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Abstract

An automated system to measure the change in wing twist and bending under aerodynamic load in a wind tunnel is described. The basic instrumentation consists of a single CCD video camera and a frame grabber interfaced to a computer. The technique is based upon a single view photogrammetric determination of two dimensional coordinates of wing targets with a fixed (and known) third dimensional coordinate, namely the spanwise location. The measurement technique has been used successfully at the National Transonic Facility, the Transonic Dynamics Tunnel, and the Unitary Plan Wind Tunnel at NASA Langley Research Center. The advantages and limitations (including targeting) of the technique are discussed. A major consideration in the development was that use of the technique must not appreciably reduce wind tunnel productivity.

Introduction

Model deformation may be defined as the change in shape of a model (particularly the wings and control surfaces) under aerodynamic load in a wind tunnel. This change in the design geometry can cause differences between the acquired and expected wind tunnel results if the expected results are based upon rigid body assumptions. Differences can also occur between acquired wind tunnel data and computational predictions based upon rigid body assumptions. These differences can lengthen and degrade the aircraft design process. The measurement of model deformation has thus been of interest for over 20 years. The fundamental technique used to measure model deformation continues to be photogrammetry as was the case 20 years ago[1], but today electronic imagers are used in place of film cameras. The rapid development of relatively low cost electronic imaging, driven largely by the consumer video market, coupled with improvements in low cost computing have enabled the application of video photogrammetric techniques to a number of different types of measurement problems, including model deformation. However, turnkey video photogrammetry systems are generally not suitable for incorporation into a wind tunnel data acquisition system because of the user interaction required. In addition, limited view ports, illumination, and targeting options often contribute to the requirement for custom measurement systems for large wind tunnels.

The history of the development of a model deformation measurement capability for the National Transonic Facility is presented in reference 2 which includes the rationale for the current single view photogrammetric technique with emphasis on the measurement of the change of wing twist due to aerodynamic load. Examples of the measurement of wing twist in non-automated mode along with error considerations are also presented in reference 2. The wind-off non-cryogenic 1-sigma error in the measurement technique was shown there to be less than 0.03°. Run-to-run repeatabilities in air mode at Mach numbers up to 0.9 and dynamic pressures up to 965 psf were shown to be better than 0.02°. Upright and inverted runs were shown to agree within 0.05°. Test-to-test repeatabilities of better than 0.03° were also noted at moderate pitch angles. Wing twist measurement examples were presented at tunnel total temperatures of -152° F and -250° F.

Major considerations in the recent development of an automated test technique for model deformation were that the productivity of wind tunnel testing should not be appreciably reduced while at the same time providing useful and accurate deformation information. In discussions about model deformation measurement requirements with a number of people involved in aerodynamic testing, the determination of the change in wing twist due to aerodynamic load appeared to be the primary concern, with wing deflection (bending) being of secondary importance. In addition, angular measurements such as model pitch, as opposed to deflection measurements, are common in wind tunnel testing. Thus the measurement of the change in pitch angle at various stations on the wing under wind-off conditions can be used for in-situ calibration. The emphasis in the development of a model deformation capability has been on the accurate and repeatable measurement of the change in wing twist due to aerodynamic load in a manner suitable for routine wind tunnel testing.

Facilities[3]

National Transonic Facility

The National Transonic Facility (NTF) is a fan-driven, closed-circuit, continuous-flow pressurized wind tunnel (ref. 3). The 8.2 x 8.2 x 25-ft long test section has a slotted-wall configuration. The wind tunnel can operate in an elevated temperature mode up to T = 140° F, normally using air, and in a cryogenic mode, using liquid nitrogen as a coolant, to obtain a test temperature range down to about -250° F. Thermal insulation inside the pressure shell minimizes energy consumption. The design total pressure range for the NTF is from 15 psia to 130 psia. The combination of pressure and cold test gas can provide a maximum Reynolds number of 120,000,000 at Mach 1.0, based on a chord length of 9.75 inches. These characteristics afford full-scale Reynolds number testing for a wide range of aircraft. Three types of investigations are possible: Reynolds number effects at constant Mach number and dynamic pressure; model aeroelastic effects at constant Reynolds number and Mach number; and Mach number effects at constant dynamic pressure and Reynolds number. The constraints imposed by operation in a high pressure environment over such a wide range of temperatures have had a significant impact on instrumentation development for the facility. Even though the facility has been operational since August 1984, instrumentation development, improvement, and optimization are still underway.

Transonic Dynamics Tunnel

The Langley Transonic Dynamics Tunnel (TDT) is a unique "national" facility that is used almost exclusively for performing aeroelastic research and for conducting flutter-clearance and other aeroelastic-verification tests of Department of Defense, industry, and NASA fixed-wing and rotary-wing flight vehicles and launch vehicles. Semispan sidewall-mounted vehicles and full-span sting-mounted or cable-mounted models can be used. In addition, a rotorcraft test-bed is available for rotor-blade loads research. The TDT is a continuous-flow, variable-pressure wind tunnel with a 16 ft by 16 ft test section. The tunnel uses either air or a heavy gas as the test medium and can operate at Mach numbers up to about 1.2 while obtaining Reynolds numbers per foot of approximately 3 x 10^6 in air and 10 x 10^6 in heavy gas.

Unitary Plan Wind Tunnel

The Langley Unitary Plan Wind Tunnel (UPWT) is a closed-circuit, continuous-flow, variable-density tunnel with two 4 ft by 4 ft by 7 ft test sections. One test section has a design Mach number range from 1.5 to 2.9, and the other has a Mach number range from 2.3 to 4.6. The tunnel has sliding-block-type nozzles that allow continuous variation in Mach number while the facility is in operation. The maximum Reynolds number per foot varies from 6 x 10^6 to 11 x 10^6, depending on Mach number. Types of tests include force and moment, pressure distribution, jet effects, dynamic stability, and heat transfer.

Experimental Procedure And Data Reduction

The optical technique used to determine the change in wing twist and bernding due to aerodynamic loading is based upon the recording and analysis of digitized video images. A video signal from a standard RS-170 solid state camera with 752 horizontal by 240 vertical pixels per field is routed to a frame grabber controlled by a PC which records a predetermined number of video fields into the frame grabber memory. The adjustable field integration time of the charge-coupled device (CCD) video camera is set to 1/250 sec or less in order to reduce the effects of dynamics on image recording. Fixed focal length lenses have been used at both the TDT and UPWT. A 10 to 100 mm focal length remote zoom lens is currently used for imaging at the NTF. Considerations when calibrating zoom lenses for wind tunnel use are discussed in reference 4

Targets must be placed on the wing at the semispan locations where change in wing twist and bending are required. The Y coordinates of the targets in the spanwise direction are determined from pressure tap and other reference locations on the wing to be used in the computation of X in the streamwise and Z in the vertical direction. To date, measurements with the single view technique have been limited to the outboard half of the wing in order to provide higher resolution. High contrast targets are required on the wing in order for the image processing routines to automatically locate the targets reliably, without ambiguity, and with no user interaction. These wing targets are either white diffuse circular targets on a dark background, or ideally, retroreflective tape targets such as have been used at the TDT and the UPWT. A light source placed near the camera will yield a very high contrast image when the retroreflective tape targets are used.

Retroreflective tape targets have not yet been used at the NTF due to difficulties in locating a light source sufficiently close to the camera. In the past at the NTF, circular targets were applied to the wing surface with a Sharpie® marking pen. These targets were neither durable nor high contrast so that the automated location of targets was not feasible. Thus image data were recorded and then analyzed at the completion of data taking. This procedure often led to long delays between data acquisition and the final data reduction. More recently (early 1996), a polished paint technique has been used at the NTF to produce high contrast white dot targets on a flat black background allowing the first automated measurements of wing twist at the facility. A typical target set at a given semispan station consists of 6 white circular targets with a diameter of 0.2 inch in a line along the streamwise direction on a black stripe 0.8 inch wide as in figure 1.

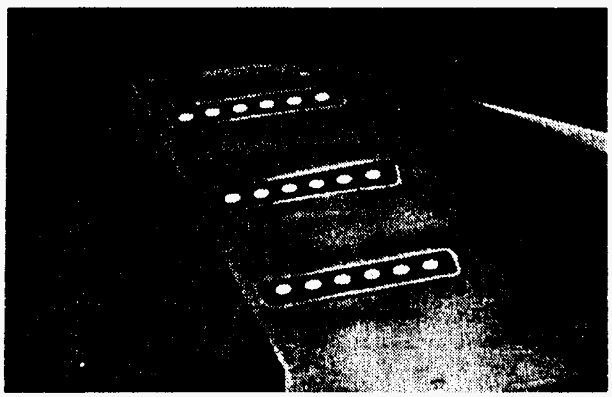

Fig. 1. Polished paint targets on model at the NTF.

The procedure for the polished paint technique used at the NTF to produce high contrast white targets on a black background follows. The model is cleaned with either methanol or Freon. Target layout is then established on the model surface. A combination of masking and plating tape are used to mask off targets and all areas that are not going to be painted. The masking is applied so that soft edges are achieved when applying the lacquer primers and paints. A thin coat of primer is then applied over the exposed area. After a 1 hour drying time for the primer, multiple layers of flat black paint with 1 minute between layers are then applied. The typical total thickness for the flat black paint is approximately 0.002 inch. The flat black paint is allowed to dry overnight before removing the masking tape over the circular targets. Precut inside diameter tape, typically 0.05 inch larger than the previously masked circular targets are then applied at each target location. All areas not to receive the white paint are also masked. Primer is then applied over the exposed circular target areas. Flat white paint is then applied to the circular target areas after allowing the primer to dry for 1 hour. The number of layers of white paint applied is equal to that used for the flat black paint. The white paint must then dry overnight before removing all masking tape in order to initiate polishing.

A preferred polishing direction for the painted model surface, usually in the streamwise direction, is established. A coarser grade (15 micron) polishing paper is used to lap off the white circular areas around the targets. Polishing is then continued over the entire painted areas with a finer grade (9 micron) polishing paper. One micron cerium oxide solution is used for the final surface finish. Final polishing must be performed with extreme care as the cerium oxide solution can easily remove the paint. A portable profilometer is then used to measure the surface finish of the polished paint targets. For wing panels where it is practical the target locations are measured with a 3D coordinate measurement machine, otherwise hand measurements of the Y values for the targets are made.

An additional consideration for the automated method is the background in the field of view of the camera. Automatic target location is much faster and more reliable if the gray levels of the wing targets are significantly greater than the background. At the TDT and the UPWT where retroreflective targets are used, special preparations of the wing and test section wall in the field of view of the camera are usually not necessary. However, at the NTF it is necessary to paint flat black not only the portion of test section wall in the field of view, but also the portion of the test section wall which is viewed by the camera as a specular reflection from the mirror-like upper wing surface. This then causes the wing surface to appear dark, making it easier to automatically locate the white diffuse targets on the wing surface.

Rather simple mounts are used for the CCD cameras at the TDT and UPWT. However, due to the extreme ranges of tunnel conditions at the NTF, the CCD camera there must be mounted in a protective housing in the test section sidewall. The camera looks over the fuselage at one of the wings of the model. The camera is rotated 90° so that the horizontal X axis is vertical on the image plane in order to provide additional viewing flexibility. In addition, the 90° rotation more nearly matches the number of pixels vertically and horizontally across a target image since perspective causes the images to be longer in the X (streamwise) direction. The protective housing at the NTF is equipped with insulation and sheath heaters to maintain camera temperature. The housing is pressure rated to greater than 9 atm. In order to prevent frost, air heated by an inline heater flows to a purge ring with a number of holes to direct the heated air over the inside surface of the one inch thick fused silica window viewport. A purge air vent to atmosphere maintains the camera housing pressure at approximately 1 atm.

The initial pre-test calibration procedure for the video optical technique determines those camera parameters necessary for conversion from pixels to corrected image plane coordinates. Techniques for determining these parameters are discussed in references 4 through 6. The need for extensive camera calibration is lessened somewhat by on-line calibration using the model pitch angle for wind-off reference at the tunnel total temperature and pressure test conditions.

The pointing angles and location of the camera in the tunnel coordinate system are determined at the start of the test by photogrammetric resection[7] on a target plate which is aligned to the X, Z plane of the tunnel. The target plate consists of a flat black plate with an 11 X 11 array of white targets with known locations. The target plate is translated a known amount along an optical rail to several Y locations where resections are made. Provided the alignment is correct, the three pointing angles and X and Z of the camera will be nearly equal at each location of the plate whereas the Y value for the camera will follow the change in location. A variation of a technique described in reference 5 can then be used to determine the photogrammetric principal point which causes best agreement with the changing Y values of the target plate if necessary. Once the three pointing angles and position of the camera are established relative to the tunnel coordinate system, measurements can then be made on the target plate for an in situ check of the technique by comparing measured and known Z values. Providing the Z value determinations are reasonable, a pitch polar can then be taken with wind-off to ensure that the change in pitch angles on the wing measured by the automated system track with the onboard accelerometer.

An alternate technique to the above for determining the pointing angles and location of the camera in the tunnel coordinate system is by photogrammetric resection of a wind-off reference run. A known set of targets for resection are established by merging wind-off points at several angles into a single reference target field based on knowledge of the center of rotation and the rotation angle from the onboard accelerometer.

The final calibration step requires a wind-off pitch sweep at run temperature and pressure over the range of angles expected during the subsequent wind-on testing. A wind-off polar in the middle and at the conclusion of a set of runs is helpful to verify system stability, especially at the NTF during cryogenic operation. Image plane coordinates are determined by gray level center-of-mass calculation after subtracting the background plus a few additional gray scales. The background is found from the maximum gray scale on the border of a window of pixels which is slightly larger than the target image[5]. The mean pixel coordinates from the sequence of recorded images are then transformed and corrected (including correction for the photogrammetric principal point x_p, y_p) to give units of length. The X and Z coordinates are determined from a single view solution of the following collinearity equations

$$x = -c\frac{[m_{11}(X-X_c) + m_{12}(Y-Y_c) + m_{13}(Z-Z_c)]}{[m_{31}(X-X_c) + m_{32}(Y-Y_c) + m_{33}(Z-Z_c)]}$$

$$y = -c\frac{[m_{21}(X-X_c) + m_{22}(Y-Y_c) + m_{23}(Z-Z_c)]}{[m_{31}(X-X_c) + m_{32}(Y-Y_c) + m_{33}(Z-Z_c)]} \qquad (1)$$

where x and y are the corrected image plane coordinates, c is the principal distance (or camera constant) which will be slightly larger than the focal length, X, Y, and Z are the object space coordinates of the target, X_c, Y_c, and Z_c are the coordinates of the perspective center, and the m terms are elements of the following rotation matrix

$$\begin{aligned}
m_{11} &= \cos\phi\cos\kappa \\
m_{12} &= \sin\omega\sin\phi\cos\kappa + \cos\omega\sin\kappa \\
m_{13} &= -\cos\omega\sin\phi\cos\kappa + \sin\omega\sin\kappa \\
m_{21} &= \cos\phi\sin\kappa \\
m_{22} &= -\sin\omega\sin\phi\sin\kappa + \cos\omega\cos\kappa \qquad (2) \\
m_{23} &= \cos\omega\sin\phi\sin\kappa + \sin\omega\cos\kappa \\
m_{31} &= \sin\phi \\
m_{32} &= -\sin\omega\cos\phi \\
m_{33} &= \cos\omega\cos\phi
\end{aligned}$$

The pointing angles of the camera, ω, ϕ, and κ, which rotate about the X, Y, and Z axes respectively, are defined as positive if they are counterclockwise when viewed from the positive end of their axes. The X and Z coordinates determined from the collinearity equations (1) for a single camera view solution are given below

$$X = X_c + (Y - Y_c)(a_2 a_6 - a_5 a_3) / (a_4 a_3 - a_1 a_6) \quad (3)$$

$$Z = Z_c - (X - X_c) a_1 / a_3 - (Y - Y_c) a_2 / a_3 \quad (4)$$

where

$$\begin{aligned} a_1 &= x\, m_{31} + c\, m_{11} \\ a_2 &= x\, m_{32} + c\, m_{12} \\ a_3 &= x\, m_{33} + c\, m_{13} \\ a_4 &= y\, m_{31} + c\, m_{21} \\ a_5 &= y\, m_{32} + c\, m_{22} \\ a_6 &= y\, m_{33} + c\, m_{23} \end{aligned} \quad (5)$$

Expression (4) above is suitable for use when the camera is rotated 90° so that the horizontal X axis is vertical on the image plane. When the camera is not rotated, the a_3 term may be nearly zero so that a_1, a_2, and a_3 in expression (4) may be replaced with a_4, a_5, and a_6 respectively.

The slope angle in the X, Z plane is determined by least squares for a set of targets at each semispan station. The slope angle with wind-on is corrected to first order based on wind-off curve fits of the measured slope angle minus the angle-of-attack (α) versus the measured slope angle. Typically, the standard deviations of the residuals after the curve fits are less than 0.03°. Separate curve fits are used for each semispan station which allows for an online calibration at condition, which is especially critical for cryogenic operation at the NTF.

Software

The software provides the interface between the hardware and the operator. It also runs in an automated mode which is contact closure activated by the tunnel data acquisition system so whenever the tunnel operator takes a data point, an optical measurement is taken as well. Data taking can also be initiated by keystroke if desired.

The software for optical measurements has two primary functions. The first is to set up the video capture hardware, and the second is to reduce and analyze the sequence of raw images automatically. The setup portion of the software reads an input file generated at the beginning of the test by the user which contains all the specifics and/or parameters of the particular test. Some of these parameters include: video resolution, camera pointing angles and location in the tunnel coordinate system, principal distance, number of targets and arrangement, approximate background lighting level, target contrast, approximate size of targets, how many images to capture, how many images to process, etc. The program reads theses parameters and sets up the video capture hardware accordingly. It then waits for a data point to be taken, or for the operator to activate any of the options at their disposal. Some of these options include: view any or all of the raw video images, set the current point number manually or read it automatically from the tunnel data computer by either FTP or RS-232, process images that are live or read them in from a pre-recorded source, check the difference between any two data points, whether to track the targets between data points, etc. Once the signal is received to take data the software captures all the raw images first and then starts to process them. It is anticipated that future versions of the software will process all the data in near real time, reducing the amount of memory needed to one image.

The process of reducing the raw images is divided into several steps. The first step is to find all the targets on each image of the sequence by a process known generally as blob analysis. To find a target, the least significant bit (LSB) of all pixels are set to zero and then checked against a pre-defined threshold matrix. To find a valid target, several conditions must be satisfied. After finding a possible target, the LSB of the pixels in the rectangular region that encompasses the target are set to one so that region is not searched again. The four corners of the region are then checked to make sure the target is not too close to the edge of the field of view. If these conditions are met, the background is subtracted out of the region and a gray-scale mass centroid is computed for the target to be used as the target location in the image plane.

If all the targets are not found on an image it will separate that image from the images in which all targets were found. If all the targets could not be found on any image the reduction process stops temporarily, the operator is notified on the computer screen, and the program waits for another data point. All the images in which all the targets were found are sorted into groups specified by the setup file and logged to a file along with the image pixel location of each target. Equations 1 - 5 are then used to compute the X, Z

coordinates automatically for each target for each image of the sequence. Individual target locations (*X*, ,*Z*) are computed and saved along with the averages. Processing then continues to calculate the angle of each group or row of targets by doing a least squares fit to the *X*,*Z* locations. A file is generated containing the slope and intercept of each row of targets on each image along with statistics. Some of this information is also displayed on the computer screen. At the end of a series of runs, the operator then designates the wind-on runs to be analyzed and the wind-off run to be used for calibration. Quick plots of the wing twist can then be viewed before transferring the reduced data to the end user.

Error Considerations

The total uncertainty is expressed as the sum of systematic, or bias error, and precision, or repeatability error. Bias errors are generally very difficult to determine under flow conditions, whereas repeatability can be computed. In addition to laboratory and wind tunnel wind-off determinations of error, run-to-run and test-to-test repeatabilities can be used to gauge the adequacy of wing twist measurements with flow[2].

The uncertainty requirements for the measurement of wing twist caused by aerodynamic loads are unresolved. It has been suggested that the desired uncertainty for wing twist which corresponds to an uncertainty of 0.01° for the model pitch angle is of the order of 0.05°, not 0.01°. In other words, an uncertainty of the order of 0.05° in wing twist is thought to have about the same magnitude effect on drag measurements as 0.01° uncertainty in model pitch angle. A sensitivity study of the effects of wing twist and bending on CFD solutions should aid in uncertainty analyses and may impact future test technique developments in this area.

Wing twist measurement error can occur due to errors in the camera position and pointing angles which are used in equations (2) through (5) to determine the *X* and *Z* coordinates. Pre-test calibration errors can also contribute to wing twist error if, for instance, incorrect lens distortion or frame grabber affinity corrections are used. Also note that errors in the onboard accelerometer will contribute to the error in the wing twist angle.

The *Y* coordinate, assumed to be known for the single camera solution, is constant and well-behaved for ambient wind-off pitch sweeps. This is verified by independent measurements in the test section as well as by the single camera technique, which typically has an rms error of 0.03° or less when compared to the onboard inertial angle sensor under wind-off ambient conditions. However, *Y* is not constant during wind-on conditions due to model yaw dynamics (for sting mounted models) and wing bending[2]. Lateral model motion at the NTF as large as ± 3 mm based on video images from a test section ceiling camera have been noted. This variation in *Y* contributes to the precision error. Recording multiple images over the data sampling period to determine mean image coordinates reduces this error in *Y* by averaging. The precision of the technique is dictated by the number of fields recorded at each data point. The time taken to analyze a given number of fields depends on the total number of targets. Thus there is a tradeoff between precision and data taking rate. Figure 2 shows the running mean

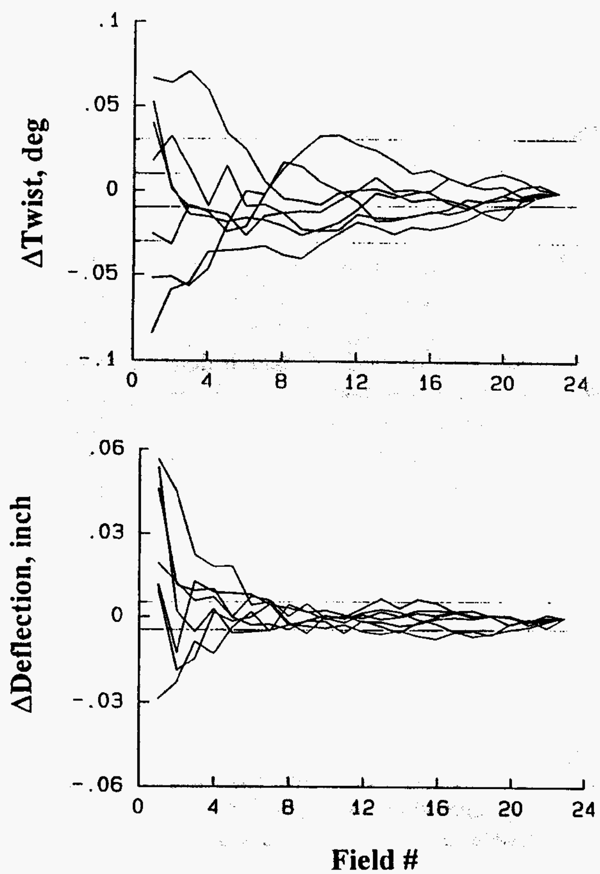

Fig. 2. Running mean of twist and deflection.

of twist and deflection for 7 data points at Mach = 0.8 away from buffet. As the AoA approaches the buffet region even more fields will be required to ensure convergence.

Any remaining error in Y will be nearly the same for all wing targets. This is verified by plots of the variation in the pixel coordinates of the targets as a function of time which show that the variations are typically equal to within a fraction of a pixel even for total excursions of several pixels. In figure 3 these variations are plotted at Mach 0.8 where the mean pixel coordinate for each of 15 targets covering about 1/2 of the outboard portion of the wing is subtracted before plotting. The individual targets nearly overlap on the plot with a mean standard deviation of only 0.13 pixel. Thus as long as the image locations are not too far separated, the errors in X and Z will also be similar and will tend to partially cancel out.

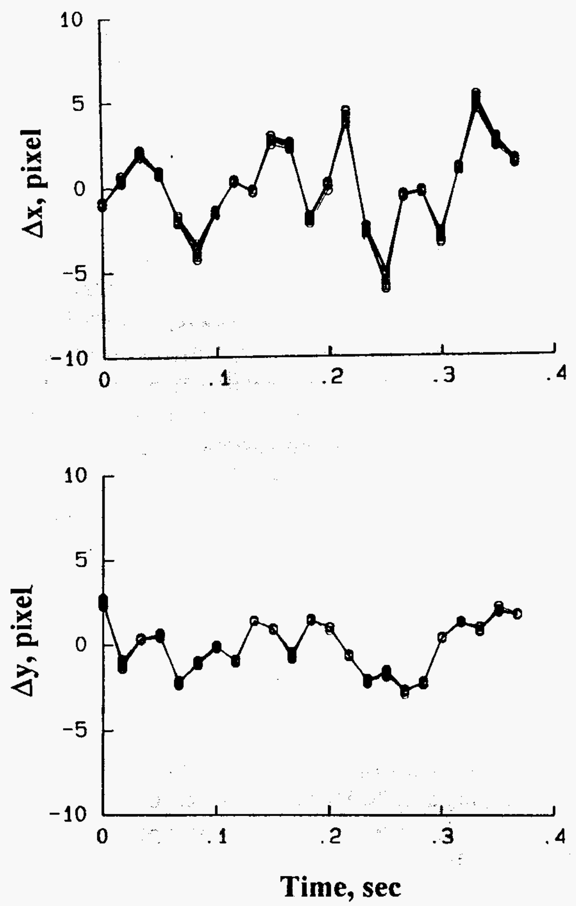

Fig. 3. Centroid variations of targets at M = 0.8.

Applications

National Transonic Facility

The NTF has had a limited capability for model deformation measurements since 1984[7]. Instrumentation developments at the NTF led to the current automated technique which was used for the first time at the NTF in early 1996. A non-automated version of the current single view technique has been used for a number of tests since 1992. The constraints imposed by operation in a high pressure environment over such a wide range of temperatures have had a significant impact on instrumentation development for the NTF. Even though the facility has been operational since August 1984, instrumentation development, improvement, and optimization continues. All of the currently available optical measurement techniques such as flow visualization, fluorescent mini-tufts, and model deformation, as well as those under consideration such as pressure and temperature sensitive paints, must be able to accommodate the limited access and mounting options at the NTF. The increased importance of productivity and the very high cost of tunnel operation make it very difficult to justify dedicated run time for test technique development or enhancement. Another instrumentation development problem which has recently become more apparent is the competition between the various optical techniques for lighting, viewports, and mode of operation. During a recent test fluorescent mini-tuft and wing twist data were taken together for some runs. This required manual changing of the test section lighting for each point with a corresponding decrease in data taking rate for these runs. As temperature and pressure sensitive paints and other flow visualization techniques are employed at the NTF, the competition between the various techniques will worsen.

A major problem in automation for the NTF has been the need for high contrast targets which do not exceed the stringent surface finish requirements. The mean surface roughness for the polished paint targets described earlier has been measured with a surface profilometer to be consistently around 10 microinch rms which is currently adequate. However, the height of the stripe containing the targets and background is typically 0.002 inch. Even though this is not an abrupt step, but rather a gradual rise to the 0.002 inch height, there may still be concern about the effects of the targets on aerodynamic data.

In order to partially assess the effects on aerodynamic data due to the painted targets, a set of 4 polars, plus 1 inverted polar, was run with the targets on and with the targets off at low Reynolds number in the air mode of operation at the NTF. Figure 4 below shows the effects. The data shown is the difference between curve fits of the data at selected angles-of-attack (α). Lift and drag coefficient data indicate a negligible effect at low α, but show an increasing effect beyond α

= 8°. Examination of the raw data indicate that the curve fits may have slightly biased the differences (on the order of one drag count high) at high α. In addition, data repeatability at the higher angles was on the order of ± 2 drag counts. Thus, it is not clear that the differences shown in the figure are significant. The effect on pitching-moment and lift-to-drag ratio is negligible, as was the effect of the lateral/directional coefficients (the targets were installed on the left outboard wing panel only). Further work is required to fully quantify the target effect on the aerodynamic data at the NTF.

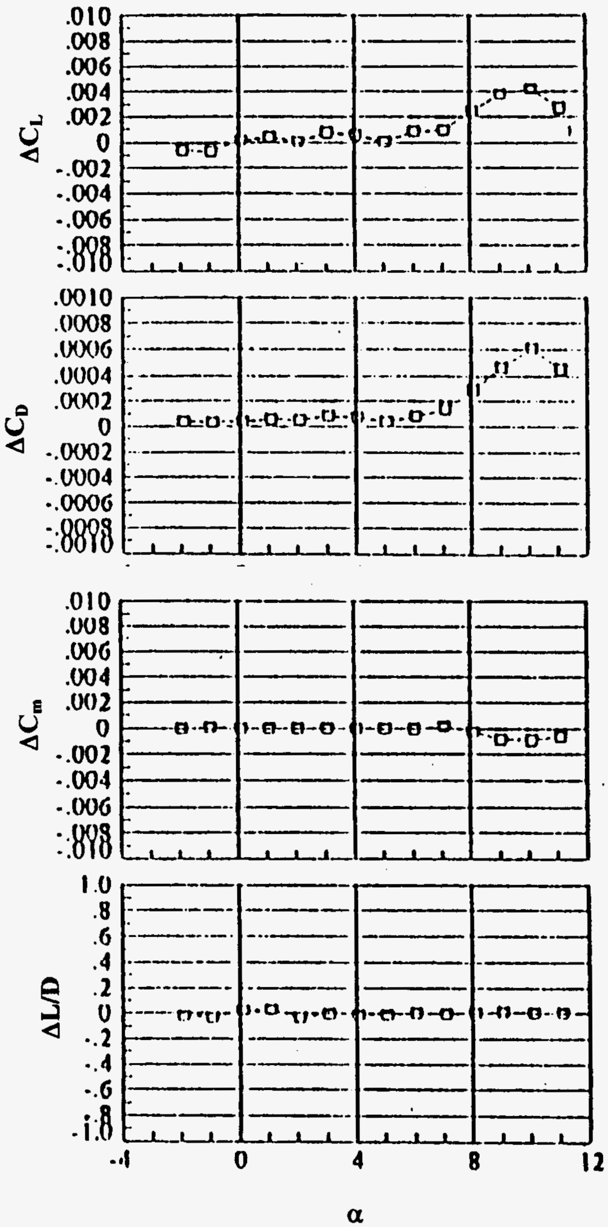

Fig. 4. Target effects on aerodynamic data.

Recently laboratory investigations conducted with a combination of shallow milling to 0.002 inch filled with paint (or proper filler) in order to maintain the surface contour appear promising. Such a target application technique is expected to be used at the NTF in an upcoming test.

Transonic Dynamics Tunnel

The first automated measurements of wing twist and bending at NASA Langley were made at the TDT in 1994 where the application of high contrast targets on the wing made possible the use of image processing techniques to automatically determine the image coordinates of the targets. The system at the TDT has been used for six tests of semispan models. A frame grabber with a large onboard memory of 64 Mbyte has been used to record and analyze up to 8 sec of video images per data point taken at a 60 Hz rate. Laboratory tests have also been conducted in preparation for the Northrop Grumman Smart Wing which will be tested at the TDT. The Smart Wing will have variable twist and adaptive control surfaces which will provide continuous wing contour and variable camber.

In addition, the measurement system originally developed for the measurement of wing twist and bending at the TDT was adapted for displacement measurements during a preliminary test of a piezoelectric wafer being investigated to control aerodynamic surfaces. Fluorescent paint on the wafer edge illuminated by UV light sources provided a high contrast image suitable for automated measurements in a small scale wind tunnel setup. Deflection measurements at a 30 Hz rate in bursts up to 1 minute (or at a 10 Hz rate for continuous operation) were possible with the modified automated measurement system.

Unitary Plan Wind Tunnel

A portable video measurement system was used to make aeroelastic wing deflection and twist measurements on a sting mounted research model at Mach 2.4 in Test Section 2 of the UPWT in 1995. These unscheduled initial measurements at the facility were made with little interruption to the scheduled test plan. The aeroelastic data obtained from this test is being used for input to a CFD code for the true model geometry under test in order to improve comparisons of experimental and predicted pressure distributions. Successful results with the portable system led to the decision to procure a dedicated system for the UPWT. Acquisition of hardware for the dedicated system is nearly complete. A feasibility study has also been initiated to determine the practicality of a similar measurement system at the Langley 16-Foot Transonic Tunnel.

Summary

An automated technique for measuring the change in wing twist and deflection due to aerodynamic load has been described. The technique has been used at three major NASA Langley facilities, two of which have dedicated measurement systems. The third facility should have a dedicated capability by the summer of 1996. The experimental procedure and data reduction have been described. High contrast wing targets are crucial in order for the automated image processing routines to work reliably. A technique to obtain high contrast targets suitable for cryogenic operation has been presented. Error considerations have been discussed.

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W. K. Goad is acknowledged for his many suggestions and dedication in the development and application of video measurement systems at the NTF and the TDT. S. Q. Tran was instrumental in the development and application of the polished paint technique for high contrast targets at the NTF. L. R. Owens and R. A. Wahls provided the measurements of the aerodynamic effects of the polished paint targets and have also collaborated on a number of tests, including the recent first application of the automated technique at the NTF. T. S. Daniels first coded the image processing routines which made possible the automation of the technique and was instrumental in the initial development. K. H. Cate has also contributed to coding. H. R. Dismond has assisted in installations and operations. Finally, the operations personnel of the NTF, the TDT, and the UPWT are acknowledged for assistance and support in developments and applications at their facilities.

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