BENCHMARK TESTING OF THE MODEL DEFORMATION MEASUREMENT SYSTEMS DEVELOPED WITHIN THE EUROPEAN WINDTUNNEL ASSOCIATION (EWA).

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OVERVIEW

A series of benchmark tests has been undertaken to investigate the performance of the Model Deformation Measurement (MDM) systems developed by members of the European Windtunnel Association (EWA). A test rig was designed which incorporated a flat steel plate which could be bent and twisted using two linear motor stages to produce the required deformations. The deflected positions were also physically measured using a 3D measurement table. The effects of system vibration and de-calibration were investigated. Analysis of the acquired data showed that it was possible to measure deflections to within limits of +/- 30µm and that a high level of technique capability is available within the EWA network.

1. INTRODUCTION

A wind tunnel model and support system can deform when under aerodynamic load during a test. It is important to determine the position and deformed shape of the model for three reasons. Firstly, to ensure that the model is accurately representing the full scale aircraft with respect to test attitude and geometry. Secondly, to make sure that the model geometry under wind tunnel test conditions is accurately known so that it can be replicated in any CFD work and allow meaningful comparison of results. Thirdly, when optical techniques, e.g. pressure sensitive paint, are being used, it is essential to quantify model deformation to enable the wind-off and wind-on measured quantities to be satisfactorily mapped onto a common grid.

A further topic requiring attention is knowledge of the position of any probes that are positioned around the model to allow the acquisition of flow field data. Inaccurate data can be acquired due to the movement of the probes resulting from aerodynamic loading. It is important to have a technique available to provide accurate information regarding the position and alignment of any probes used during a test.

This is an important topic and several EWA members have developed systems to allow the accurate measurement of model position and surface deformation during tests.

An EWA MDM workshop was held at ETW, Cologne, Germany on 20th October 2005. This provided valuable information about the status and performance of the different approaches that have been employed by the different EWA system developers. It also provided an opportunity for a demonstration of some of the systems under test conditions in the ETW wind tunnel. The systems produced very similar results and the good agreement demonstrated their satisfactory performance under test conditions. This can be seen in Fig.1 in which a typical set of results acquired during this workshop is presented.

Although the results obtained at the EWA workshop were of high quality it was decided that it was necessary to undertake a series of benchmark tests in which a surface of known geometry would be used to quantify the accuracy and repeatability of the MDM systems available within the EWA network. The test programme was to be carried out under laboratory conditions in order to maximise the accuracy of the acquired data. It was planned that many aspects of system performance would be investigated, e.g. duration of data reduction time, ease of operation, loss of markers and the effect of system vibration and de-calibration.

The following EWA members took part in the MDM benchmark tests:

DLR	- StrainMaster
DNW	- Painted Pattern Method
ETW	- Stereo Pattern Tracking
ONERA	- Deformation Measurement Method (OD2M)

2. DESCRIPTION OF THE SYSTEMS INCLUDED IN THE TESTS

The following section gives a brief description of the model deformation systems that were included in the benchmark tests.

2.1. DLR

The complete DLR model position and surface deformation measurement system presented in Ref.1 consists of two techniques. Firstly, a system of cameras is used to obtain images of reflective markers attached to the model surface and the images are analysed using the PointTracker image processing software to provide the 3D position of the model surface. Secondly, the deformation of the model can be determined by covering the surface of the model with a random dot pattern. Stereoscopic pattern correlation techniques are used to determine the deformation of the surface relative to a reference surface. The images of the surface are obtained using a stereo camera arrangement and the analysis of the images is undertaken using the Strain Master software module.

A photograph of the system can be seen in Fig. 2. It shows a video stroboscope which is used to capture a rotating propeller blade at varying speeds of revolution in a phase locked manner. Analysis of the acquired images allows determination of the deformation of the propeller blade as the aerodynamic loading is changed.

2.2. DNW

The DNW system is called the Painted Pattern Method. This is a correlation technique in which a random pattern of black dots is painted on the area of interest.

A CCD video camera is used to record the images of the surface, deflected and undeflected. The deformation of the surface can be determined from the changes in the image pattern. The techniques employed to analyse the pattern images are similar to those employed in the particle image velocimetry technique (PIV). A commercially available PIV data processing software package is used for this purpose.

A very similar technique used by DNW is the Projected Pattern Method. The difference is that the pattern is projected instead of painted onto the surface.

A typical example of the use of the system is shown in Fig. 3. Further information about this technique is presented in Ref. 2.

2.3. ETW

The Stereo Pattern Tracking method of the European Transonic Wind Tunnel is based on the tracking of predefined markers attached to the observed model surface.

This method is used to measure the deformation of half model and full model wings as well as to measure the deformation of flaps or horizontal tail planes.

During the test run the real-time calculation of the 3D-coordinates is carried out using the PICCOLOR software suite while the coordinates of the markers are stored and processed by ETW's high level acquisition system. The evaluation of the twist and bending based on these coordinates is done on-line for monitoring purposes and during the post processing of the data reduction.

The markers can be seen attached to a typical model in Fig. 4. Further information about the system is given in Ref. 3.

2.4. ONERA

The ONERA system is a stereo vision technique called the ONERA Deformation Measurement Method (OD2M). A description of the system is presented in Ref. 6. A calibration plate, similar to the DLR unit, is used to calibrate this system.

The principles used are nearly identical to those used for the ETW method:
- Camera calibration.
- Camera base and model base fitting.
- Changes in temperature or total pressure may create extra camera displacements and optical path changes. The camera/model base fitting step is carried out before each run and enables compensation for small changes in the optical arrangement.
- 3D coordinates computation using stereovision and post processing to evaluate the wanted information (twist and bending).
- Real time tracking (up to 20Hz).

There are differences in the detailed implementation of the image processing algorithms. Great care has been taken in marker detection so that the detection is very fast (which provides the real time capability) and very accurate (less than 0.1pixel). Fig. 5 displays the marker detection tool which detects markers within a radius range. The image was acquired at the EWA MDM workshop held at ETW.

3. BENCHMARK TESTS

Although the benchmark tests were to be undertaken under laboratory conditions the participants agreed that they should be undertaken in a way to replicate wind tunnel test conditions as closely as possible, e.g. optical access problems through windows and vibration produced by tunnel operation. This would be achieved by carrying the out tests in a wind tunnel test section. The range of suitable wind tunnels was discussed and it was agreed that the tests should be undertaken in the dummy working section of the TWG at DLR, Göttingen. This facility is shown in Figs. 6 & 7. Although it is not an operational wind tunnel, representative vibration of the system mounts was generated and its effect examined.

The EWA MDM Benchmark tests were undertaken at DLR, Göttingen during the week beginning May 21st 2007. All systems described above were incorporated in the test. This did and will further promote interaction and collaboration between the different development groups.

The test plate of spring-steel, shown in Fig. 8, had an overall size of 210mm x 280mm. It was fixed along one edge. It was possible to independently move the remaining two corners using two linear motor stages. The motors allowed movement of both the free corners of the plate in the range of +20mm to -20mm from the datum position to produce the required bending and twist deformations.

A wide range of plate bend and twist were produced with the increments in corner movement being either 0.1mm or 0.01mm.

The deformed position of the plate had been previously measured for a range of deflections using a 3D measurement table to allow direct comparison with the results obtained using the MDM systems. The repeatability of the deformed shape was better than 10µm.

The test rig was rigidly mounted in the working section of the dummy TWG at DLR, Göttingen, as displayed in Figs. 9 and 10. Suitable markers and patterns were attached to the plate at the necessary positions.

The systems were calibrated using the appropriate targets. These were the standard DLR calibration plate (used by DLR, DNW and ONERA), shown in Fig. 10, and the ETW calibration frame (used by ETW), shown in Fig. 11. The test plate can be seen positioned next to the DLR calibration plate in Fig. 10. The marker size on the DLR calibration plate was 0.4mm. The markers and pattern can be observed on the surface of the test plate.

Vibration of the wind tunnel can degrade system performance and it was considered necessary to include an examination of this effect to allow a full investigation of system performance to be undertaken. A system incorporating electrodynamic actuators was produced which provided camera vibration of defined magnitude and frequency. The system is shown in Fig. 12. Data were acquired with the system producing vibrations at 12Hz, 18Hz and 22Hz. The image acquisition frequency of the cameras was 5Hz and therefore the images were not phase locked. The effect of camera de-calibration was also investigated by undertaking tests with the cameras moved in small steps of about 10pixels in the image over a range of 50 pixels, both for translational and rotational de-calibration.

One single image was captured for each test case when no camera vibration was occurring. This was increased to typically 20 images when vibration was occurring.

The acquired data were analysed to provide an understanding of the current performance of model deformation measurement systems available within the EWA network.

3.2. Results

The tests were undertaken recently and it has only been possible to carry out limited data processing to date. Examination of the processed data displays that accurate results were achieved and that all systems provided data of a high quality.

An example of the results obtained during these tests is shown in Fig. 13. The plot displays the bending of the plate along the center line. The test case presented is one where the plate was bent through a range of 2mm in steps of 100μm. There was no twisting of the plate in this case.

The data acquired using the MDM systems were within +/- 30µm of the geometry measured using the 3D measurement table.

4. CONCLUSIONS

A successful series of benchmark tests has been undertaken to investigate the performance of the model deformation measurement systems currently available within the EWA network. Examination of processed data showed that each system provided accurate and repeatable data. A suitable test rig has been produced which provides an easy method of generating the required deformed shapes. This rig will be available for use in the future development of these systems.

5. REFERENCES

1. D.Michaelis, H.Frahnert and B.Stasicki. ‘Accuracy of Combined 3D Surface Deformation Measurement and 3D Position Tracking in a Wind Tunnel’ ICEM 12 – 12th International Conference on Experimental Mechanics, Politecnico di Bari, Italy, 2004.

2. R.K.van der Draai, R.P.M. van Schinkel and A.Telesca. ‘A New Approach to Measuring Model Deformation.’, ICIASF 99. 18th International Congress on Instrumentation in Aerospace Simulation Facilities, Toulouse, France, 1999.

3. E.Germain and J.Quest. **‘**The Development and Application of Optical Measurement Techniques for High Reynolds Number Testing in Cryogenic Environment.’ 43rd AIAA Aerospace Sciences Meeting, January 2005. AIAA 2005-0458.

4. Y.Le Sant, A.Mignosi, B.Deleglise and and G.Bourguignon. ‘Model Deformation Measurement (MDM) at ONERA.’ AIAA 25th Applied Aerodynamics Conference, Miami, USA. June 2007.

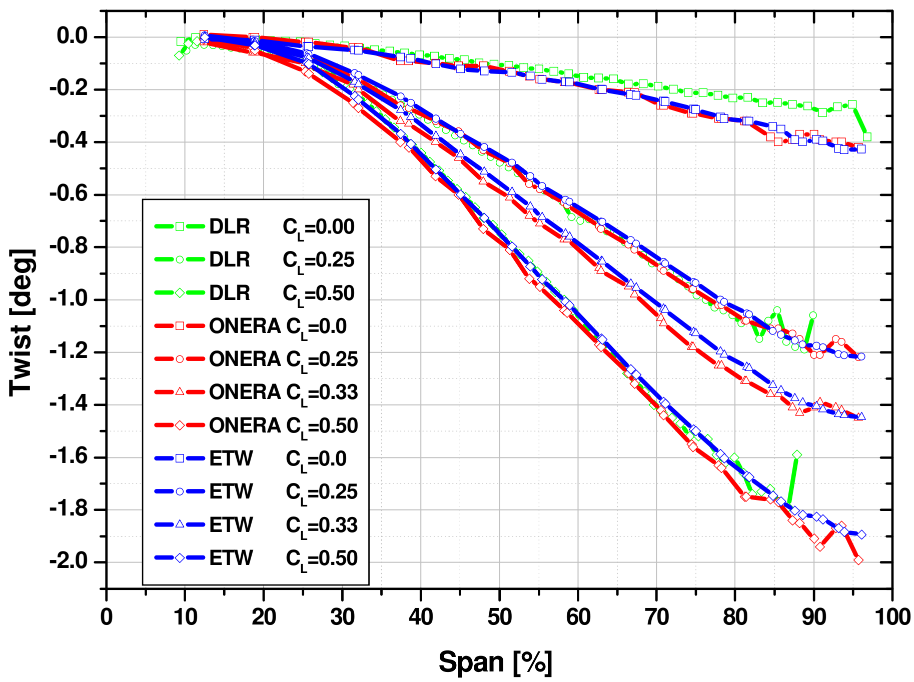

Fig.1 MDM Measurements obtained during the EWA Workshop at ETW.

Fig. 2. DLR Strainmaster System

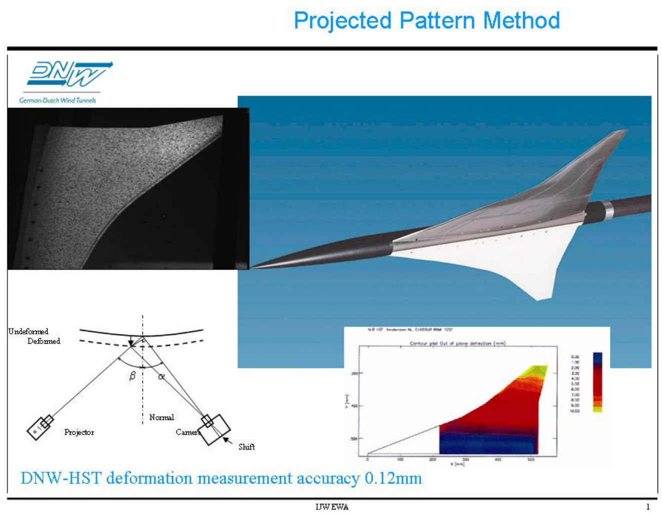

Fig. 3. DNW Projected Pattern Method

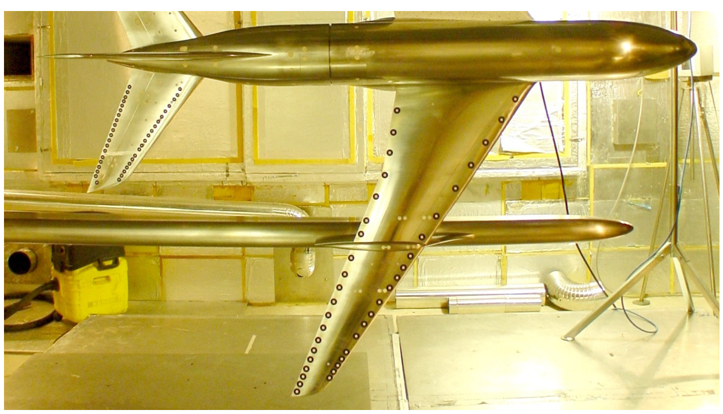

Fig. 4. ETW System showing the attached markers on the main wing and HTP.

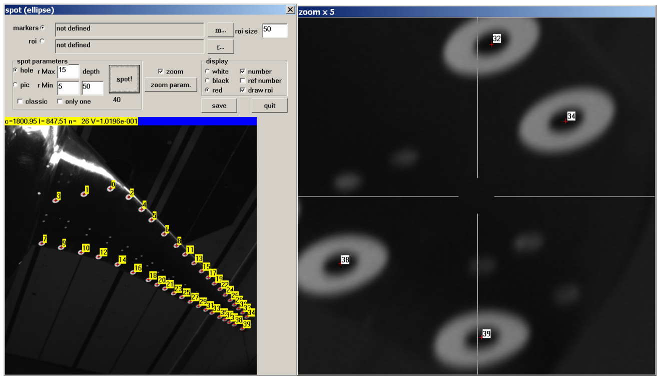

Fig. 5. Marker detection using the ONERA System

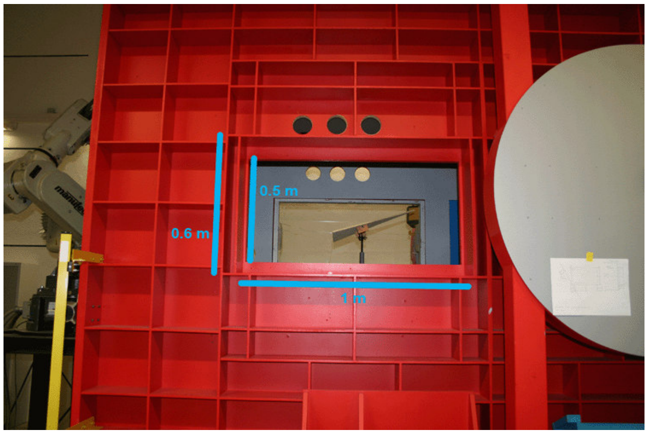

Fig. 6. Dummy TWG Working Section at DLR, Göttingen.

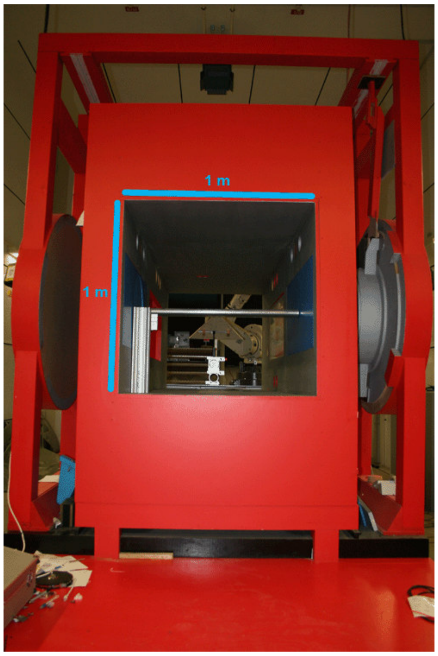

Fig. 7. Dummy TWG Working Section at DLR, Göttingen.

Fig. 8. Test Plate

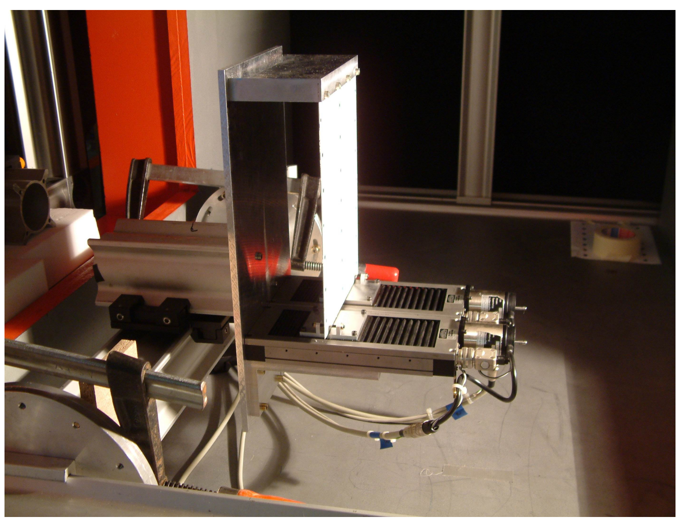

Fig. 9. Test plate mounted in dummy TWG

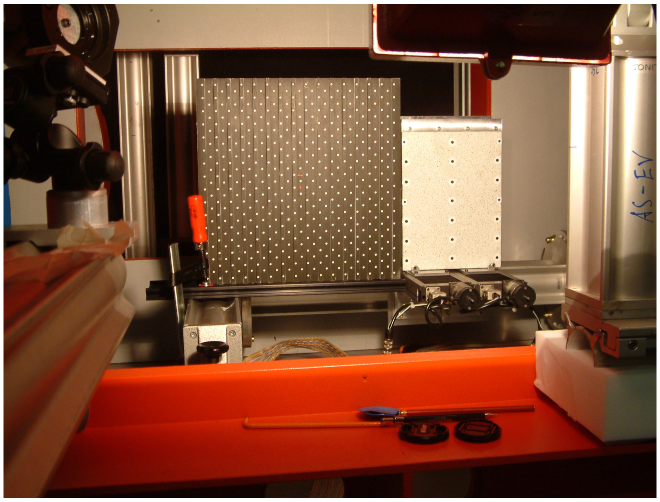

Fig. 10. DLR Calibration Plate Mounted Next to Test Plate

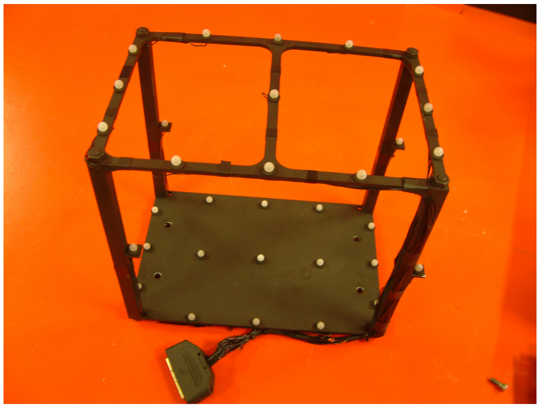

Fig. 11. ETW Calibration Frame

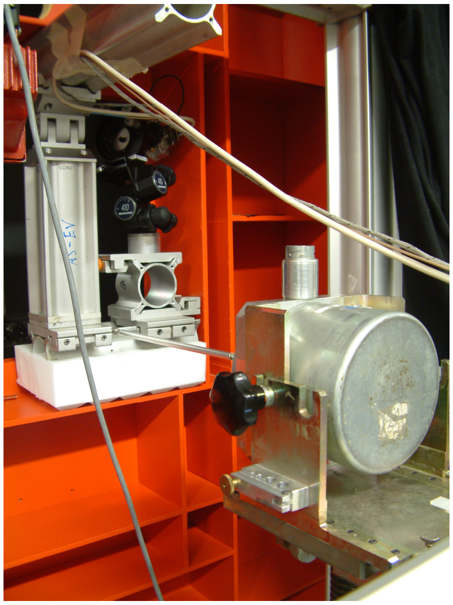

Fig12. Vibration System

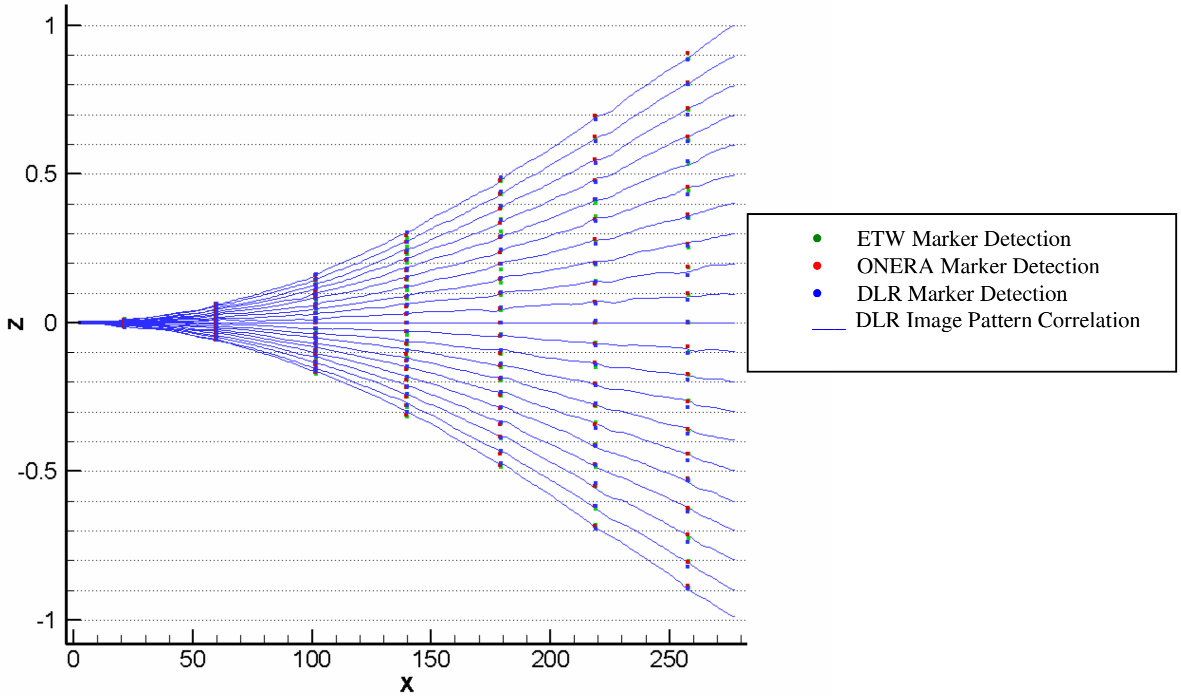

Fig. 13 Benchmark Test Results