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PSP- Measurements in Transonic Wind Tunnels of DLR

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ABSTRACT

A selection of PSP measurements are presented to understand as well as the qualitative and quantitative aerodynamic in transonic regime. A number of investigations were realized and compared with conventional techniques like pressure taps and laser light sheet technique. Also the influence of errors were checked and the comparison to numerical method done. Finally an excellent tool now is available to control the theory using the PSP measurements.

INTRODUCTION

The results of the last years using the DLR-PSP system and the basic physical background of PSP are described. After a phase of intensively exploration of hard- and software development DLR designed two systems - the intensity and lifetime method. Different illumination systems were tested and finally a flash lamp and laser system including four connecting 20m long optical liquid fibers developed. Several cameras (intensified and non intensified CCD) were tested for comparisons of different paints with different excitation wavelength to obtain the emitted light spectra for various paint sensitivities, temperatures and humidity influences, photodegradation and illumination differences. External calibration procedures were developed and calibration tests in the wind tunnel itself because the Transonic Wind Tunnel of Göttingen (TWG) can be pressurized and therefore a pixel by pixel calibration was realized. Finally an accuracy of ± 1.5 mbar in absolute pressure using a very sensitive paint can be reached.

Binary and normal paints were used and the results on different models are presented. Also correction systems for minimizing model distortions (wind on - wind off) are realized and combined with the data acquisition system DeAs. Using this philosophy an automatically run and a self correction of the angle of attack support is possible for real time imaging. A number of measurements in the Transonic Wind Tunnel Göttingen (TWG) were performed and several results presented.

THEORETICAL BACKGROUND

The Relation between intensity and pressure is given by the equation:

$$I \sim I_0 \cdot 1/(\kappa \cdot p) \qquad (1)$$

with:

I : Intensity of detected light,
I_0: Intensity of detected light
κ : Quenching-constant, dependent on O_2 concentration,
p : Partial pressure of O_2

and the Stern-Volmer-Relation for pressure reconstruction by the equation:

$$\frac{I}{I_0} = A \cdot p + B \qquad (2)$$

with:
I : Intensity of detected light,
I_0 : Intensity of detected light for p= 1bar
A : Sensitivity of PSP, constant,
B : Intensity at p= 0bar, constant

To combine the Intensity- and lifetime method for non time resolved measurements the following equation is given:

$$\frac{I_{(p=0)}}{I} = \frac{\tau_{(p=0)}}{I} = 1 + K_q \cdot p \qquad (3)$$

$\tau_{(p=0)}$ = lifetime for vacuum conditions,
K_q = Stern Vollmer constant.

MODELS

A space glider model with a flat wing surface and rounded fuselage on the top and square formed fuselage in the rear part, a basic model with flat surfaces and a cylindrical air data probe will be presented and discussed.

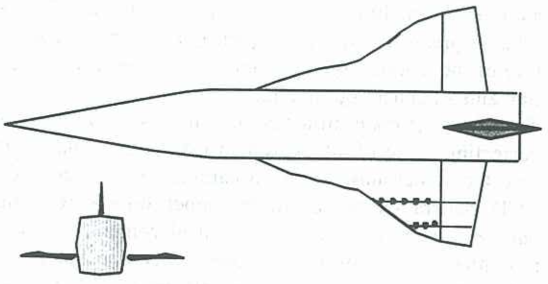

Figure 1 : DASA-HYTEX model

Different vortices are generated by the fuselages and the wings of the HYTEX model, shown in Figure 1 for Ma= 0.5 - 1.1. and α= -2° to +24° can be measured and visualized. A number of interactions can be identified that means combinations of vortices and the vortex breakdown on the surface. Figure 3 illustrates the FTT model with only flat areas including a lot of reflections between them. Very different additional vortex interactions can be visualized around the Air-Data-Probe-model, showed in Figure 2.

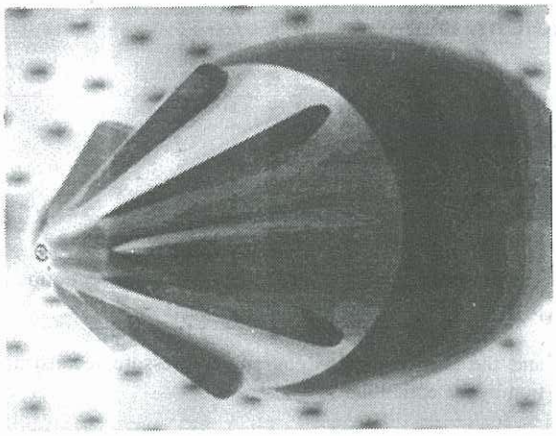

Figure 2 : Air-Data-Probe-model

PAINT

Several paints were investigated with the two basic excitation wavelength in the region of 337nm and 450nm. The paints are different sensitive to temperature and pressure at different excitation wavelength. DLR contacted paint distributors for spaying paints and paint folios, finally an own paint in cooperation with the Organic-Chemical-Institute of the University of Göttingen is under development.

A number of spectra were obtained to get own detailed information about photodegradation, temperature influence and filter setting, because different statements about the temperature sensitivity in the emitted fluorescence bandwidth exist.

RESECTION

As well known an alignment between the both wind-on and wind-off images is necessary for accurate PSP results. To reduce the main influence of sting distortion an optical system to measure the real angles was installed. The typical error without correction of alignment is in the region of 8-10 pixel. Using the optical system the shift is near 1-3 pixel. Therefore a later correction with a model including markers on characteristic positions is the best solution for the final resection program. First test showed a better precision then 1 pixel shift. The form and structure of the markers is important for an later exact detection and alignment optimizing.

To reduce the main influence of sting distortion, the self correcting angle of attack system OWI was installed. In fact, the model moves with an parallel shift closer to the CCD camera - mounted in the upper wall panel. This parallel image shift due to model displacement, has to be minimized by an image alignment procedure before dividing the two wind-on and wind-off images. In this case the shift was not automatically corrected. Fig.3 gives an impression of the result without the alignment procedure. For the alignment procedure a two dimensional transformation was performed, using power series. This transformation is expressed as:

$$x = E_1\left(x',y'\right) \quad (5)$$

$$y = E_2\left(x',y'\right)) \quad (6)$$

where E is a correction function and the unprimed coordinates (x,y) are used for the wind-off image and the primed coordinates (x‘,y‘) for the wind-on image.

$$E_1\left(x',y'\right) = a_0 + a_1 x' + a_2 y' + a_{11} x'^2 + a_{12} x' y' + a_{22} y'^2 + \cdots$$

$$E_2\left(x',y'\right) = b_0 + b_1 x' + b_2 y' + b_{11} x'^2 + b_{12} x' y' + b_{22} y'^2 + \cdots \quad (7)$$

By the assumption that a few points (x,y) and (x‘,y‘) can be related together exactly, and that for the other points the transformation characteristics is identical, the following equation can be written as in the equation before. The coefficients a1, b1 can be calculated with known pairs of points (x,y) and (x‘,y‘). We get an linear equation system with (a0,a1,a2, ...) and (b0,b1,b2, ...) as unknown quantities. For the biquadratic formulation the location of a minimum of six points on the model surface (wind-on and wind-off image) must be known. Therefore markers, e.g. circles, must be placed on the model surface for the recognition of the related points in both images. At last a two dimensional bicubic spline interpolation was used to obtain the intensity values at the non-distorted pixel location. The result after alignment is given in Fig. 4.

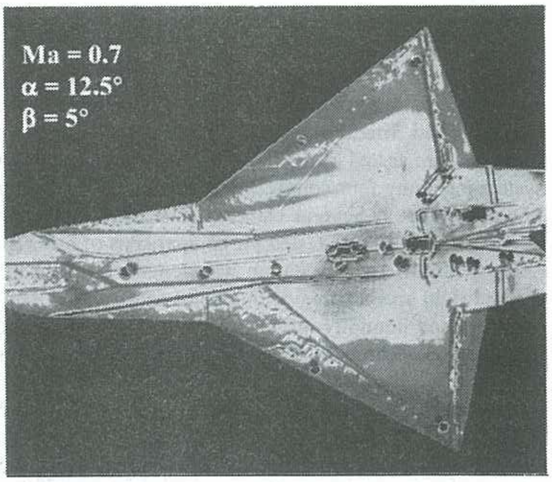

Figure 3 : DASA-FTT-model without alignment

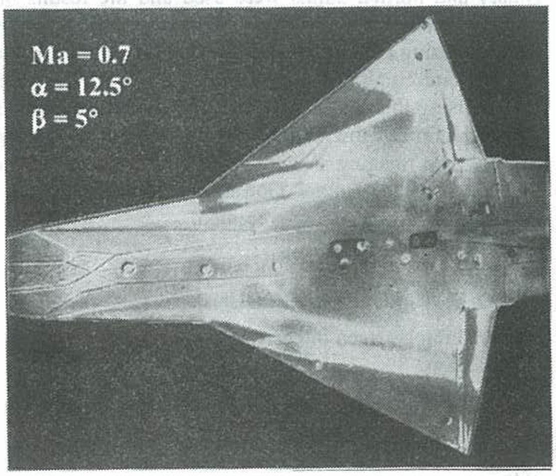

Figure 4 : DASA-FTT-model with alignment

PSP RESULTS

For aerodynamic comparisons the Dasa-HYTEX model was chosen for Mach numbers between Ma= 0.5 and 0.9 at various angle of attack. For a fast decision the pseudo color version was used to optimize the illumination.

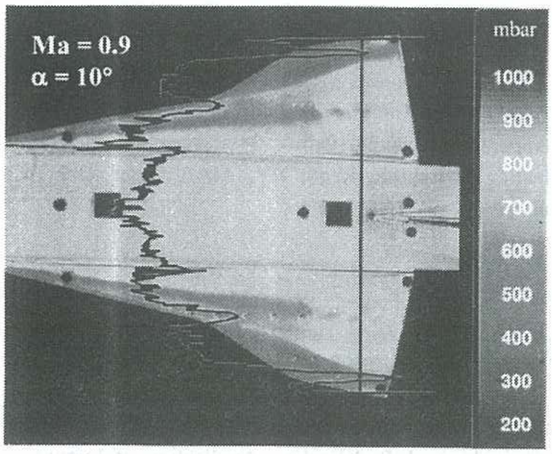

Figure 5 : Pressure distribution at the HYTEX model with the absolute pressure curve at the cursor position

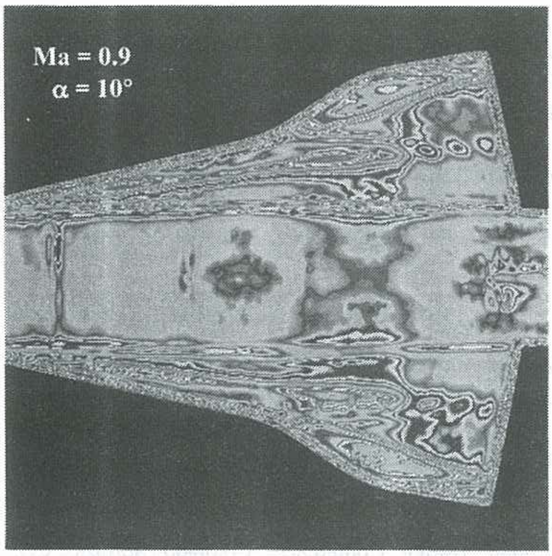

Figure 6 : Pseudo color contour plot of the HYTEX model

The image in Fig.5 shows a specific vortex structure which becomes evident only after special filtering (Fig. 6). The three spot-like areas which are identifiable on both wing sides in the rear region are not caused by vortex breakdown. Here the vortex shear layer which rolls up into a spiral particularly at Mach number = 0.9 and $\alpha=10^\circ$, this layer encounters a deceleration caused by an increase in slide pressure which leads to the layer touching the surface of the wing at small spot areas. At larger angles of incidence the vortex core is positioned at a higher distance above the wing. No influence on the surface of the wing is observed. To support this statement, laser light sheet photographs as shown in Figure 7 were taken after the PSP measurements which make this development of the vortices evident. Figure 8 shows a laser light sheet perpendicular to the flow at the same position were the pressure distribution curve was obtained like in Figure 5. The angle of attack here is $\alpha=15^\circ$ and all the generated vortices are clear visible as expected. A vortex breakdown at this angle of attack can not be stated, because all vortex cores are undisturbed.

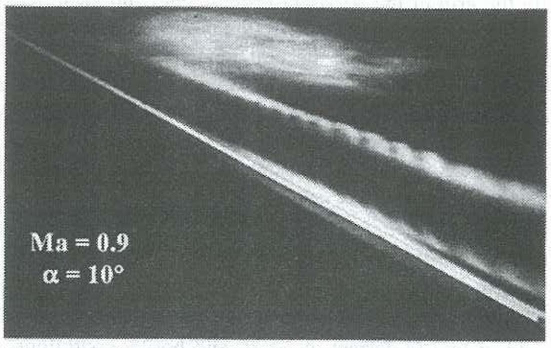

Figure 7 : Laser light sheet along the vortex axis

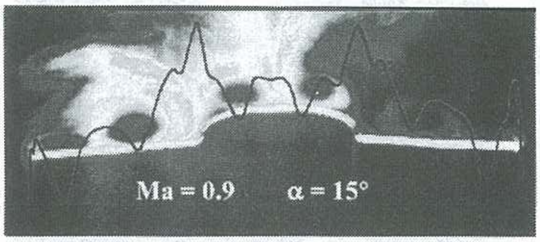

Figure 8 : Laser light sheet including pressure distribution curve at the same position like in Fig. 5.

The combination of the PSP surface measurement technique and the laser light sheet for flow control leads in such cases to a better interpretation of vortex interaction and their understanding.

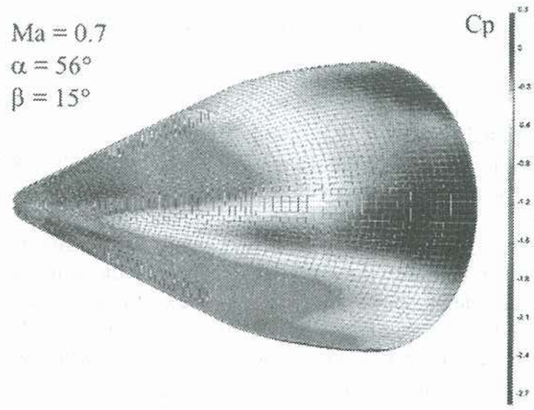

Figure 9 : Cp values obtained by the PSP method at the Dasa Air Data Probe

Figure 9 shows the result of a PSP measurement using binary paint. Here in the binder of the paint are implemented two different dyes of molecules - a pressure

sensitive and a only intensity sensitive one. Using two different filters two images has been taken for a later optimized illumination correction. In Figure 9 the transformation from the pixel orientated image is combined with the grid of the Air-Data-Probe-model and all influences like illumination an reflection were eliminated.
After reconstruction of the real image (grid) very fine pressure structures on the Air Data Probe are visible. For the here used surface on each knot point of the grid a Cp value of the PSP measurement exist as a ASCII value. Comparisons with other measurement systems or numerical calculations now are easy to handle.

Figure 10 shows a sample for comparison between Euler code calculations and PSP measurements for the FTT-model. The PSP measurements are as recognisable an excellent tool to correct the start- and border conditions for theoretical calculations because the fuselage vortices are not correct calculated as well as the wing vortices.

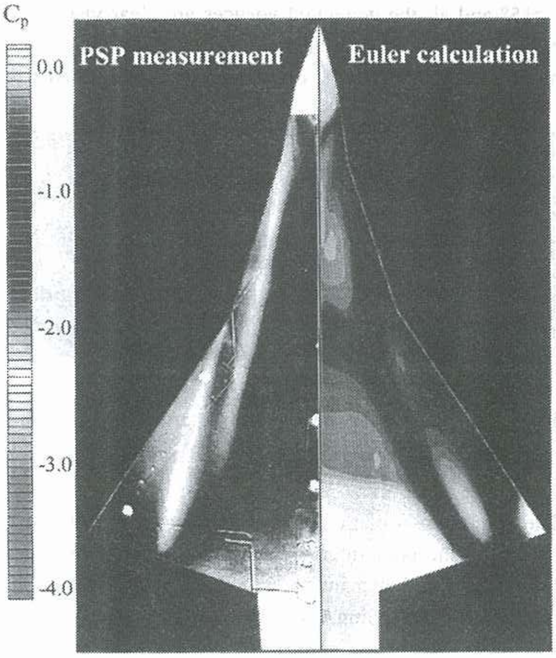

Figure 10 : PSP-CFD-comparison on the Dasa-FTT-model

CONCLUSION

It was proven that the designed PSP system can be used for steady and unsteady flow measurements as well. After the exploration phase, real wind tunnel measurements using different models were performed. The results presented here for the intensity method in the transonic speed range shows an acceptable accuracy and gives a good impression about the flow field around a model in the wind tunnel. A lot of industrial measurements have already been performed and evaluated. These measurements under real wind tunnel conditions gave experiences of great value.

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