Supersonic Testing of NAL Binary Pressure Sensitive Paint

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Abstract
The main objective of the present study is to subject NALPSP-02, an indigenously developed binary pressure sensitive paint, to supersonic flow conditions. An experimental study was carried out on a double-delta wing model at a free stream Mach number of 2.0 in the 0.3 m trisonic wind tunnel at NAL. Pressure Sensitive Paint (PSP) technique was used to measure the pressure distribution on the lee side of the double delta wing at an incidences of 0°, 5°, 10° and 15°. The PSP results were compared against surface pressure data obtained using conventional pressure taps on the same model.

1. INTRODUCTION
Delta wings have advantages over conventional aerofoils in terms of aerodynamic characteristics. The counter rotating leading edge vortex pair creates high suction on the top surface of the wing. This energised vortex pair delaying the separation stall and thus leads to higher stall angles. Research on flows over delta wings has tremendous effect on the design and development of high speed fighter aircrafts and missiles [1, 2].

To measure the surface pressure distribution on any wind tunnel model, conventional pressure measurement systems which are time consuming and limited in spatial resolution are being used. Alternative to this measurement is the pressure sensitive paint (PSP) technique which is based on the principle of oxygen quenching of luminescence [3]. PSP offers higher spatial resolution compared to the conventional electronic sensor based pressure measurement systems.

An intensity based PSP system is being used in the NAL 0.3 m blow down tunnel [4, 5]. The paint sensor is a key element of the system. Earlier PSP efforts at NAL used the commercially available Optrod-B1 paint. Efforts have been underway to develop an indigenous industry standard binary PSP and the processing software [6–9]. Calibration tests and the wind tunnel aging tests in the 0.3 m tunnel have confirmed that paint formulation NALPSP-02 is on the advanced stage of development and is ready for tunnel applications in transonic and supersonic flow. This study on a delta wing is to determine the applicability of the PSP so developed.

2. EXPERIMENTAL SETUP
The experiments were conducted in the NAL 0.3 m trisonic blow down test facility which has a square test section of 0.3 m × 0.3 m [Figure 1]. The tunnel can provide Mach numbers ranging from 0.2 to 4.0 and a Reynolds number range of 15 million to 60 million per meter. Total pressure for the current experiments was set at an absolute pressure of 206 KPa which resulted in a unit Reynolds number of 44 million. All tests were carried out at a tunnel total temperature of 303° K.

3. MODEL DETAILS
Figure 1 shows the model mounted in the 0.3 m trisonic wind tunnel. The dimensions of the model used in the study are given in figure 2. The model is a double delta wing configuration without the fuselage section. The model has a first sweep angle of 69° and 47° as the second sweep angle. The length (l) and span (b) of the model are 148 mm and 180 mm respectively. The model was mounted on a bent sting

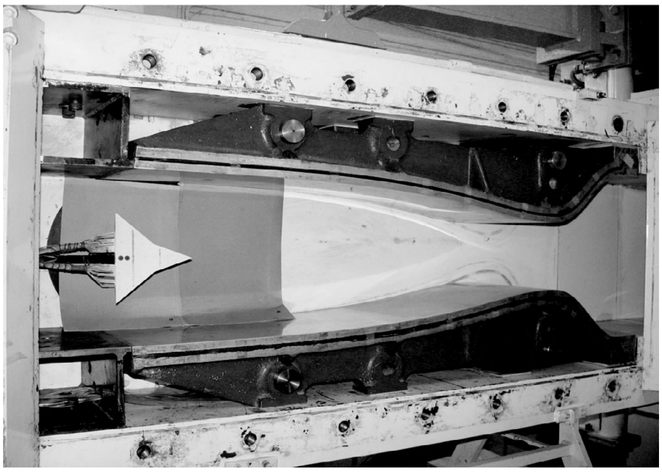

Figure 1. Photograph of model mounted in the 0.3 m Trisonic Tunnel.

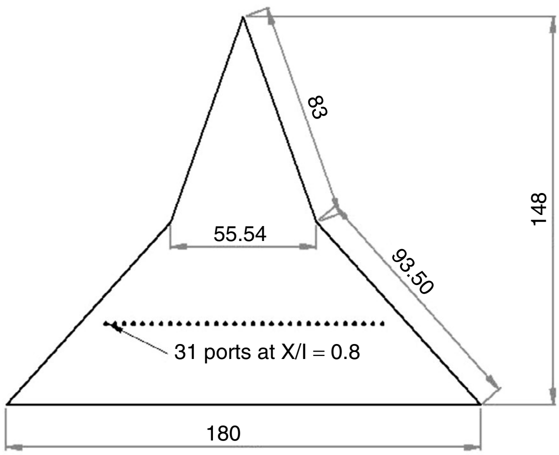

Figure 2. Dimensions of the Model in mm.

to attain the required angle of attack (α). Three bent stings were used to vary the angle of attack. The model was fixed with the lee ward side facing the modified Schlieren window in the tunnel to facilitate imaging.

The maximum blockage of 8% occurred at 15° angle of attack. The model was provided with 31 static pressure ports of 0.5 mm diameter to validate the PSP measurement. Two differential ESP scanners of range ± 103 Kpa were used to measure the surface pressure distribution through the ports laid on the model. The uncertainty estimated was in the range of $\Delta Cp < \pm 0.02Cp$.

4. PSP SETUP

A modified Schlieren window on the side wall of the test section provided the optical access for illumination of the model as well as detection of emission from the model [Figure 3]. The model was illuminated using a Xenon flash lamp providing UV excitation of the paint in the range of 300 nm. The pressure sensitive and intensity images were captured using two identical peltier cooled 12-bit scientific grade CCD cameras sensitive to the the ranges of 450–550 nm and 600–650 nm respectively.

The intensity images were converted to the corresponding pressure images based on a priori coupon calibration obtained in a special calibration chamber. The temperature coefficient of the NALPSP-02 paint is small (< 0.3%/°C), and hence the PSP data does not require any temperature corrections [9].

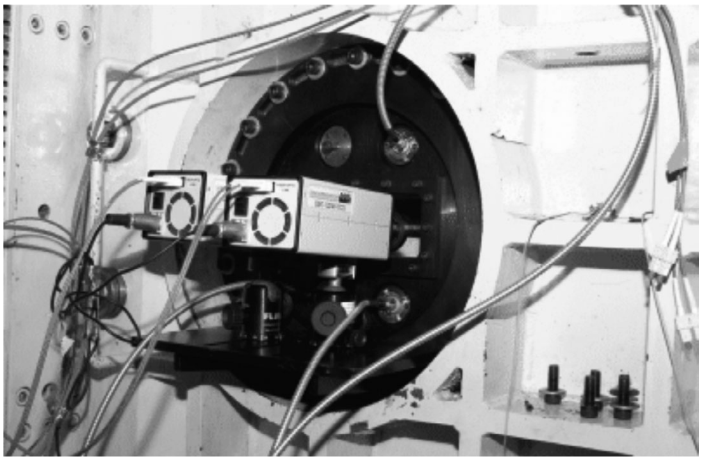

Figure 3. PSP arrangement and Optical Access.

5. CALIBRATION

Prior to the wind tunnel experiments, Aluminum coupon of 25 mm by 25 mm in size coated with NALPSP-02 was calibrated. The pressure in the calibration chamber was varied from 100 mbar to 1600 mbar and the corresponding pressure sensitive and illumination reference images (at a temperature of 25°C) were acquired. The variation of intensity in sensitive, reference and normalized images with respect to pressure is shown in figure 4. The normalising pressure was taken to be 1 bar and the sensitive and reference images corresponding to this pressure were taken as normalising images. The results from the calibration data was used to process the images acquired during wind tunnel experiments. The pressure sensitivity of paint was 64.57%/bar.

6. PSP DATA PROCESSING

In house developed Matlab based software [6] was used to process the PSP images. The software uses the resection based approach, which incorporates the collinearity equations of photogrammetry. A comprehensive camera model, which takes into account the lens distortions as well as errors in identifying marker locations, is used to resect each of the wind-on and wind-off images from both cameras onto a 3D body surface grid, prior to ratioing. A total number of twenty seven markers were used as control points during the image processing. These points are visible in the PSP images shown later.

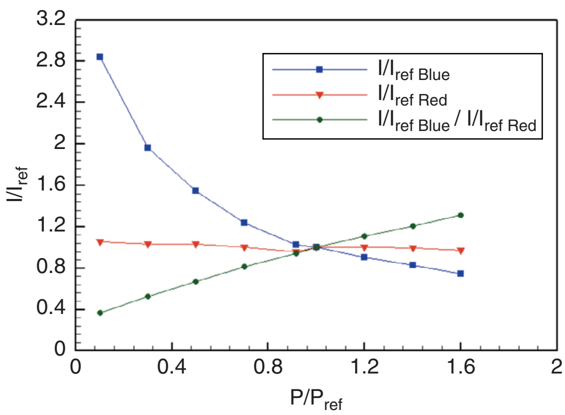

Figure 4. Variation of intensity with pressure.

7. RESULTS AND DISCUSSION

7.1. $\alpha = 0°$

Figure 5 shows the Cp distribution on the delta wing at an angle of attack of 0°. It is seen that the pressure map is highly informative and has completely captured the pressure distribution over the entire surface. It may also be noted that the PSP image is not just a flow visualisation; alternately it gives quantitative data of surface pressures at every location on the model surface. The two red circles seen are the model mounting locations. The surface pressure ports were covered using adhesive tape during model coating and is seen as a horizontal red stripes across the model at two locations. The higher Cp shown at the port side edge of the main wing is due to the error in mapping. A very weak vortex originating from the strake is captured by PSP as a reduction in pressure is seen in this region.

Comparison between PSP and ESP measurements at 0° is shown in figure 6. PSP measurement matches well with the ESP measurement. The model exhibited a slight roll (< 1°) during blowdown. This causes an asymmetric flow development on the model and is captured in the corresponding span wise Cp distribution. Both the primary and secondary vortices were captured well by the PSP measurement.

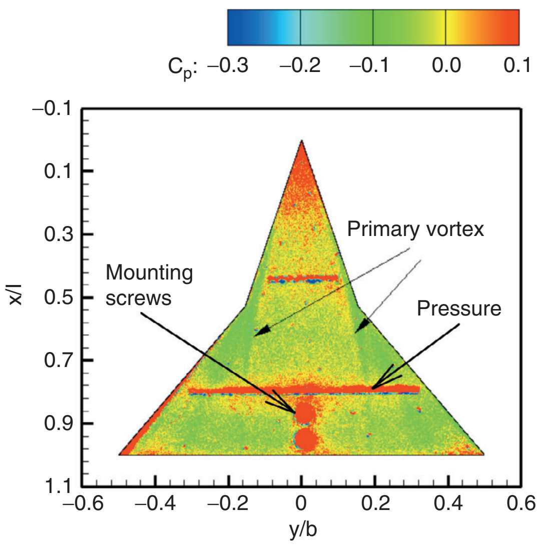

Figure 5. Cp distribution over delta wing at 0°.

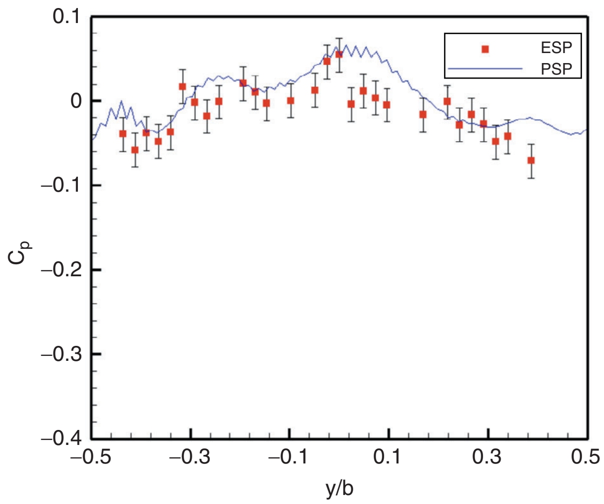

Figure 6. Comparison between ESP and PSP measurement at 0°.

The surface flow pattern visualized using surface oil flow visualisation is shown in figure 7. A weak vortex from the strake leading edge is clearly seen. The asymmetric flow captured in PSP and ESP measurement is also visible in the picture shown.

7.2. $\alpha = 5°$

Pressure field captured by PSP, comparison between PSP and ESP and the surface flow pattern at 5° are shown in figures 8 to 10. The dominating primary vortex from the strake leading edge is clearly visible in the PSP field. The pressure difference occurred due to the presence of the counter rotating vortex pair was captured well by PSP measurement.

Comparison of Cp measured by PSP against ESP measurement revealed that PSP captured the Cp distribution across the primary and secondary vortex. The reduction in Cp across vortices is larger than that of at 0°.

Surface oil flow pattern shows that the flow is almost symmetric about the stream wise axis. The vortex from the main wing does not contribute much to the flow and a dead air region is observed near the trailing edges.

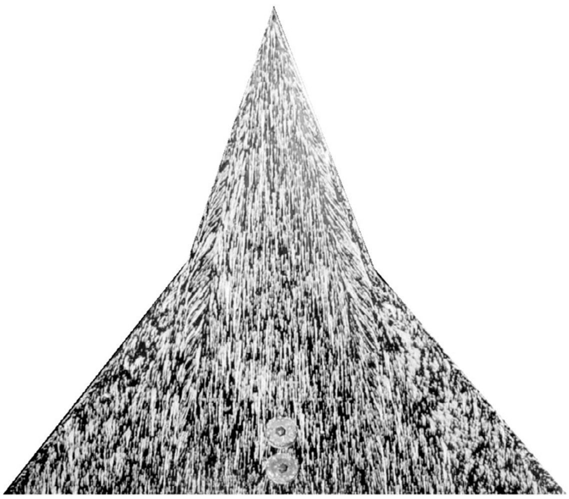

Figure 7. Surface flow pattern at 0°.

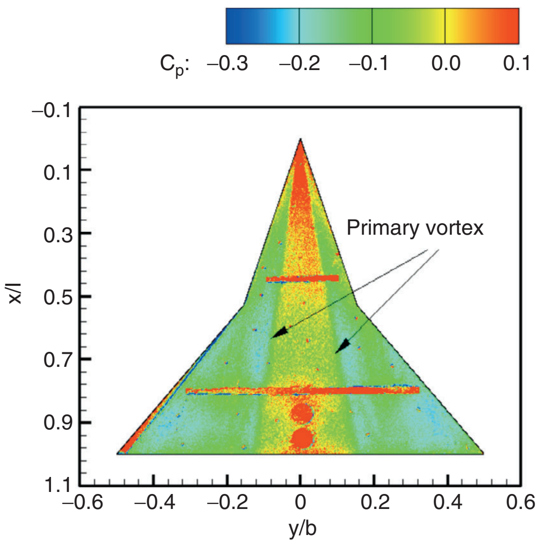

Figure 8. Cp distribution over delta wing at 5°.

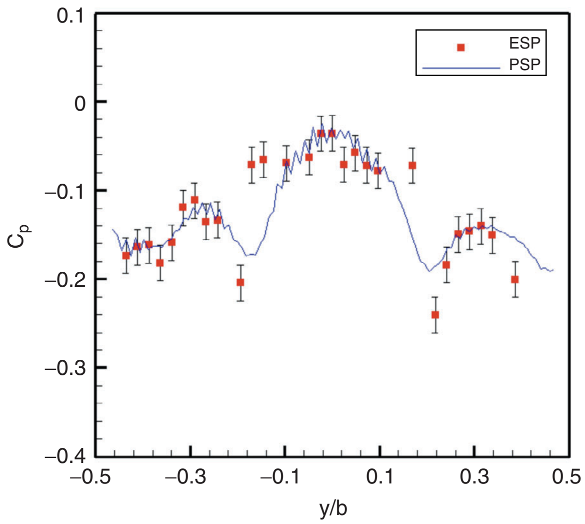

Figure 9. Comparison between ESP and PSP measurement at 5°.

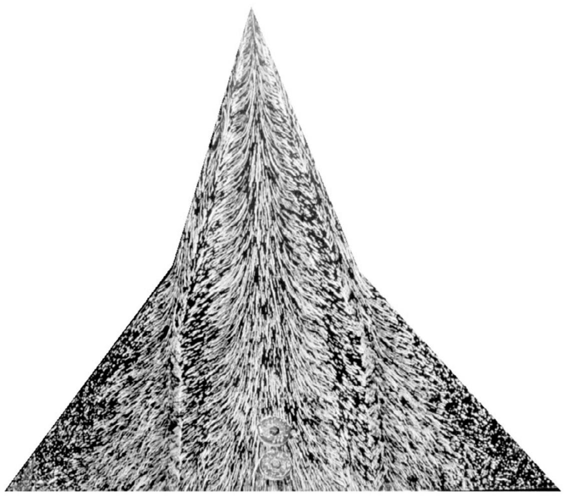

Figure 10. Surface flow pattern at 5°.

7.3. α = 10°

Cp distribution at 10° is shown in figure 11. The comparison between ESP and PSP measurement is shown in figure 12. PSP data matches very well with the ESP data. Surface flow pattern shown in figure 13 shows the vortex induced span wise flow in the center portion of the model.

7.4. α = 15°

Figure 14 shows the Cp distribution captured by PSP at 15°. Comparison of Cp captured by PSP against the Cp measured by ESP is shown in figure 15. The reduction in Cp across the primary vortex is greater than the reduction in Cp at lower angles of attack since the strength of the vortex increases with increase in angle of attack. Surface oil flow pattern is shown in figure 16. The size of the primary vortex from strake leading edge is increasing with angle of attack. Secondary vortex on the star board side of the strake is clearly visible.

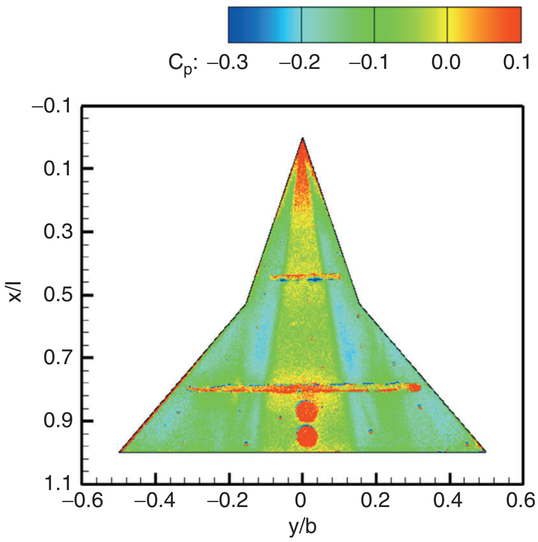

Figure 11. Cp distribution over delta wing at 10°.

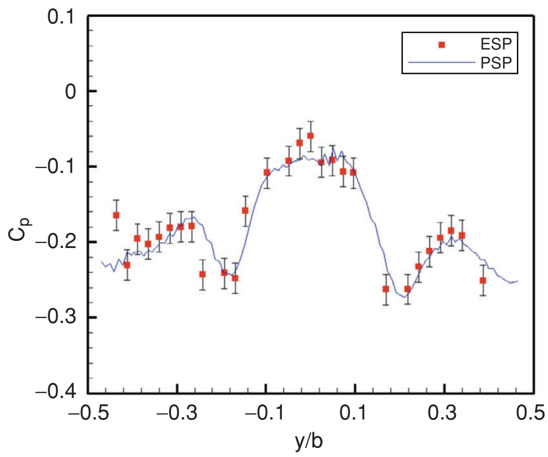

Figure 12. Comparison between ESP and PSP measurement at 10°.

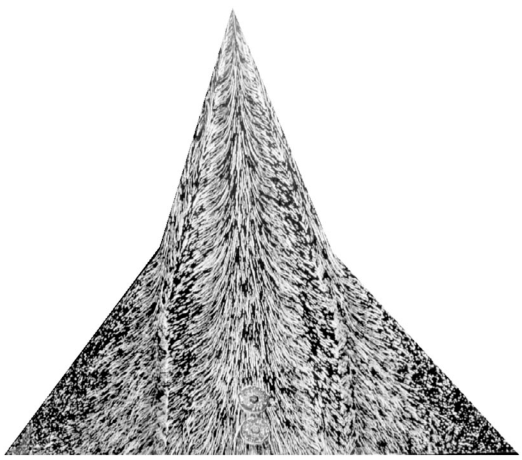

Figure 13. Surface flow pattern at 10°.

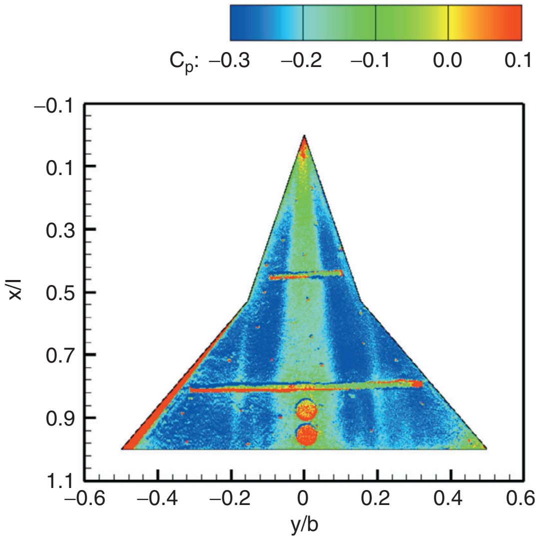

Figure 14. Cp distribution over delta wing at 15°.

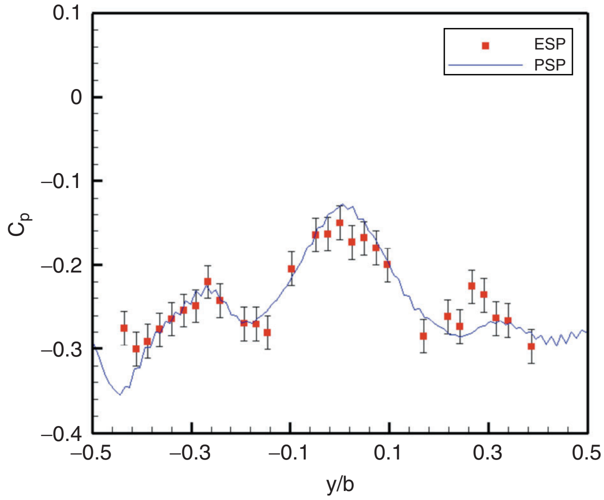

Figure 15. Comparison between ESP and PSP measurement at 15°.

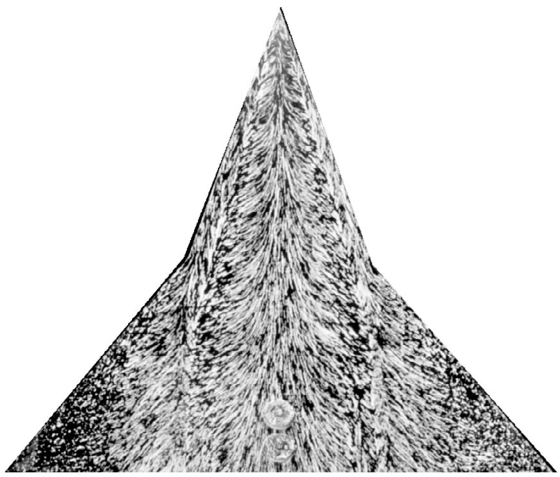

Figure 16. Surface flow pattern at 15°.

8. CONCLUSIONS

Wind tunnel experiments have been carried out over double delta wing coated with NALPSP-02. The results showed a satisfactory performance of NALPSP-02 in supersonic regime. The surface pressures as obtained from PSP match that from conventional measurements to within 6%. Thus it is concluded that NALPSP-02 can be applied to supersonic pressure measurements in blow down wind tunnels.

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