OPERATIONAL FLOW VISUALIZATION TECHNIQUES IN THE LANGLEY UNITARY PLAN WIND TUNNEL

William A. Corlett
NASA Langley Research Center
Hampton, Virginia

INTRODUCTION

The purpose of this paper is not to illustrate the latest innovations in flow visualization techniques, but to show what the Unitary Plan Wind Tunnel (UPWT) uses in daily operation. This paper is presented more from the viewpoint of a user than a pioneer. Although improvements have been made in several of the old techniques used in Unitary, there are still shortcomings. We are currently developing new ideas for improving the quality of established flow visualization methods and are pursuing cooperative programs on promising new flow visualization techniques.

The Unitary Plan Wind Tunnel is Langley's only supersonic facility. It is a highly productive facility and is normally referred to as a production facility, although the majority of our tests are inhouse basic research investigations. The facility has two 4 ft. by 4 ft. test sections which span a Mach range from 1.5 to 4.6. The cost of operation is about $10 per minute (3rd shift power rate). Therefore, one of the problems is the time often required for a flow visualization test setup and the cost of an extensive investigation. Another is the ability to obtain consistently repeatable results; this is essential for qualitative analysis.

Following are examples of sublimation, vapor screen, oil flow, mini-tufts, schlieren, and shadowgraphs taken in UPWT. These results are from typical research investigations. All tests in UPWT employ one or more of these flow visualization techniques.

SUBLIMATION

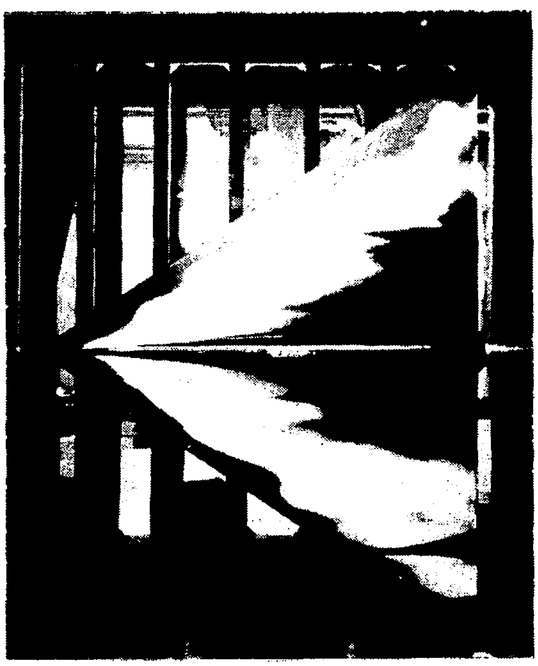
Sublimation is used in the Unitary Plan Wind Tunnel as a flow visualization technique. This technique is based on areas of higher skin friction sublimating faster and is used to locate the laminar to turbulent transition region.

The procedure requires painting the model a flat black and then uniformly coating with a white sublimation chemical. In the tunnel, fluorine in a petroleum ether solvent is sprayed on the model.

An example at Mach 1.5 in the UPWT is shown below. As time progresses, the fluorine sublimates from the rear of the model toward the transition region. At the point where the fluorine sublimation rate becomes a minimum, a pattern of coated area is formed and the location of transition region is indicated. Figures (a) and (b), for example, show the same pattern after 3 minutes of elapsed time. The transition region is the juncture of the coated and clear portion of the model. (An area of high skin friction along the leading edge will also cause rapid sublimation.)

The problems encountered with this technique are the ability to apply the required uniform coating and the wind-tunnel time required to obtain the results.

$M=1.5$; $RN/FT=2\times10^6$; $T_0=150°F$.



(a) t=11 minutes

(b) t = 14 minutes

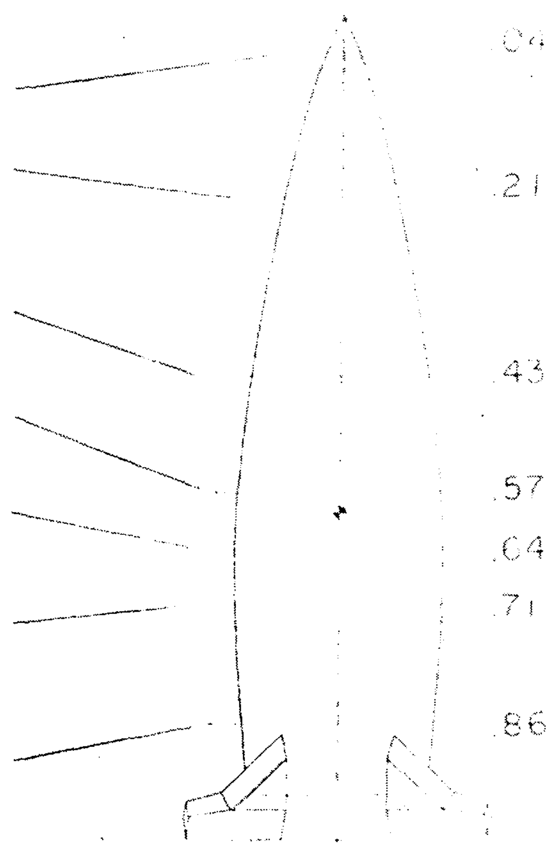
VAPOR SCREEN

The vapor screen method of flow visualization utilizes an intense sheet of light to illuminate water paticles which have been induced into the air flow. A variation in particle density caused by a strong disturbance such as a shock or a vortex varies the intensity of the scattered light in the vapor screen resulting in a two-dimensional illustration of the flow field.

In an effort to obtain consistently high quality photographs, several light sources varying from a 1000 watt Hg arc lamp to a large 5 watt laser have been used in the UPWT. A 1 watt fanned argon laser source produces an excellent light screen. However, getting consistently good photographs with either the laser or Hg arc lamp is still a problem. The figure below represents several longitudinal stations using two 1000 watt Hg arc lamps. Photographs were taken with a Hassalblad 500 EL/M camera mounted inside the tunnel directly behind the model. Kodak ASA 400 tri-x pan film was used with an exposure time of 1/4 sec at f/2.8.

Currently, experiments using smoke instead of water vapor are being evaluated. A chloride flare produces a favorable smoke screen which is anticipated to have a lesser effect on flow properties than wet air (water added downstream of test section to raise dew point to approximately +20°F for vapor screen).

$M = 2.50; \ \alpha = 16.2°$



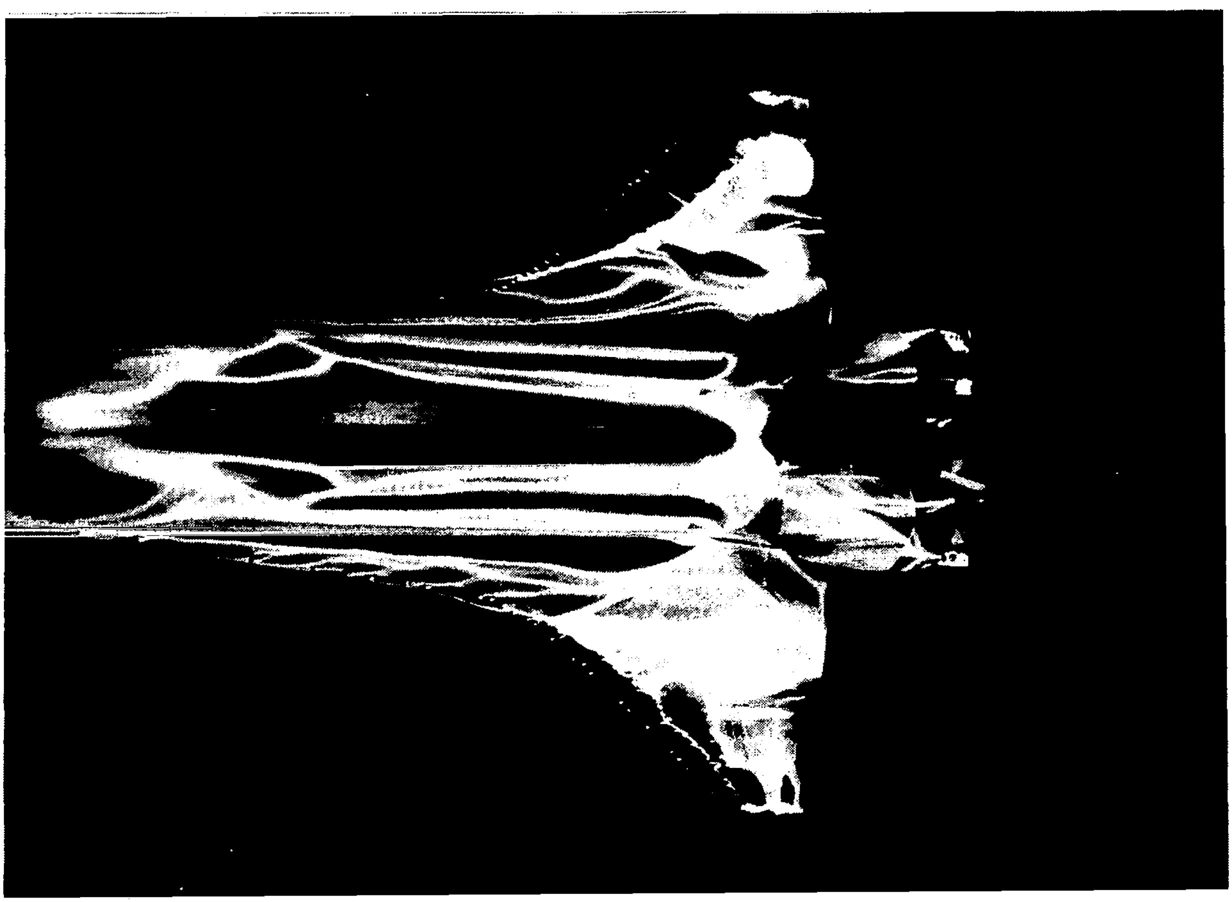
OIL FLOW

This visualization technique utilizes a fluorescent oil illuminated with ultraviolet light to show surface flow patterns.

The procedure uses a mixture of heavy oil and "fluorescent green" (3 tablespoons per pint of No. 600 w. oil). The model is painted a flat black, then a uniform coating of the fluorescent oil is brushed over the complete model. The heavy oil is required in order to maintain a uniform coating on the model during the supersonic start and required time to establish desired flow conditions. Once on point, 10 to 15 minutes are required to develop the flow pattern. Normally only two test conditions can be photographed before the model requires recoating. A technique to continuously supply a light weight fluorescent oil from the model leading edge during the tests is desired. This, however, adds to the model cost.

The photograph below shows the surface flow pattern on the shuttle configuration with aft reaction control jets firing. Compare separation regions on the left wing (jet on) with the right wing (jet off).

$M = 2.5; \ \alpha = 20°$



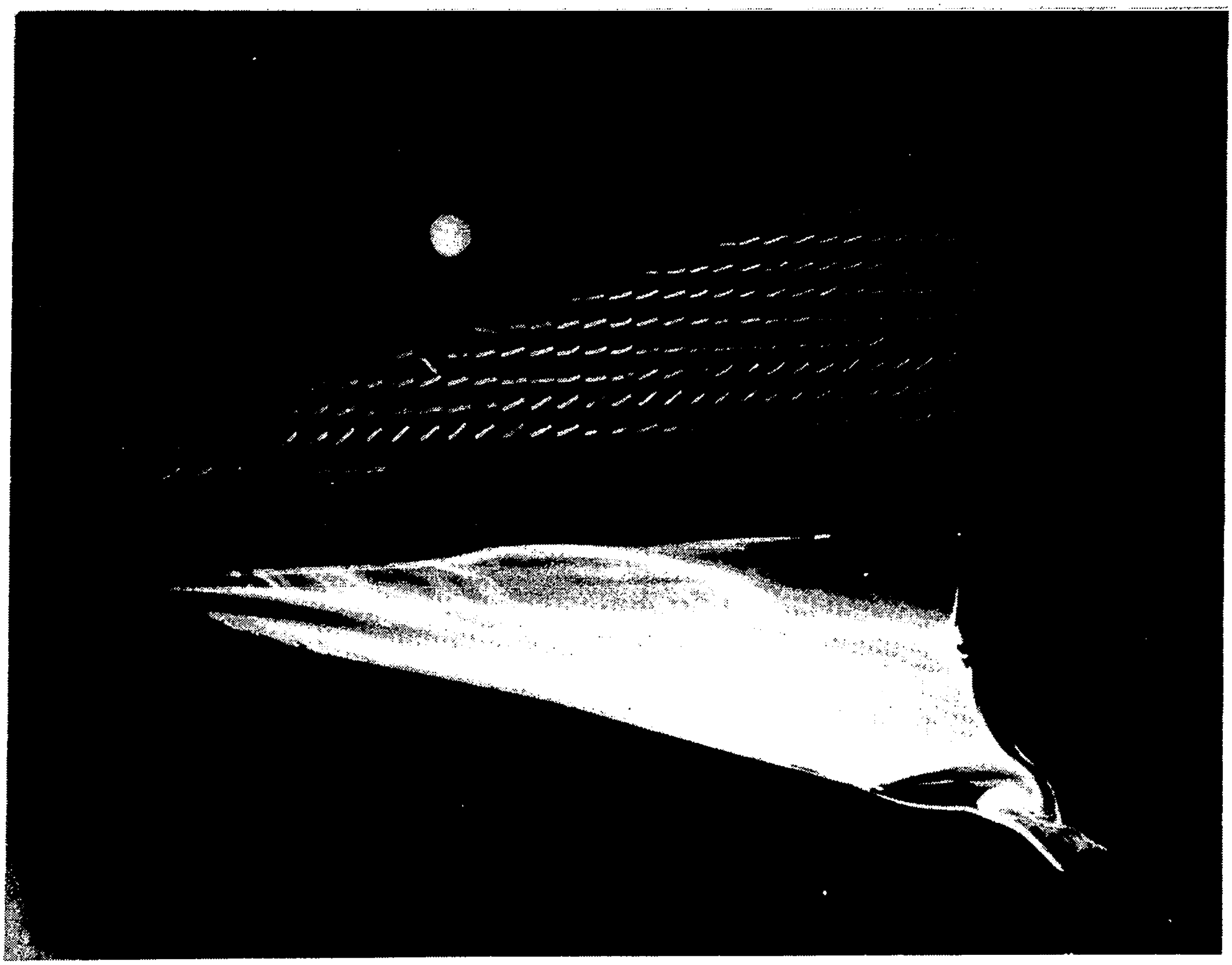
MINI-TUFTS

The mini-tuft flow visualization technique employs a grid of very fine monofilament tufts illuminated with ultraviolet light.

The procedure requires painting the model a flat black and attaching the desired grid of tufts. The tufts are 0.003 inch diameter nylon monofilament. The length is varied from 0.3 to 1 inch. Due to their very small size, there is no apparent tuft interference on the surface flow field. Tests have indicated that the mini-tufts have a negligible effect on model aerodynamic performance characteristics. There is also no delay in establishing the flow pattern.

The same camera and ultraviolet lamps are used for both the oil flow visualization technique and the mini-tufts. Therefore, both techniques can be readily employed at the same time as indicated in the figure below. Shown is an advanced supersonic transport model at Mach 2.7 and an angle of attack of 10°. Flow direction and instability are more apparent with the mini-tufts; however, the oil flow technique gives more distinct patterns.

AST 205 MODEL; $M = 2.7$; $\alpha = 10°$



SCHLIEREN

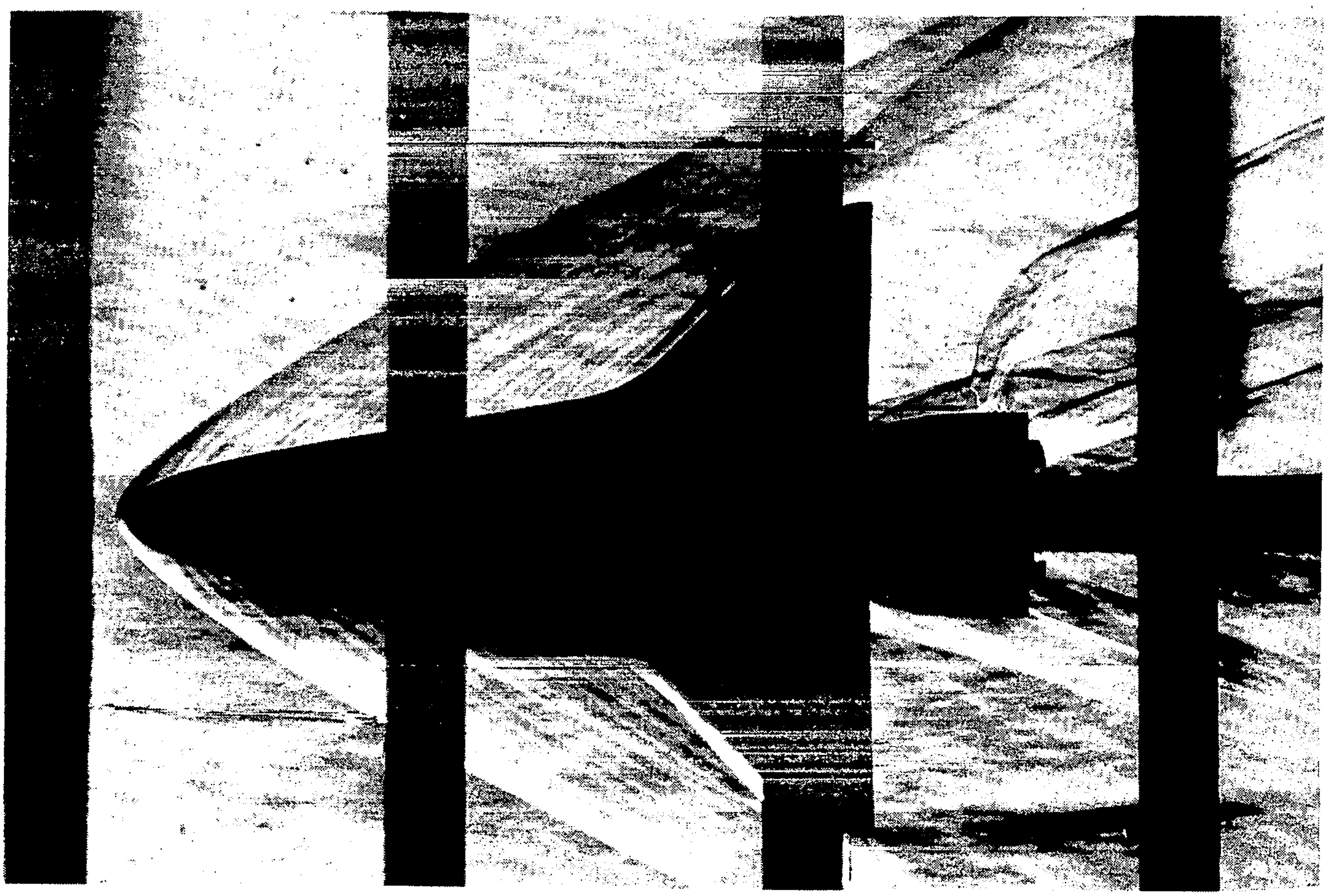
Schlieren is a flow visualization method based on the refraction of light while passing through a varying air density. Collimated rays of light are bent while passing obliquely through a density gradient.

Each test section in the Unitary Plan Wind Tunnel is equipped with a schlieren system having a 49-inch field of view. The system uses a silvered knife edge at the focal point to provide simultaneous viewing and recording of the image. The schlieren image is photographed with a 9-inch by 9-inch still camera or the image may be recorded on video tape. This system has the same problem that all optic systems have in that continuous focusing and aligning is required to obtain consistently good results. Vibration transmitted to the system also cannot be tolerated.

The schlieren system in UPWT is used to monitor all tests from establishing supersonic flow to dropping flow. (The only exception being tests that require installing steel doors.)

The photograph below is of the shuttle model showing the influence of the reaction control jets. (Shuttle control surfaces removed to show jet plume.)

$M = 2.5 \quad \alpha = 20° \quad W_j/W_\infty = 0.0071$

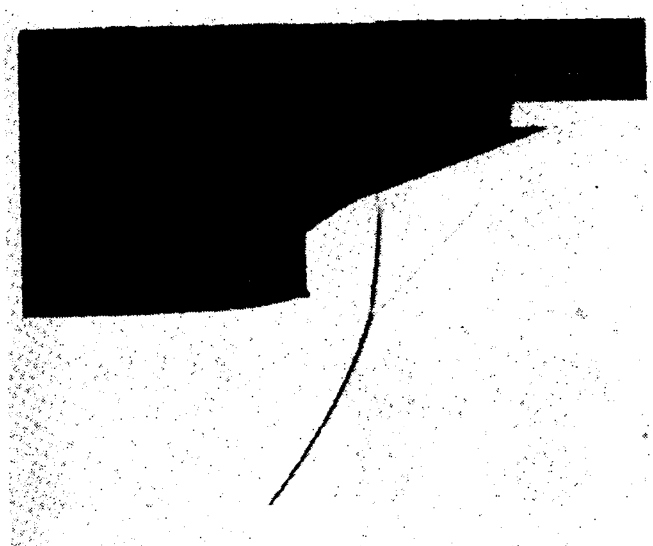


SHADOWGRAPH

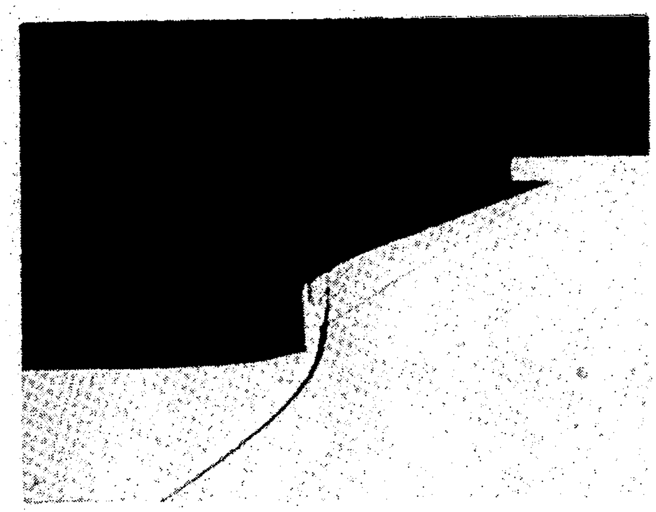
A shadowgraph shows steep pressure gradients in the air flow. The shadowgraph differs from a schlieren in that the schlieren depends on the first derivative of the refraction index while the shadowgraph depends on the second derivative.

Normally in a shadowgraph, only the shock waves and the model silhouette are visible. The most common use of the shadowgraph at UPWT is in monitoring model inlet flow conditions.

The photographs below show the variation of inlet shock location with change in Mach number. At Mach 1.6 the inlet appears completely choked with little air flow passing through the inlet.



(a) M = 1.6



(b) M = 2.5

CONCLUSIONS

The Langley Unitary Plan Wind Tunnel currently relies on the more conventional flow visualization techniques that are very familiar to test personnel. Some problems are apparent such as the time required for test setup and the cost when 10 to 15 minutes are required per data point. However, good quality results are obtained and one or more of these techniques are used for all investigations in the Unitary wind tunnel.

A continuous effort to improve the quality of established flow visualization methods and the development of new ideas is maintained.