun acquired from the digital camera at a resolution of 1280 X 1024. The heat gun was 22 ft. from the camera and the reflexite screen was 30 ft away. The field of view was 50 in. high corresponding to an image resolution just under 0.05 in. per pixel.

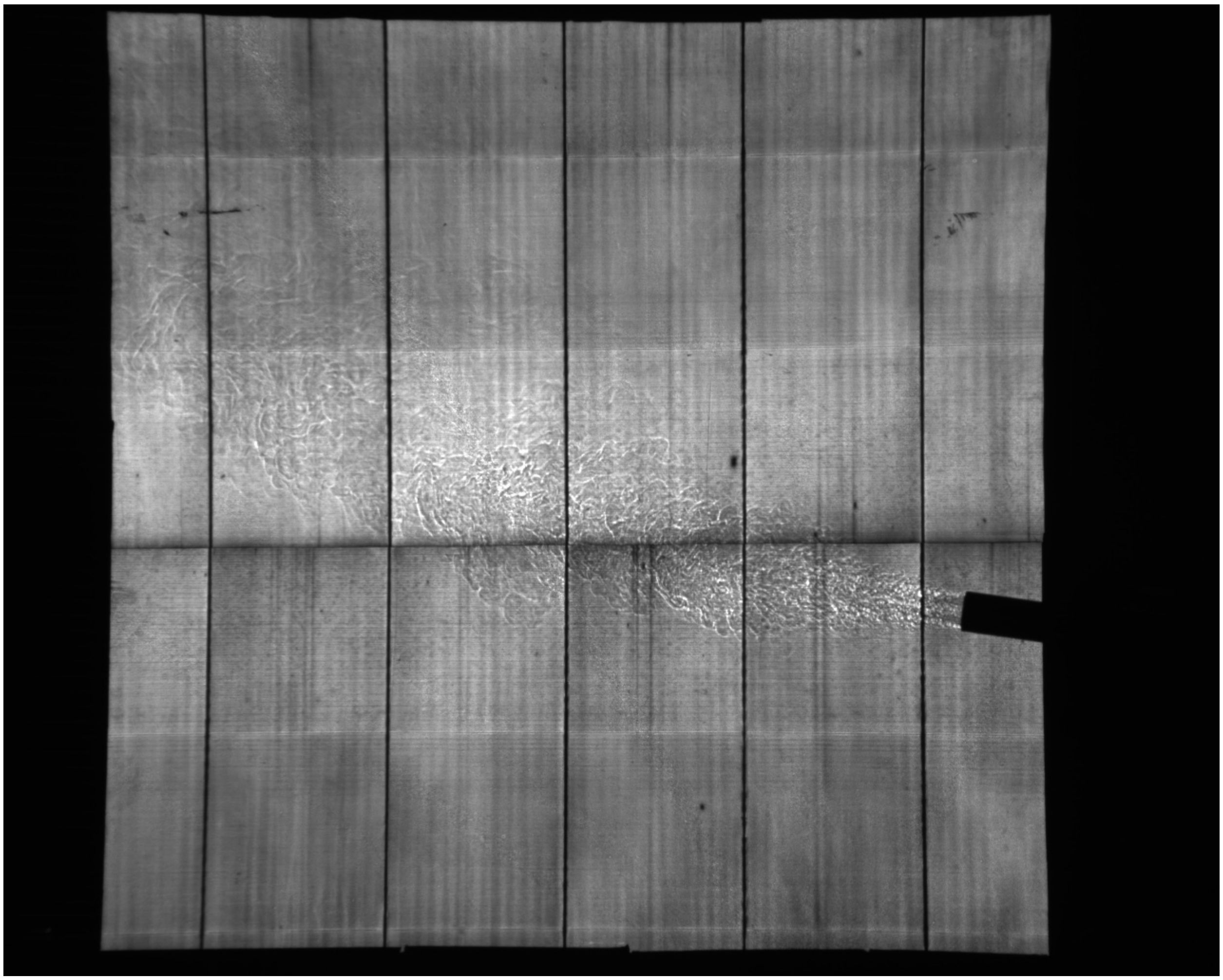

Figure 9. Digital image of flow from heat gun using a 4 ft. X 4 ft. Reflexite screen.

Figure 9 was enhanced by subtracting a background image in which the heat gun was removed. The result is that more flow detail can be seen as shown in **Figure 10**. This

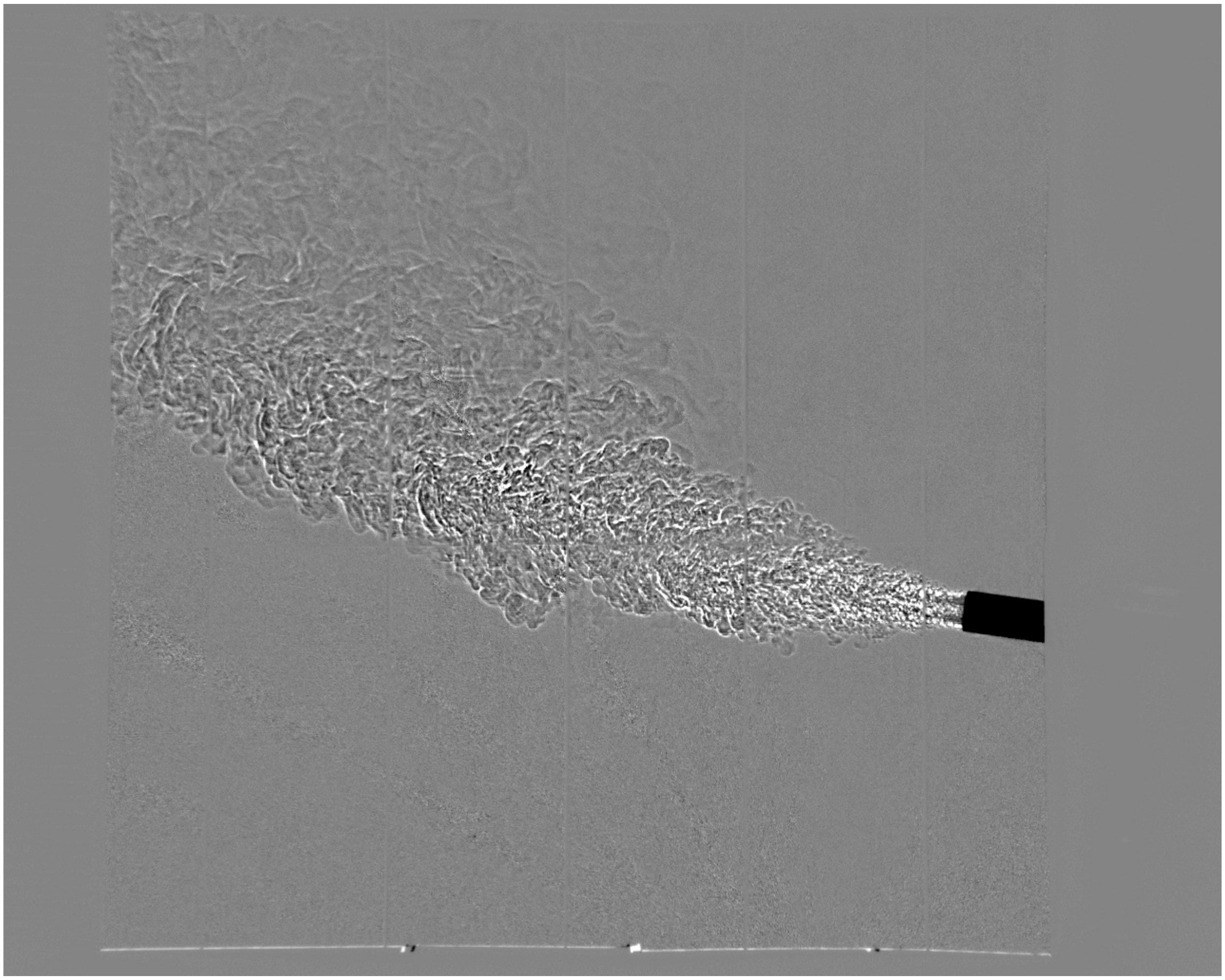

Figure 10. Heat gun flow after background subtraction.

enhancement technique provides significant improvement, however, the location of the retro-reflective screen must stay fixed relative to the shadowgraph camera.

5.2 Tests to Assess Background Subtraction Technique

Background subtraction was not possible due relative displacement of the test section wall with respect to the shadowgraph camera location. Horizontal relative displacements of 3 targets (X1, X2, and X3) on the test section wall were measured from the shadowgraph camera location using video photogrammetry. Over 700 data points were taken over an operational range of Mach 0 to Mach 1.2 where the tunnel air temperature ranged from 65F to 170F. The displacement for each target at each data point is plotted with respect to the air temperature as shown in **Figure 11**. Measured vertical displacements were insignificant.

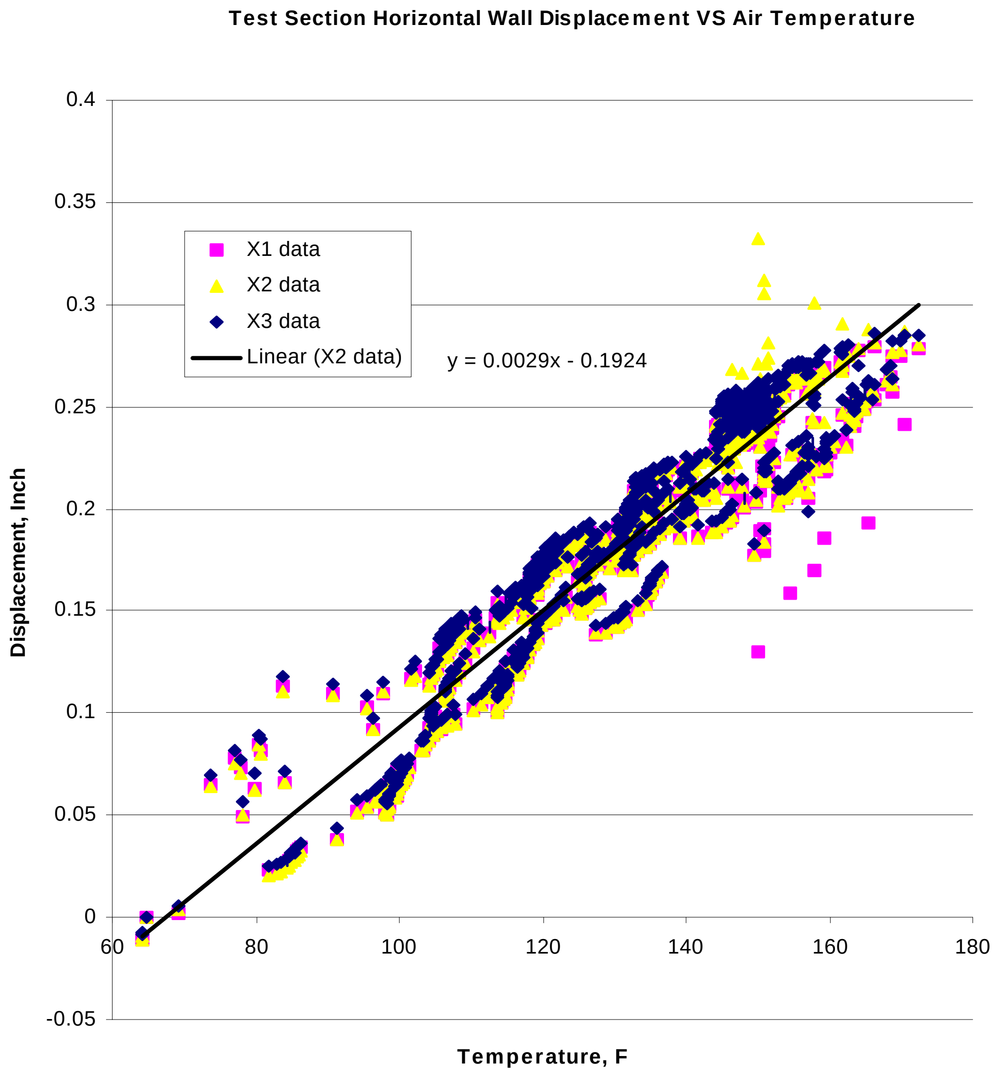

Figure 11. Test section horizontal wall displacement versus temperature.

5.3 Aerodynamic Tests in the 16 ft. TT

Use of shadowgraph measurement technique during Boeing Airborne Laser Test 534 at 16 ft. Transonic Tunnel made it possible to successfully evaluate flow control improvements in an attempt to eliminate unsteady shocks on a laser turret. This was possible due to the visualization of flow features associated with different aerodynamic configurations of the laser turret cover plates. **Figure 12** shows the laser turret and location of cover plates. Test results from three plate configurations which demonstrate different flow features have been selected for discussion. These are: the baseline plates; plates with 15% porosity and 1/4 in. plenum depth; and plates with 25% porosity and 1/2 in. plenum depth. The 25% porosity plates were partially covered with Patch 1 as shown in the figure.

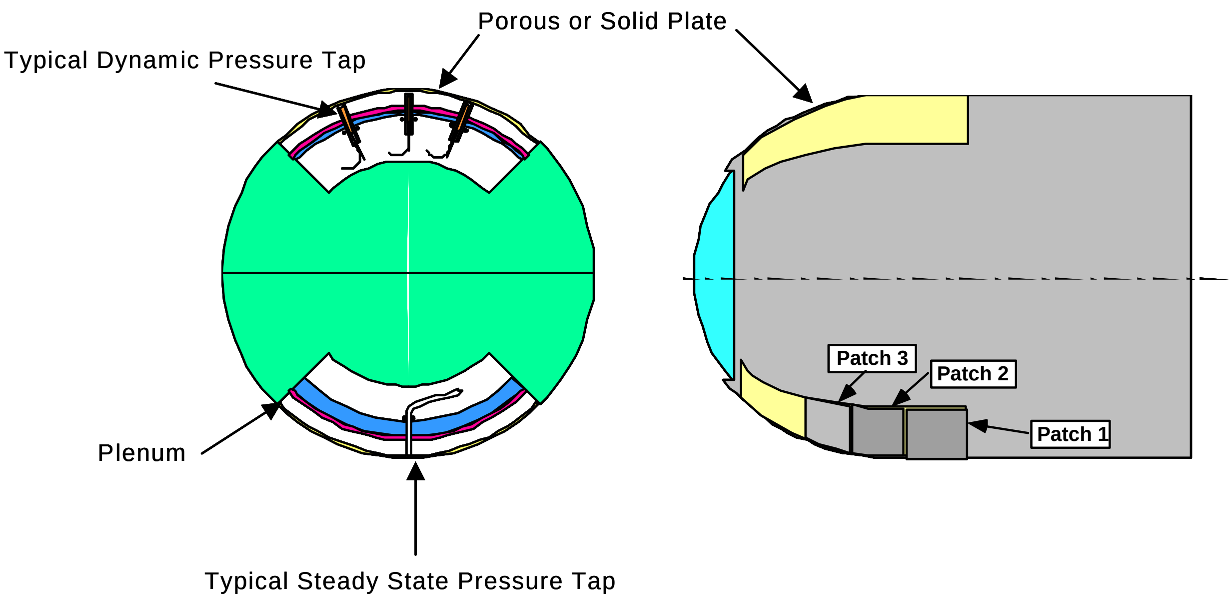

Figure 12. Location of cover plates and plenums on Laser turret.

As an alternate means of enhancement, an average of a sequence of 10 images for each data point was subtracted from a single image. This provided enhancement of the dynamic features in the flow. Table 1 summarizes the 3 configurations, notable flow features associated with each configuration, and the corresponding figures that show the features.

Table 1

Turret Plate Configuration	Test Conditions	Notable flow features	Images Showing Features
Baseline - no porosity	Mach=0.78 Alpha=5.2 Beta=3.0	Unsteady lambda shock followed by recirculating turbulent flow below a low angle free shear layer	**Figure 13** & **Figure 14**
15% Porosity with 1/4 in. Plenum	Mach=0.76 Alpha=5.2 Beta=0.0	Recirculating turbulent flow below a high angle free shear layer - no lambda shock formation	**Figure 15** & **Figure 16**
25% Porosity (Patch 1) with 1/2 in. Plenum	Mach=0.74 Alpha=4.0 Beta=0.0	Significant vortex formation & bursting below the free shear layer	**Figure 17** & **Figure 18**

Size and location constraints limited the number and spacing of dynamic and steady state pressure transducers on the turret. Without continuous or close spacing of pressure taps, both on- and off-body, the presence of flow phenomena such as small lambda shocks, vortices, and high angle shear layers would have to be inferred. The availability of the shadowgraph images depicting ongoing global flow phenomena provided immediate insight into flow phenomena affecting local pressure responses.

The continuous real time information in the shadowgraph images provided the observer the ability to immediately determine which configurations: 1) eliminated the unsteady shocks; 2) generated unwanted vortices; and 3) provided the desired result. This allowed unnecessary configurations to be eliminated from the test matrix.

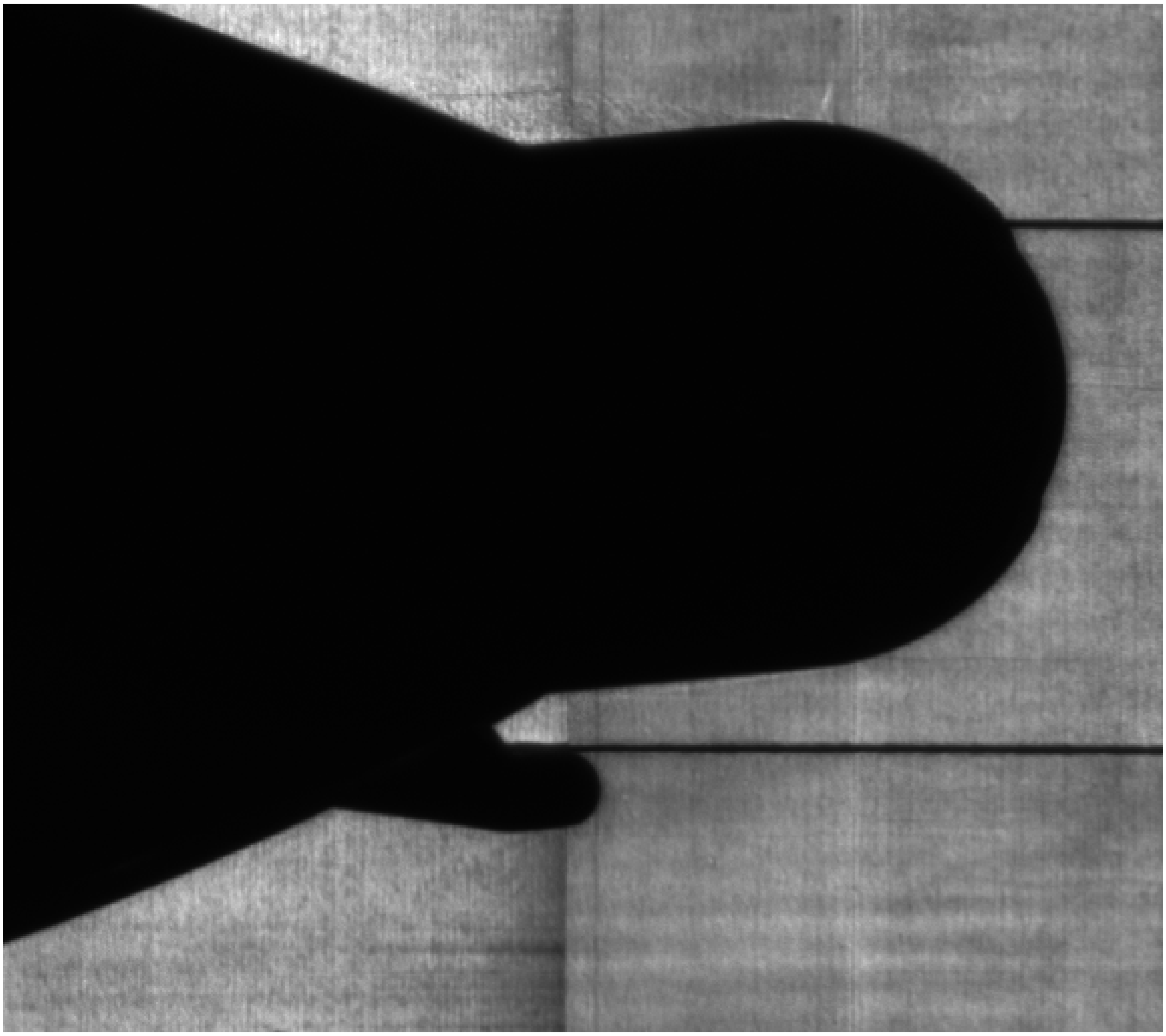

Figure 13. Baseline configuration at Mach=0.78, Alpha=5.2 deg, and Beta=3.0 deg (Point 69).

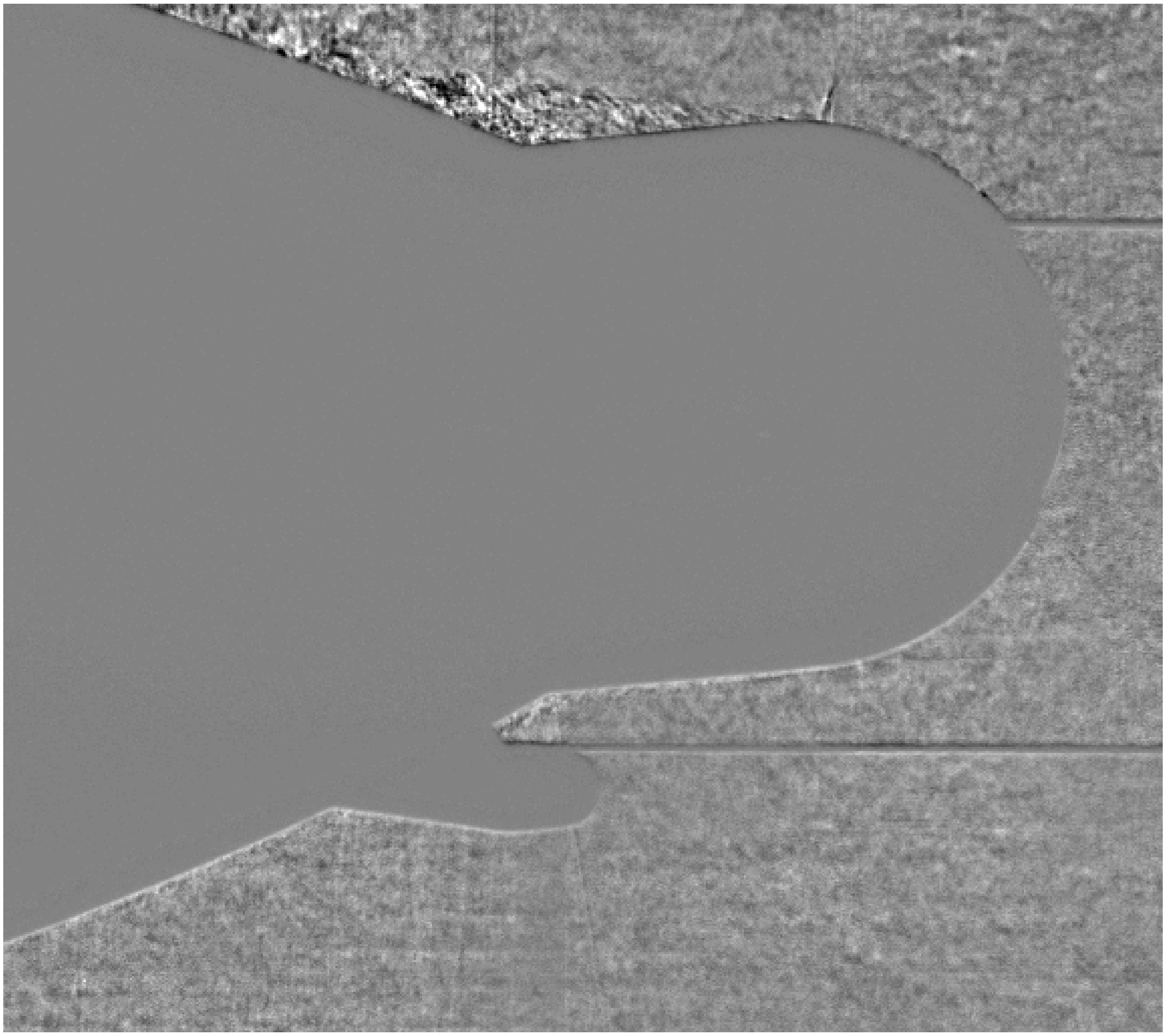

Figure 14. Baseline configuration at Mach=0.78, Alpha=5.2 deg, and Beta=3.0 deg (Point 69) with sequence average subtracted.

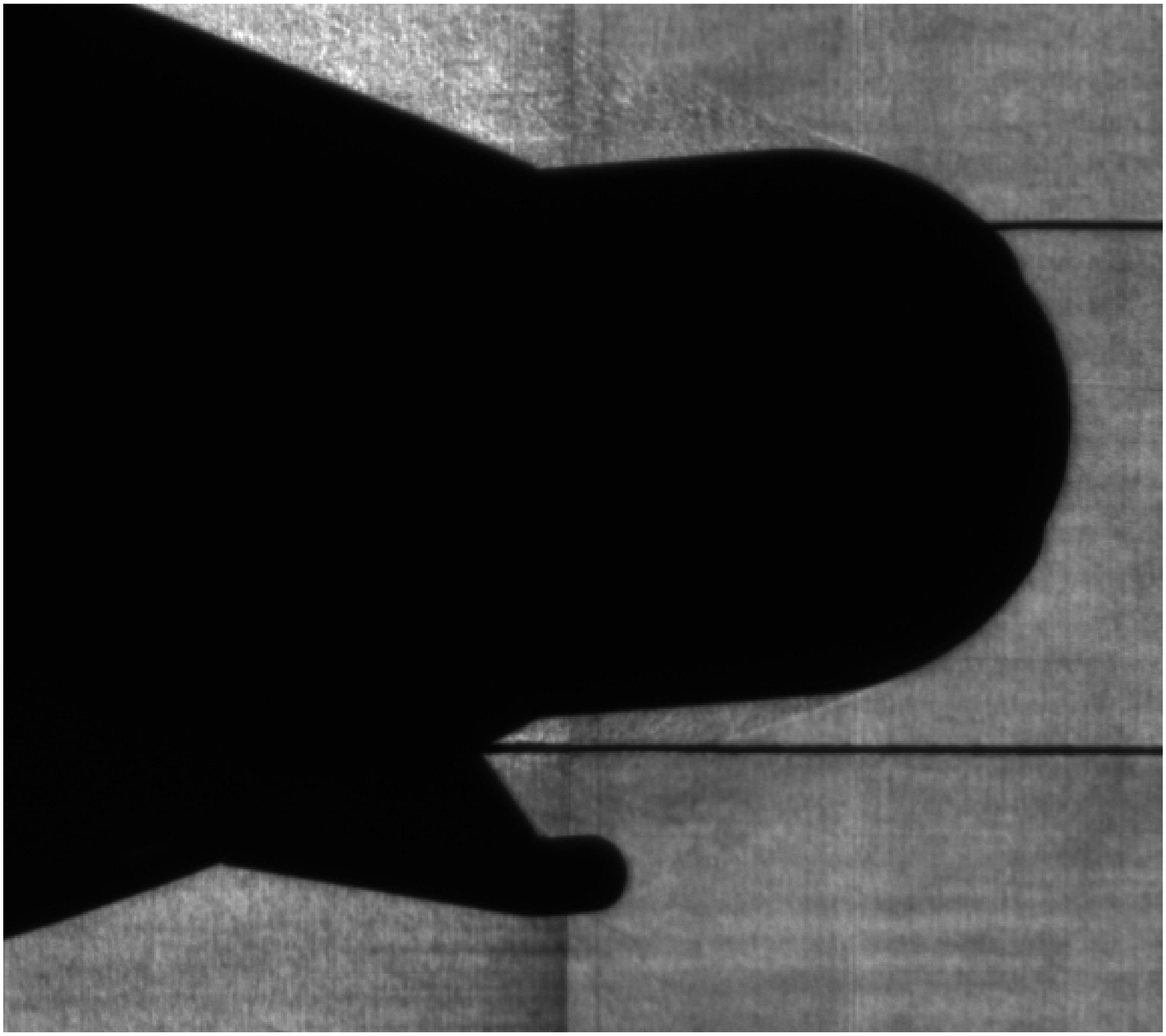

Figure 15. 15% Porous plate configuration with plenum at 0.25 inches. Mach=0.76, Alpha=5.2 deg, Beta=0.0 deg (point 108).

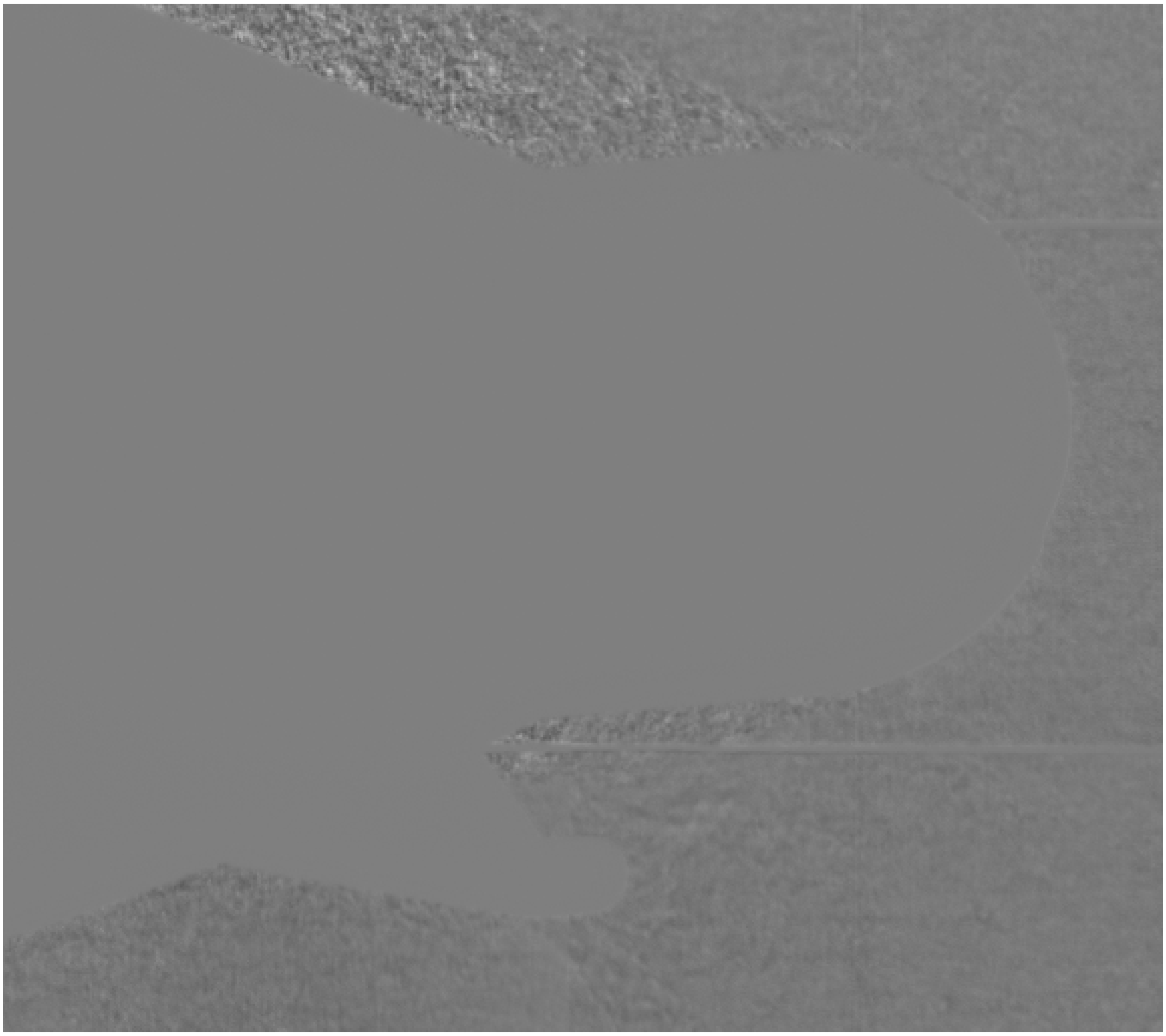

Figure 16. Sequence average subtracted from image of 15% Porous plate configuration with plenum at 0.25 inches. Mach=0.76, Alpha=5.2 deg, Beta=0.0 deg (point 108).

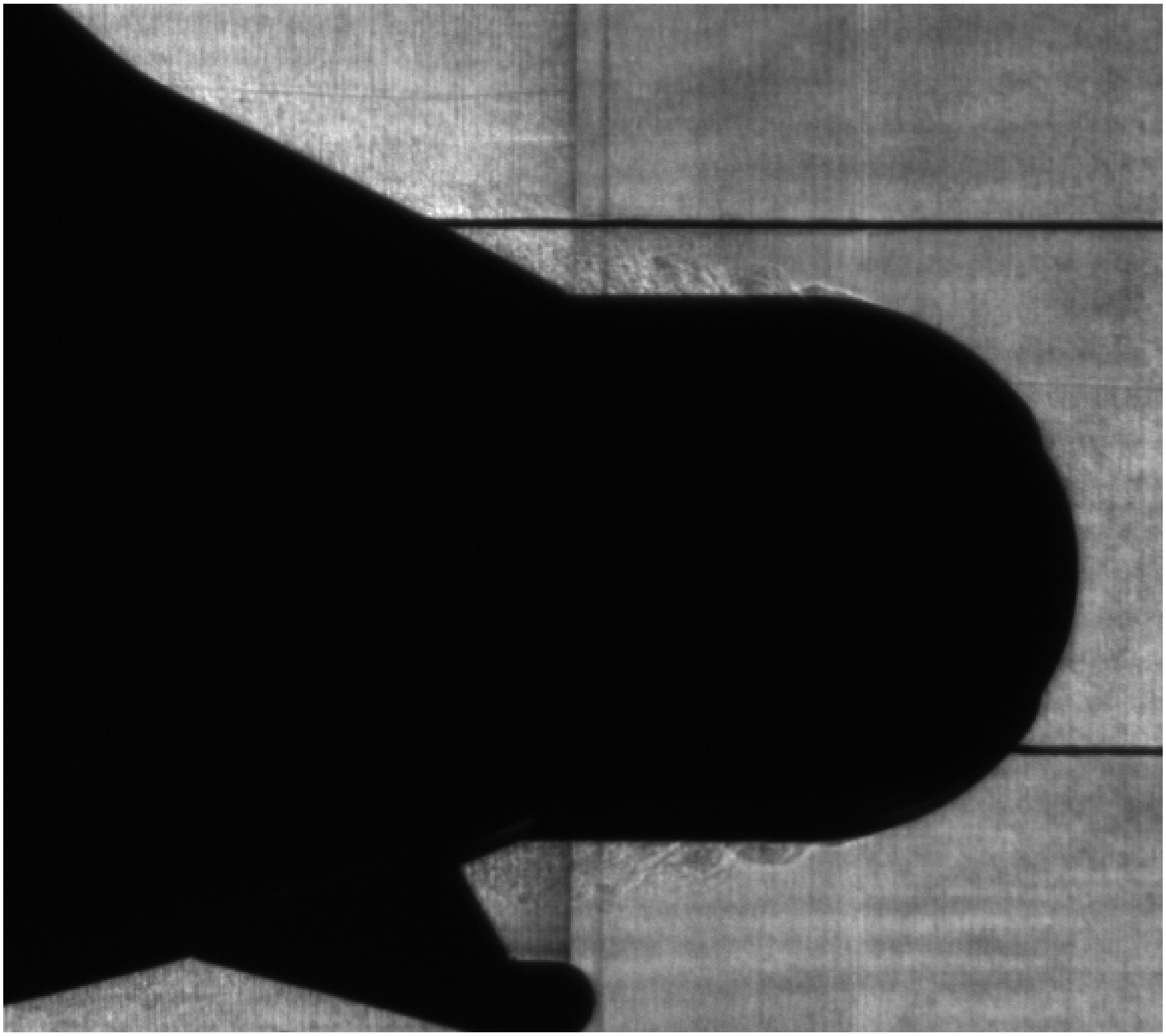

Figure 17. Porous plate configuration with ½ inch deep plenum cavity. Mach=0.74, Alpha=4.0 deg, Beta=0.0 deg (point 688).

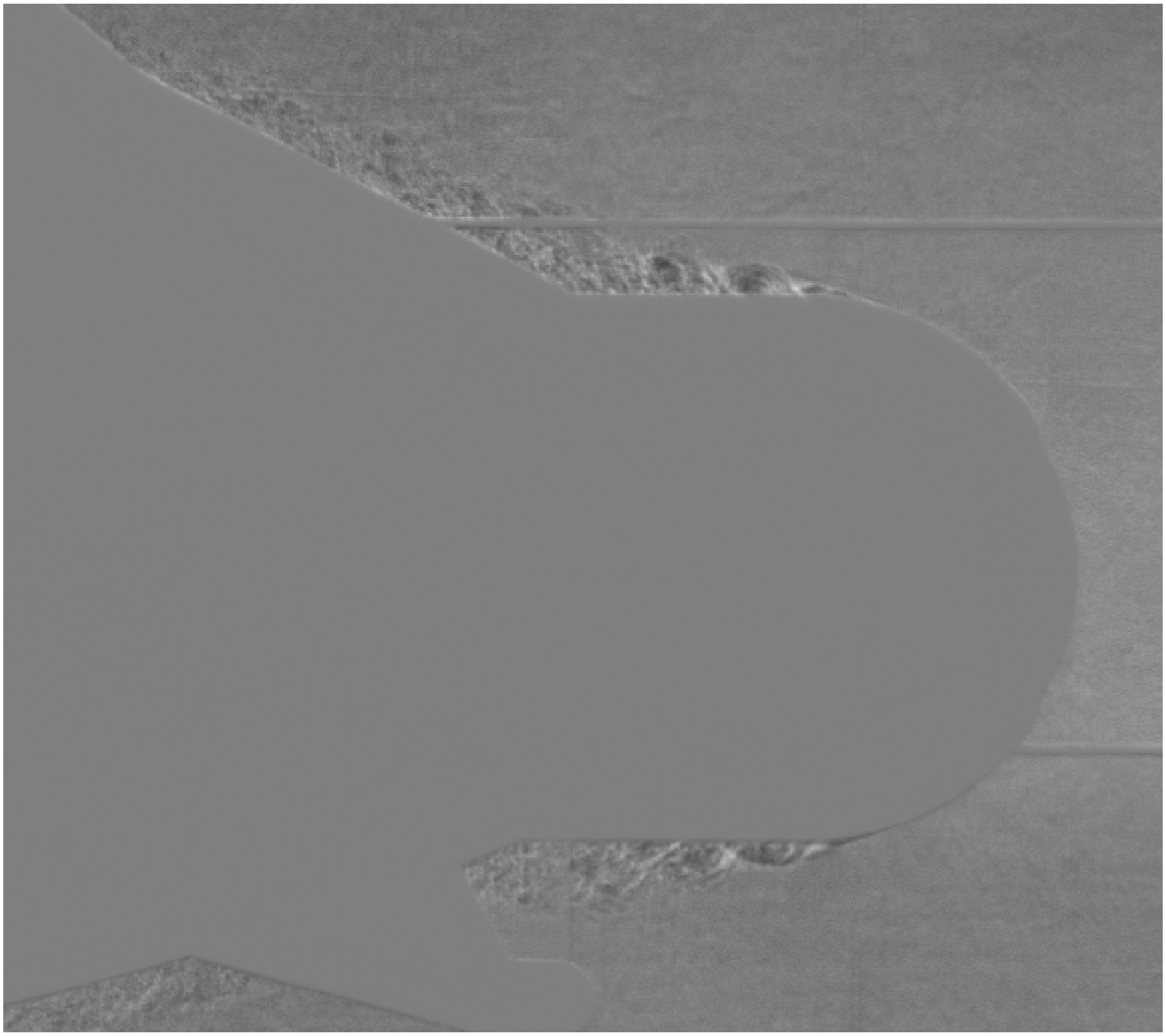

Figure 18. Sequence average subtracted from image of porous plate configuration with ½ inch deep plenum cavity. Mach=0.74, Alpha=4.0 deg, Beta=0.0 deg (point 688).

6.0 CONCLUSIONS

A large field of view shadowgraph flow visualization system for the Langley 16 ft. Transonic Tunnel (16 ft.TT) has been developed to provide fast, low cost, aerodynamic design concept evaluation capability to support the development of the next generation of commercial and military aircraft and space launch vehicles. Key features of the 16 ft. TT shadowgraph system are: 1)high resolution (1280 X 1024) digital snap shots and sequences; 2) video recording of shadowgraph at 30 frames per second; 3) pan, tilt, & zoom to easily find and observe flow features; 4) one microsecond flash for freeze frame images; 5) large field of view approximately 12' X 6'; and 6) a low maintenance, high signal/noise ratio, retro-reflective screen to allow shadowgraph imaging while test section lights are on.

Use of the shadowgraph system during Boeing Airborne Laser Test 534 at 16 ft. Transonic Tunnel made it possible to successfully evaluate flow control improvements in an attempt to eliminate unsteady shocks on a laser turret. The availability of the shadowgraph images depicting ongoing global flow phenomena provided immediate insight into flow phenomena affecting local pressure responses. The continuous real time information in the shadowgraph images provided the observer the ability to immediately determine which configurations: 1) eliminated the unsteady shocks; 2) generated unwanted vortices; and 3) provided the desired result. This allowed unnecessary configurations to be eliminated from the test matrix.

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2. *LS-1130 FLASHPAC Operation Manual*. PerkinElmer Optoelectronics, Salem, MA.
3. Innovative Internet Marketing Solutions: *About Reflexite - Microprism Technology*. http://www.reflexite.com/microprism_technology.htm Accessed April 18, 2000.

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