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Videogrammetric Model Deformation Measurement System User Manual

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April 2002

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Contents

The purpose of this guide is to provide the user of the NASA **VMD** system, running the **MDef** software Version 1.10, all information required to operate the system.

Overview

The NASA Videogrammetric Model Deformation (**VMD**) system consists of an automated videogrammetric technique used to measure the change in wing twist and bending under aerodynamic load in a wind tunnel. 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 fixed (and known) third dimensional coordinate, namely the span-wise location. The measurement technique has been used successfully at the National Transonic Facility, the Transonic Dynamics Tunnel, the Unitary Plan Wind Tunnel, and the 16-FT Transonic Tunnel at NASA Langley Research Center and the 12-Ft Subsonic Tunnel at NASA Ames Research Center. A major consideration in the development of the measurement system was that productivity must not be appreciably reduced. *(Reference 1.)*

Hardware List:

• Minimum: Pentium-based personal computer; 64 MB RAM; 500 MHz processor; 30 GB hard disk; LS-120 disk drive or 100 MB zip drive; 40x CD-ROM; and a mouse.
• Motherboard with two, adjacent, full-length card slots with no obstructions.
• 17-inch monitor.
• EPIX Model 12 frame grabber board.
• EPIX external cable bundle, model 1DB25.
• 4MIP Software, Ver. 3.0; 4MEG VIDEO – Image Acquisition, Display, Processing, Analysis.

Note: For examples in this report a Hitachi CCD Camera, model KP-M1U with pixel clock output for optimum performance was used (see fig. 001 Hitachi CCD Camera-Side View). However, a video camera can be used without pixel clock output at reduced performance.

• Hitachi CCD Camera, model KP-M1U, with pixel clock output option.
• Camera Junction Box with clock out (if using pixel clock lock option).
• Hitachi mounting plate, model TA-M1(or equivalent).
• Hitachi AC adapter, model AP-130U (or equivalent).
• Hitachi camera cable, model C-501KS (or equivalent).
• Fostec fiber optic light bundle, Part # A08051.40 (when using retro-reflective targets only, when using polished paint targets [NTF] use existing test section lighting).

- Various lens sizes: 16mm, 25mm 35mm, 50mm and 75mm, 10-100 mm zoom (fixed focal lengths are preferred for optimum performance if possible).
- Two video monitors, (1) live-view direct from camera with loop through to Epix frame grabber, and (2) output from Epix frame grabber.
- 4 BNC RG-59, 75 ohms cables.
- 1 BNC RG-59 cable connected to a contact closure.

Note: Other parts may be needed depending on the manner in which wind-tunnel data is being sent to the **VMD** system (See **"Trigger Connections"**).

Experimental Setup:

Camera

The camera is mounted at an angle to the model and at a distance to adequately frame the portion of interest of the model (usually 1 of the wings) to be measured. The camera should also be positioned at an angle to the model (typically around 30 degrees to the horizontal for horizontally mounted models) in order to view all targets on the wing. The camera's shutter should be ON with the shutter speed set to the shortest exposure (usually 1/250 sec or shorter if the lighting is adequate) that can be used at a moderate f-number. *(Reference 2.)* For some dynamic applications with sufficient return from the targets, 1/10,000 sec exposure may be used to lessen image smear. The camera should be in **FIELD** mode. Lens choice is determined by the proximity of the camera to the model and the need to see all the targets on the model*.*

Connections

- With the computer turned off, mount the EPIX Model-12 frame grabber board into an ISA slot with enough room to accommodate the 2 board widths.
- The EPIX external cable bundle is connected to the rear of the EPIX Model-12 frame grabber board. (See fig. 002, EPIX bundle cable.)
- Connect one end of the camera cable, (HR10A-10P-12S [01] for Hitachi KP-M1U), to the camera output, DC IN/SYNC and the other end to the junction box.
- A BNC cable is connected to VIDEO OUT on the junction box and the other end is connected to VIDEO IN on one of the video monitors; this is LIVE video. (See fig. 003, Cable Junction Box-Hitachi Camera.)
- Connect a BNC cable from VIDEO OUT of the live monitor to the EPIX external cable bundle connection labeled VIDEO_IN.
- Check that the connection to the monitors are properly terminated if not automatically terminated. 75 ohms should be used for the last termination and High Input impedance termination used if feed through loop is used.
- Connect a BNC cable from the green-labeled EPIX connection from the external cable bundle to the input of the second monitor sometimes labeled "EPIX".

- From the junction box, connect one end of a BNC cable to CLOCK and the other end to CLOCK_IN on the EPIX external cable bundle. (Skip this step if using a video camera without pixel clock output.)
- Connect the contact closure cable to EXT_IN on the EPIX external cable bundle.
- Connect the AC adapter's DC cable to DC IN on the junction box. (See fig. 004, AC Converter-Hitachi Camera.)
- Power-up (117V) the computer, monitors and the camera.
- Select a lens focal length that will allow the targets on the model to fill the camera view, allowing enough image space for movement of the model – due to changes in angle of attack and wing bending - under test conditions, while keeping the all targets within about 80% of the field of view.
- Re-position the camera as necessary for optimum viewing with consideration for the angle of attack range and anticipated sting and wing bending.

Trigger Connection

The EPIX card has a trigger input connection labeled (EXT_IN) on the cable bundle that can be used to trigger data taking. The trigger is a TTL level high to low transition. The EXT_IN floats high (~5V) and a simple short to ground (0V-contact closure) is needed to trigger the signal.
An alternative method of triggering the system is via a network connection to the Data Acquisition System (DAS) in the facility where the test is conducted. A network connection requires the computer to have an Ethernet card installed, network address to be assigned, and the network port that is to be monitored. When MDef is started with the proper command-line options, it will establish a network connection with the DAS; MDef will then pole the DAS several times a second to determine when to take data. *(Reference 3.)*

Software Setup:

Software Environment

Windows 98/2000 is the primary operating system of the computer.
The primary software application used to acquire model deformation
measurements is MDef Ver. 1.10. The secondary software applications used are
EPIX 4MIP Ver. 3.0 and MatLab Ver. 5.3 (or later). It is also suggested that a text
editor, such as TEXTPAD be installed.

System Initialization

Windows 98/2000 provides a login requirement to operate the computer. The
user should login as "mdef".

Windows Icons: Essential test software programs and test files can be accessed
with short-cut icons on the desktop. They are:

- **MDef:** The Model Deformation program.
- **4MIP:** The Image Acquisition, Display, Processing and Analysis program.
- **MATLAB 5.3** (or higher).
- **Param.dat:** The configuration file for MDef.
- **Tunnel.log:** Tunnel data acquired through DAS for each point taken.
- **Test Directory Folder:** Windows file structure of test sub-directories and
  files.

Icons are created by right-clicking on an application or file. Select **Send To**
then select **Desktop (Create Shortcut).** Right click on the icon and select
Properties → Shortcut (if not the default). For files such as **param.dat** and
tunnel.log, verify in the **Target** field that the Notepad application is indicated
as the source to open the file. For example, the **Target** field should be set as:
Notepad\C:\Facility\NTF\T119.777. The paths for the icons **Target** field
should match the current test's work directory. For software applications,
the **Target** field should indicate the current test directory.

Data Directory Structure:

All directory data setup files and acquisition files are located in the FACILITY
directory. Directories are named after the facility where the test is being
conducted. Test (or work) directories are created in the appropriate facility
directory. *(Reference 3.)*

For example, for a 777 model tested at the National Transonic Facility, the test
number was 119, therefore, the work directory would be:

C:\FACILITY\NTF\T119.777

At the beginning of a test, the user must set the path directory for all associated files. This is done in the Windows directory.

• Open Windows Explorer.
• On the c:\ drive, go to the Windows directory.
• Scroll down to file **"mdef_dir.bat".** Double click on the file.
• Edit the two lines in the file to reflect the test name of the current test. For example, the test name lines would be:

ECHO. C:\Facility*NTF\T119.777* and
CD C:\Facility*NTF\T119.777*.

• Go to **File**, select **Save**, then **Exit** file.

The necessary files are:

• **MDef.exe**   The main VMD program
• **Param.dat**   The test configuration file
• **FlapAngl.ini**   Flap and wing angle configuration file
• **Polydat.ini**   Target locations, **eta**, are entered here; user created file
• **Loadsensitivity.ini** Load values of each target row station; user created file. Values are customer generated.

The user created files can be copied from the previous test and edited for the current test.

The miscellaneous files are:

• **GetFile.bat** The file used to obtain the wind tunnel data when a socket connection is not used
• **For-A.exe** Reads a stream of RS-232 data and uses it to create a copy of Video.dat
• **For-A.ini** Configuration file used by For-A.exe
• **MDef.send** A sample script file used by the DAS to format and send data to MDef via a socket connection
• **ReRun.exe** Re-processes the target data using a modified copy of Param.dat
• **ReDoFlap.exe** Re-processes the Flap-Angle data (FlapAngl.txt) using a modified copy of FlapAngl.ini

The subdirectories associated with the test directory are:

CENTROID   Centroid data files are saved here in the format, Centxxxx or Cerrxxxx, where the Cerr files are files with an insufficient number of targets to allow automatic sorting

IMAGES   RAW and TIFF image files are saved here
XYZ   XYZ data files are saved here in the format, XYZxxxx
ZSLP   Z-intercept/Slope files are saved here in the format, ZSLPxxxx
The above are output files used only when the proper number of targets are found and data is written.

Other subdirectories associated are:
BACKUP   After a series of test runs are completed, data is saved here
CALIBRAT   Camera calibration and configuration is determined in this subdirectory
DISTORT   Camera distortion values are determined in this subdirectory

Operational Procedure: National Transonic Facility (NTF)

Camera Set-up

In the NTF, the camera is used with a 10 - 100mm Rainbow zoom lens, (see fig. 005, Rainbow Zoom Lens, 10 – 10mm with Control Box). If the area of interest to be measured is on the far-side (right) wing, camera port 55 is generally used. If the area of interest is on the near-side (left) wing, camera port 17 is generally used. (See fig. 006, Test Section Video Configuration drawing). Adjust the camera position and the zoom lens for optimum viewing of the wing to be measured so that all the targets remain in the field-of-view of the camera during a pitch sweep over the maximum excursion expected. The camera is positioned manually (in its housing) and the zoom is adjusted from the control room. During setup at room temperature, allow for model displacement in the flow direction of up to 1 inch due to contraction at very low temperatures.

Lighting

Open the camera iris just enough to see the targets.

To set lighting in the NTF, first turn off all of the lights from the light control panel. The panel must be in "local" mode. Then, beginning with light number 3, increase the pot setting for each light, one-at-a-time, to determine which lights (and at what pot settings) best illuminate the targets for maximum contrast while at the same time minimizing extraneous glints. (In past tests, lights 3 and 11 have been the primary lights.) The lights can be adjusted until optimum lighting is achieved in an iterative manner, (see fig. 007, targets as they appear during testing). This can be a very tedious and time-consuming effort, often requiring a few hours or so. When the light settings have been established, request a wind-off pitch sweep to check for glints that may interfere with accurate data acquisition at certain angles. Adjust the lighting as needed to minimize the glints that may occur at some angles. **Note:** In the NTF, glints on the wing surface are difficult to completely eliminate. Therefore, other methods have been developed (e.g., area of interest boxes) to help obtain robust data acquisition.

Using the Computer for Lighting

• The lights can also be set using the computer.
• Set the light control panel to **computer** mode.
• Select **server 10** on the server router.
• On the computer, **Video Set-up Deck**, select **Lighting**.
• From the **File** menu, select **Open Log File**, then, select **Lighting**.
• From the pull-down menu, select **mdef**. The light control window will be displayed.
• For first time lighting set-ups, the user should select **All On** from the bottom left-hand corner of the screen.
• Begin adjusting the light settings, as stated above in **local** mode, by moving the slider bars associated with each light.
• When complete, from **File** menu, select **Save log file**, then select **Lighting**.
• Enter a **filename** and then click **OK**.
• Use the slider bar to adjust the lighting as needed once initial set-up is complete.

If the user finds that slightly different light settings are needed for different tunnel testing conditions (i.e., cryogenic vs. heat), filenames can be given to each condition and recalled as appropriate.

Using 4MIP:

4MIP is an EPIX software program that performs image acquisition, display, processing and analysis. In **4MIP** the user can determine target size and threshold. Once these values are found, they then can be entered in the parameter data file **(param.dat).**

To validate the light settings, run the software program **4MIP** (**4MIP Locked** if using the pixel clock locked at ~14.318 MHz) from the Windows Desktop. The 4MIP software can aid in determining contrast between the targets and background.

• On the main menu page, open the **EXAMINE** menu, click **PIXEL PEEK, POKE & PLOT.**
• Click **PIXEL PEEK, X – Y.**
• Press **SHIFT + F1** to obtain a live image of the model.
• Right-click and hold mouse button to place the cursor on the center of a target (or blob). Targets are indicated by high pixel values. (See fig. 008, 4mip_ppp.bmp).

• Count the pixel width, in x-direction, and pixel height, in y-direction to estimate the target/blob size. For example, in fig. 008 , the pixel width, x, of the blob would be about 11 pixels and the pixel height, y, of the blob would be about 9 pixels.
• Exit (press the **Delete** key) **PIXEL PEEK, X – Y**.
• Click on **PIXEL PLOT LINE, X**.
• Position the cursor (right-click on the mouse) so that the x-axis line is over a row of targets. (See fig. 009, 4mip_plotlinex.bmp) The objective here is to determine a threshold value of about 50 percent between the maximum average pixel value of all of the targets in that row and the background. Subtract the background pixel value from the targets' maximum average pixel value, divide the result by two, and add the result to the background level to establish a starting threshold. It should be noted here that if a target in a particular row has a pixel value much lower than the other targets, a separate threshold can be set for that target. Creating an "area of interest box" (discussed below) around the target allows for this.
• Exit the **EXAMINE** menu (press **Delete** key twice).
• On the main menu page, open the **MEASURE** menu, click on **BLOB ANALYSIS**.
• Set the **Threshold Level** to 100 (or starting threshold level found above).
• Set the **Max Width, X** to 15 (four pixels greater than size found in **PIXEL PEEK, X – Y)**.
• Set the **Max Height, Y** to 13 (four pixels greater than size found in **PIXEL PEEK, X – Y)**. **Min Width, X and Min Height**, Y are set at the default 3 which is adequate for this example, but may be increased to about 4 pixels less than the target X and Y size if small glints are present in the regions of interest.
• Move cursor to highlight **Blob Search as per Constraints, Light Blobs** and <Enter>.
• Check the **RESULTS** of the analysis by observing **Number of Blobs** and **Number of Bad Blobs**. The number of blobs found in **Number of Blobs** should equal the number of targets and be located at each target**.** If the results indicate there are any Bad Blobs, adjustments can be made to **Threshold Level, Max Width, X and/or Max Height, Y**. Before re-executing **Blob Search as per Constraints, Light Blobs,** press **SHIFT + F1** to get a **Live** image.
• If no bad blobs are found, the **Threshold Level and Search** values for X and Y can be entered into the Param.dat file. *(Reference 3.)*

Reducing glints on the wing:

Area of interest boxes

When glints on the wing cannot be completely eliminated by adjusting the lights, MDef will allow areas of interest to be defined around the targets. (See fig. 010 Targets with area of interest boxes).

In the parameter data file (param.dat) are entries for northwest-x, northwest-y (nw.x, nw.y) and southeast-x, southeast-y (se.x, se.y) coordinates. (See

Appendix A parameter data file). These coordinates are determined by using the 752 by 240 viewing area, where (0,0) is the upper-left corner of the viewing area and (752,240) is the lower-right corner of the viewing area.

From fig. 010, targets with area of interest boxes, the user can see that the model has five areas of interest regions. Each region is numbered in the upper left corner of the box. The size of each box is determined by the movement the targets on the model make through the angle-of-attack range.

Using area of interest box 1 as an example, the nw.x, nw.y coordinate is (27,8) and the se.x, se.y coordinate is (228, 119). When these boundaries are entered and saved, a white box is then drawn around the targets. Also, a threshold value can be entered at the beginning of this row in **param.dat** for this particular region.

If the user finds that one target within a row of targets requires a much lower threshold, that target can be given its own area of interest region and threshold value as is the case with targets 11 and 12 in area of interest regions 4 and 5, respectively.

Black wall

Another method to reduce glints on the wing is to paint both tunnel walls flat black. The NTF normally tests highly polished steel models. When painted flat black, the tunnel walls reflect black from the polished steel. This creates a higher contrast between the model and the white targets. (See fig. 011, T111_cal07.jpg).

Painted black stripes

Painted black stripes may also be incorporated in the painted-target method to help reduce glinting near the targets, especially for semi-span models. The black stripes are painted in the flow direction of the wing.

This procedure should be discussed with the lead aerodynamicist prior to testing. The resulting black stripes surface roughness should not exceed 10 micro-inches, as measured with a surface profilometer. The thickness of the paint should not exceed 0.0005 inch (0.5 mil) as measured with a paint thickness gauge. See Appendix B, Target Painting Procedure Using Black Stripes.

MDef.exe:

The primary means of image capture and target measurement is the software package **MDef.exe** or **MDef**, written as an MS-DOS application for use with the EPIX Model-12 video capture card. **MDef.exe** can capture images in the EPIX

card's memory, locate light or dark targets (a.k.a. blobs) within the images, and compute the XZ coordinates for each target. When enabled, **MDef** can also compute the amount of twist along specified rows of targets. *(Reference 3.)*

MDef Operation

Fig. 012 shows the MDef program window in the ***Flap-Angle*** display. The Flap-angle mode runs when the first line in Param.dat is negative.
Fig. 013 shows the MDef program window in the ***Zintslpe*** display. There is no negative sign at the first line in Param.dat.

The MDef program can be executed from the Windows Desktop icon.

Prior to data acquisition, the MDef operator should request a wind-off polar sweep of the model from the tunnel operators, to ensure that the external trigger or DAS trigger is operational and that all targets are found and successfully numbered over the angle of attack range of the model.

Press **"B"** (Box test) to sample and process an image without writing to any of the appended files. Boxes will be drawn around regions of interest and targets and the regions will be numbered.

Press **"T"** to manually Trigger data acquisition. The image will be processed and data will be written to the appended files. The appended files are:

- **Tunnel.log**
- **Log.dat**
- **ZintSlpe**
- **XYZmean.dat**

Separate files written for each point (xxxx) are:

- **Centxxxx or Cerrxxxx**
- **XYZxxxx**
- **ZSLPxxxx**

Work Directory:

The work (or test) directory is where all test data is acquired and processed.

Data Sub-Directories

When the VMD code is executed, sub-directories save and append the output files, but only when data is to be written. The directories that MDef uses are:

- **Centroid**
- **XYZ**
- **ZSLP**
- **Images**

Data Acquisition Files

When the VMD system is triggered, MDef creates several output files.

- **Tunnel.log**
- **Blobs.dat**.

Within the **Centroid** sub-directory are two file types:

- **Cent**   valid rows of targets containing proper number of targets (ex. Cent0015).
- **Cerr**   invalid rows of targets that do not contain proper number of targets (ex.Cerr0015).

Computations are made using valid centroid locations to determine the X and Z locations of the targets in 2-dimensional space at each semispan location where a row of targets resides. The results are then written to a **XYZ**-type file in the **XYZ** sub-directory. The averaged X, Y and Z values for all fields are written to the **xyzmean.dat** file in the work directory. The slope (angle-of-attack) of each row is calculated, along with the Z-axis displacement and the standard deviation values, and written to the **zintslpe** file.

Image Adjustment:

If some or any of the targets are not found, adjustments can be made by quitting (**Q**) MDef and opening the **param.dat** file icon. Adjustments can be made to:

- **Target threshold:** Gray-scale level for detecting targets.
- **Target size, min- and max-x and y:** The maximum and minimum sizes for the targets within each search region. If the entire image is used as a single region, the first set of these values is used as the default.
- **Region threshold:** The threshold value for a search region (region of interest) within an image. A positive value here overrides the default threshold. A negative value marks the end of the search region information within this table. The number of consecutive positive threshold values determine the number of regions.

Appendix A is an example of **param.dat** file.

Save and exit **param.dat** and return to MDef.exe. Do a **'B'** test for validation.

Threshold adjustments can also be done within the **MDef** environment. The function key **F1** can be used to pull up a scrollable help screen. **ALT-L** will allow the operator to change the **LUX** (threshold) setting for any region.

Note: If the camera is moved anytime after calibration, another calibration must be done if the camera cannot be reset to near its original setting so that the current image overlays an old image at the same angle of attack with wind off.

Targeting:

Circular retro-reflective or white polish-painted targets are used to measure deformation. The target size is dependant on the area to be measured and field-of-view.

Targets must be placed on the wing at the semi-span locations where change in wing twist and bending are required. The Y-coordinates of the targets in the span-wise direction are determined from pressure tap and other reference locations on the wing to be used in the computation of X in the stream-wise and Z in the vertical direction. 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.

Retro-reflective Targets

Retro-reflective tape targets are ideal for achieving a high contrast image. They are best suited for facilities where aerodynamic considerations will tolerate their thickness (0.004 inch). This is achieved by closing the aperture of the camera lens until the background with tunnel lighting is minimized and then increasing the variable light source placed near the camera until the desired threshold is achieved.

Retro-reflective targets are made using 3M brand retro-reflective tape, series 7610. The targets are produced using a punch set with sizes from one-eight inch to three-quarter inch punches. The tape targets are then placed on the model in the pre-determined span-wise locations.

Painted Targets

Polished painted targets are used when the tunnel environment will not allow the use of retro-reflective tape targets (i.e., locating a light source sufficiently close to the camera is not possible or application of the 4 mil thick targets may undesirably affect the aerodynamics).

Polished painted targets require more time and preparation than retro-reflective tape targets (up to 1 shift). Target templates are punched in strips of foil tape and

another tape medium (such as mailing labels) to create a slightly raised target. The paint (actually a mixture of primer and paint activator) is applied with a paint sprayer, which requires the use of proper ventilation. A minimum of two hours is needed to allow the paint to completely dry and then to wet sand the targets. (For complete details, see "Target Painting Procedure" in Appendix B. The finished surface roughness of painted targets, measured with a surface profilometer, should not exceed 10 micro-inches. The thickness of the targets should not exceed 0.0005 inch (0.5 mil) as measured with a paint thickness gauge.

Appendix A

Parameter Data (Param.dat) File

```
1    -7595          Tab Point         |NTF Test 119 777 Full-Span
2    752       Horizontal pixels ( Must be divisible by four, Max=752 )
3    0         Horizontal offset ( -1 to center )
4    240       Vertical pixels   ( Max = 240, 480 if interlace On )
5    0         Vertical offset   ( -1 to center )
6    0.02600000   Vertical   pixel spacing of camera in mm
7    0.01098698   Horizontal pixel spacing of camera in mm
8    354.83   Pixel x principal point ( To be measured during cal )
9    107.39   Pixel y principal point    "         "
10   354.83   Pixel x symmetry point ( Measured by zoom symmetry on image )
11   107.39   Pixel y symmetry point    "         "
12   5.962e-004   k1 3rd order radial distortion mm^-2    ( Put K2,K3,P1 & P2 after this
     line if needed )
13   4.168e-005   k2 5th order radial distortion mm^-4
14   0.000e+000   k3 7th order radial distortion mm^-6
15   -3.724e-004  p1 1st de-centering term mm^-1
16   4.984e-004   p2 2nd de-centering term mm^-1
17   1.0000000    Unitless sh_ratio locked/unlocked
18    0.00        Pixel x shift unlocked to locked
19    0.00        Pixel y shift unlocked to locked
20   0        Delta_x  ( how much to increase the box over min of 4 )
21   1        Delta_y  ( how much to increase the box over min of 2 )
22    26.3269        Camera constant c in mm
23    61.57981992730000    Deg omega
24    -2.79960458070000    Deg phi
25   -90.77486139849999    Deg kappa
26    -8.43687491760000    Inch Xc
27   -55.19514700000000    Inch Yc
28    34.47654654810000    Inch Zc
29   1        White-on-black             ( 0 = Dark targets, else Light )
30   12       Minimum_blob_mass
31   -4       Fields delay  ( if <= 0 get tunnel data AFTER scanning for blobs )
32   109      Target threshold      ( difference for White-on-black )
33   60       Maximum buffers to process ( 0 to let it compute number )
34   7        Skip buffer offset       ( 0 to process every buffer )
35   0        Row orientation ( <0 = No sort, 0 = vertical, else horizontal )
36   6        Number of rows of targets  ( See: f12atv.cal in plates directory )
37   ROW 1 INFORMATION
38   2     Number of targets on Row 1
39    0.9910  Y/b/2        (Row 1)
40    0.0000 Z ref offset (Row 1)  z_int = (intercept - zref) * zref_slope
41    0.0000  AOA ref offset    (Row 1)  angle = (aoa - aoaref) * aoaref_slope
42    1.0000  Z ref slope   (Row 1)
43    1.0000  AOA ref slope (Row 1)
44    1.0000  Ref Point     (Row 1) (x.y -> .y after point x)
     ROW 2 INFORMATION
     2     Number of targets on Row 2
      0.8780  Y/b/2        (Row 2)
      0.0000 Z ref offset  (Row 2)
     0.0000   AOA ref offset    (Row 2)
     1.0000   Z ref slope  (Row 2)
```

```
     1.0000   AOA ref slope (Row 2)
     1.0000   Ref Point      (Row 2) (x.y -> .y after point x)
     ROW 3 INFORMATION
     2        Number of targets on Row 3
      0.7690  Y/b/2         (Row 3)
       0.0000 Z ref offset  (Row 3)
      0.0000  AOA ref offset    (Row 3)
      1.0000  Z ref slope   (Row 3)
     1.0000   AOA ref slope (Row 3)
      1.0000  Ref Point      (Row 3) (x.y -> .y after point x)
     ROW 4 INFORMATION
     2        Number of targets on Row 4
      0.6190  Y/b/2         (Row 4)
       0.0000 Z ref offset  (Row 4)
      0.0000  AOA ref offset    (Row 4)
      1.0000  Z ref slope   (Row 4)
      1.0000  AOA ref slope (Row 4)
      1.0000  Ref Point      (Row 4) (x.y -> .y after point x)
     ROW 5 INFORMATION
     2        Number of targets on Row 5
      0.3500  Y/b/2         (Row 5)
       0.0000 Z ref offset  (Row 5)
      0.0000  AOA ref offset    (Row 5)
      1.0000  Z ref slope   (Row 5)
      1.0000  AOA ref slope (Row 5)
      1.0000  Ref Point      (Row 5) (x.y -> .y after point x)
     ROW 6 INFORMATION
     2        Number of targets on Row 6
     -0.0470  Y/b/2         (Row 6)
       0.0000 Z ref offset  (Row 6)
      0.0000  AOA ref offset    (Row 6)
      1.0000  Z ref slope   (Row 6)
      1.0000  AOA ref slope (Row 6)
      1.0000  Ref Point      (Row 6) (x.y -> .y after point x)
45   Thres nw.x nw.y minx miny maxx maxy yref[]    Light bac_sub add_sub          X
     90     27   8    3    2   12   10  31.65600   0    1      1            0.00000
46   Z        Mtar se.x se.y
     0.00000   6    228  119
```

Description of Parameter Data File

Line 1 **Tab point:** Used as a starting value for the point numbers when either Video.dat or a socket connection is not available. A negative point number indicates that flap-angle computations are to be solved, otherwise, MDef defaults to a Zintslpe display.

Line 2 **Horizontal pixels:** The image dimensions used by the Epix card, normally 752 X 240 for non-interlaced images. If a full image is not desired, the horizontal and vertical offsets, in pixels, of the portion of the image to capture is given on lines 3 and 5, respectively.

Line 3 **Horizontal offset:** Normally 0; use -1 to center the captured region on the screen.

Line 4 **Vertical pixels:** Maximum pixels is 240 in non-interlace; if interlace ON, then 480 is maximum pixels.

Line 5 **Vertical offset:** Normally 0; use -1 to center the captured region on the screen.

Line 6 **Vertical pixel spacing:** The spacing of the camera's pixel, in millimeters. For the Hitachi KP-M1U CCD camera, the vertical spacing is approximately 0.026 mm.

Line 7 **Horizontal pixel spacing:** For the Hitachi KP M1U CCD camera, the horizontal spacing is approximately 0.011 mm.

Line 8 **Pixel x principal point:** Measured during distortion process.

Line 9 **Pixel y principal point:** Measured during distortion process.

Line 10 **Pixel x symmetry point:** Measured by zoom symmetry on image.

Line 11 **Pixel y symmetry point:** Measured by zoom symmetry on image.

Line 12 **k1 3rd order radial distortion, mm^-2:** Measured during the distortion process.

Line 13 **k2 5th order radial distortion, mm^-4:** Measured during the distortion process.

Line 14 **k3 7th order radial distortion, mm^-6:** Measured during the distortion process.

Line 15 **p1 1st de-centering term, mm^-1:** Measured during the distortion process.

Line 16 **p2 2nd de-centering term, mm^-1:** Measured during the distortion process.

Line 17 **Unitless sh_ratio:** Measured during the distortion process.

Line 18 **Pixel x shift:** Determined in the distortion process.

Line 19 **Pixel y shift:** Determined in the distortion process.

Line 20 **Delta_x:** How much to increase the target bounding box over the default minimum 4.

Line 21 **Delta_y:** How much to increase the target bounding box over the default minimum 2.

Line 22 **Camera constant:** Measured in the calibration process, measured in mm.

Line 23 **Deg omega:** The camera's rotation (orientation) about the x-axis within the wind tunnel.

Line 24 **Deg phi:** The camera's rotation about the y-axis within the wind tunnel.

Line 25 **Deg kappa:** The camera's rotation about the z-axis within the wind tunnel.

Line 26 **Inch Xc:** The camera's position in relation to the model, in inches, along the air flow axis.

Line 27 **Inch Yc:** The camera's horizontal position in relation to the model, in inches.

Line 28 **Inch Zc:** The camera's height in relation to the model, in inches.

Line 29 **White-on-black:** 0 = Dart targets on light background, else, light targets on dark background.

Line 30 **Minimum_blob_mass:** The minimum number of pixels in a valid target.

Line 31 **Fields delay:** If <= 0 tunnel data is acquired AFTER scanning for blobs.

Line 32 **Target threshold:** Gray-scale level for detecting targets.

Line 33 **Maximum buffers to process:** If set to 0, then MDef computes this value based on the image size and the size of the Epix card's memory.

Line 34 **Skip buffer offset:** When set to 0, MDef processes every buffer; a value of 5, for example, processes the fields in the sequence: 1, 7, 13, etc.

Line 35 **Row orientation:** If <0, MDef sorts the targets as horizontal rows; If set to 0, MDef sorts the targets as vertical rows.

Line 36 **Number of rows of targets:** The targets are aligned as rows parallel to the model's center of axis. This is the number of rows for sorting, etc.

Line 37 **Row 1:** Start of the information describing the target row.

Line 38 **Number of targets on Row 1:** Actual number of targets for this row.

Line 39 **Y/b/2:** The normalized semi span offset.

Line 40 **z ref offset:**

Line 41 **AOA ref offset:**

Line 42 **Z ref slope:**

Line 43 **AOA ref slope:**

Line 44 **Ref point:** Point within a row to use to determine z_int; can be a fraction to specify a position between two targets.

Line 45 Header line specifying information when search <u>region(s)</u> are used. If the first threshold value below is set to a negative value, then the threshold value on line 32 will be used. Columns 4, 5, 6, 7, and 8 on the first line of information, are always used to describe target size and location.

Column 1 **Thres:** The threshold value for a search region or "region of interest" within an image. A positive threshold value would utilize the threshold value on line 32.

Column 2, 3 **nw.x, nw.y:** The area of interest boundaries, in pixels, for a search region within an image. Nw.x and nw.y designate the upper-left boundary.

Column 4,5,6,7 **minx, miny, maxx, maxy:** The maximum and minimum sizes for the targets within each search region. If the entire image is used as a single region, the first line values are used as the default.

Column 8 **y-ref:** Y-reference value. This value is the distance of each target from the centerline of the model, in inches. Each target's y-ref is indicated.

Column 9 **compl:** This value determines if the pixels within the rectangle bounding a target are to be complemented.

Column 10 **bac_sub:** This value indicates if the background is to be subtracted from every pixel in the target rectangle.

Column 11 **add_sub:** An additional value to subtract from the pixels in the target rectangle.

Column 12 **X:** The target's x-reference value, in inches.

Column 13 **Z:** The target's z-reference value, in inches.

Column 14 **Mtar:** The maximum number of targets to be found in a particular search region. When this number is reached, MDef begins searching for targets in the next region.

Column 15,16 **se.x, se.y:** The location, in pixels, for a search region within an image. Se.x, se.y designate the lower-right boundary.

Appendix B

Target Painting Techniques

White Targets:

1. Shake primer for about 10 minutes in paint shaker.
2. Fill 4oz. mixing jar about half-full with black primer.
3. Fill remainder of mixing jar with activator.
4. Shake mixture well. (Note: Primer settles quickly, shake mixture often.)
5. Strain paint mixture into sprayer, filling half full.
6. Attach sprayer to air hose.

7. Turn on air
8. Adjust pressure on sprayer to 20 – 25 psi. Air pressure on hose should be set at 40 – 45 psi.
9. Adjust spray stream on sprayer to medium-wide dispersion.
10. Spray paint over template(s) using sweeping motion.
11. Allow paint to dry about 10 minutes. Remove masking.
12. Dry paint with heat lamps for 1 hour.
13. Allow model to cool to room temperature.
14. Wet-sand targets using 1000 – 2000 grit sand paper.
15. Targets should be sanded down to within 0.5 – 1.0 mil in height.

Clean-Up
Use paint thinner to clean sprayer jar. Spray thinner through sprayer to clean nozzle.

Lay-out Procedure

Note: Templates will be made based on target-lay information from researcher.

1. Punch holes in sheeting or 2-in. copper foil tape at least 1/8-in. larger than actual size of targets. Punch actual target-sized holes in another medium, i.e., labels (do not remove backing).
2. Lay copper template on model on pre-designated target locations. Tape down.
3. Lay label cut-outs over copper cut-outs. Tape down.
4. Mask off rest of model.
5. Spray on targets.
6. Allow to air dry about 10 minutes before removing masking.
7. Dry under heat lamps for 1 hour.
8. Allow model to cool to room temperature.
9. Wet-sand targets to within 0.5 – 1.0 mil in height.

Materials

1. 3M 1000, 1500, 2000 grit sand paper.
2. Thin copper sheeting or 2-in. copper metallic tape.
3. Hole punch set.
4. 1-in. masking tape.
5. 1-inch feathering tape.
6. DuPont Prime n Seal, #2610S-white; Prime n Seal, #2690S-black; Prime-n-seal, #2675-activator and; Acrylic Lacquer Thinner, #3602S.
7. Tack cloth.
8. Paper towels.
9. Nitrile synthetic co-polymer gloves or equivalent.
10. Masking paper.

Black Stripes with White Targets:

1. Shake primer for about 10 minutes in paint shaker.
2. Fill 4oz. mixing jar about half-full with black primer.
3. Fill remainder of mixing jar with activator.
4. Shake mixture well. (Note: Primer settles quickly, shake mixture often.)
5. Strain paint mixture into sprayer, filling half full.
6. Attach sprayer to air hose.
7. Turn on air
8. Adjust pressure on sprayer to 20 – 25 psi. Air pressure on hose should be set at 40 – 45 psi.
9. Adjust spray stream on sprayer to medium-wide dispersion.
10. Spray paint over template(s) using sweeping motion.
11. Allow paint to dry about 10 minutes. Remove masking.
12. Dry paint with heat lamps for 1 hour.
13. Allow model to cool to room temperature.
14 Wet-sand targets using 1000 – 2000 grit sand paper.
15. Targets should be sanded down to within 0.5 – 1.0 mil in height.

Clean-Up
Use paint thinner to clean sprayer jar. Spray thinner through sprayer to clean nozzle.

Lay-out Procedure

Note: Templates will be made based on target lay-out information from researcher.

1. Using 1-in. feathering masking tape, lay-out areas to be painted black.
2. Mask-off rest of model.
3. Using thin copper sheeting, cut-out templates the length and width of black stripes.
4. Punch holes in sheeting at least 1/8-in. larger than actual size of targets. Punch actual target-sized holes in another medium, i.e., labels (do not remove backing).
5. Spray paint black stripes. Allow to air dry 10 minutes; remove masking.
6. Dry under heat lamps for 1 hour.
7. Allow model to cool to room temperature.
8. Ready sprayer for white paint using above mixing procedure.
9. Lay copper sheeting template over black stripes. Tape down.
10. Lay target sized templates over holes in copper sheeting. Tape down. Mask off rest of model.
11. Spray on white targets.
12. Allow to air dry about 10 minutes before removing masking.
13. Dry under heat lamps for 1 hour.

14. Allow model to cool to room temperature.
15. Wet-sand targets to within 0.5 – 1.0 mil in height.

Materials

1. 3M 1000, 1500, 2000 grit sand paper.
2. Thin copper sheeting or 2-in. copper metallic tape.
3. Hole punch set.
4. 1-in. masking tape.
5. 1-inch feathering tape.
6. DuPont Prime n Seal, #2610S-white; Prime n Seal, #2690S-black; Prime n Seal, #2675-activator and; Acrylic Lacquer Thinner, #3602S.
7. Tack cloth.
8. Paper towels.
9. Nitrile synthetic co-polymer gloves or equivalent.
10. Masking paper.

References:

Reference 1.
Journal of Aircraft, vol. 38, No. 4, July – August 2001, pp. 745-754.

Reference 2.
Hitachi Denshi, Ltd., Operation Manual Hitachi KP-M1U Black & White CCD Camera, "How To Use Electronic Shutter", p. 11.

Reference 3.
Cate, Kenneth H.: Videogrammetric Model Deformation Measurement Software Package, Reference Manual for MDef.exe. NASA TM-2001-210554, 2001.

Figure 1. Hitachi CCD Camera-Side View.

Figure 2. Epix Bundle Cable.

Figure 3. Cable Junction Box for Hitachi Camera.

Figure 4. AC Converter for Hitachi Camera.

Figure 5. Rainbow Zoom Lens, 10 – 100mm with Control Box.

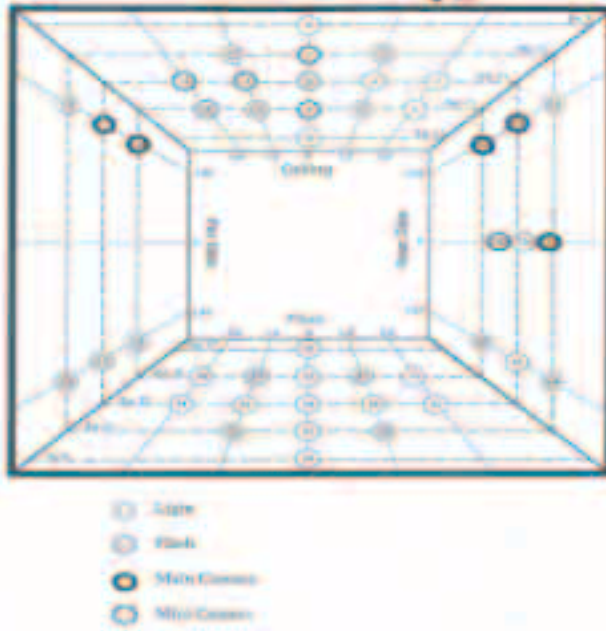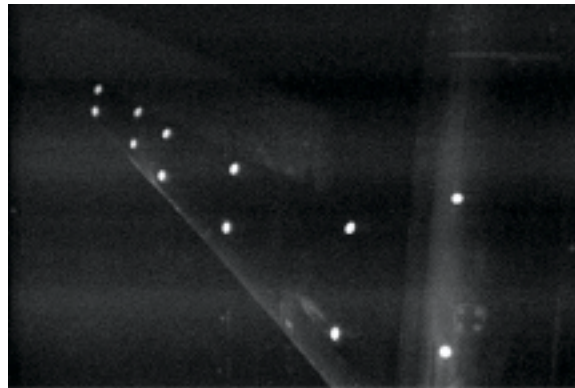Figure 6. NTF Test Section Video Configuration.

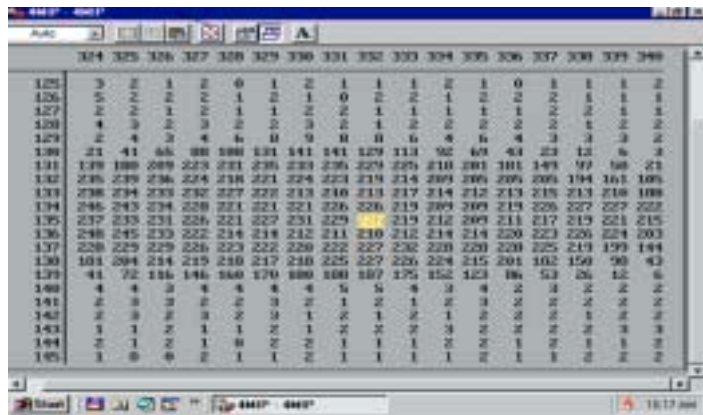Figure 7. Targets as they appear during test.
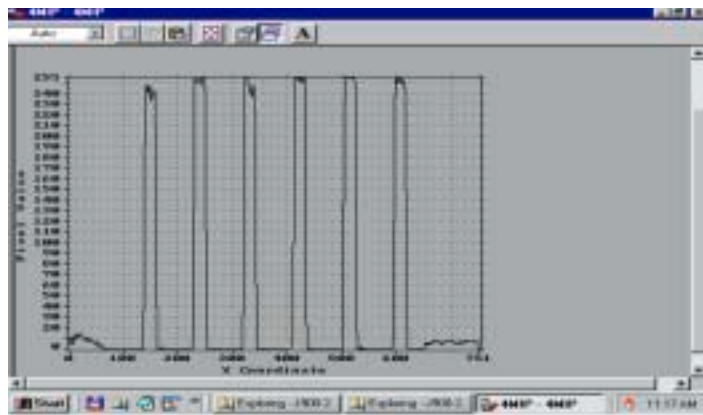
Figure 8. 4MIP, Pixel Peek, X –Y.
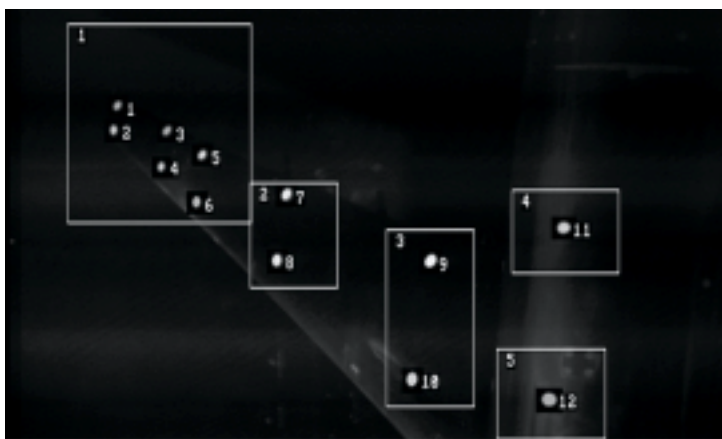

Figure 9. 4MIP, Pixel Plot Line, X.

Figure 10. Targets with area of interest boxes.

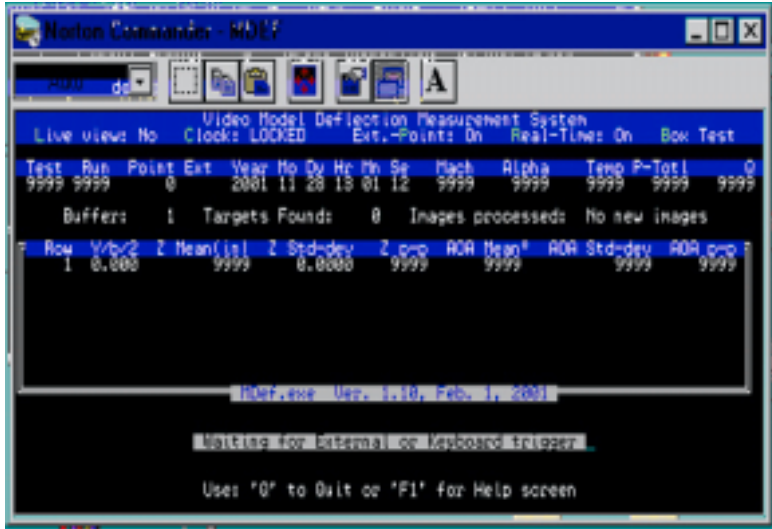Figure 11. Tunnel wall painted flat black for contrast.

Figure 12. Mdef in Flap-Angle display mode.

Figure 13. Mdef in Zintslpe display mode.

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13. ABSTRACT *(Maximum 200 words)*
The purpose of this manual is to provide the user of the NASA VMD system, running the MDef software, Version 1.10, all information required to operate the system. The NASA Videogrammetric Model Deformation system consists of an automated videogrammetric technique used to measure the change in wing twist and bending under aerodynamic load in a wind tunnel. 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 fixed (and known) third dimensional coordinate, namely the span-wise location. The major consideration in the development of the measurement system was that productivity must not be appreciably reduced.

14. SUBJECT TERMS
Model deformation; wing twist; flap angle; z-interslope

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