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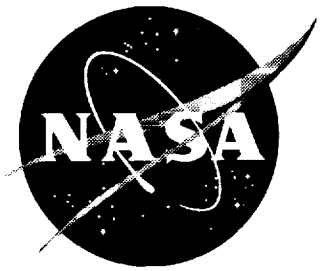

Videogrammetric Model Deformation Measurement Software Package

Reference Manual for MDef.exe

Kenneth H. Cate
Langley Research Center, Hampton, Virginia

March 2001

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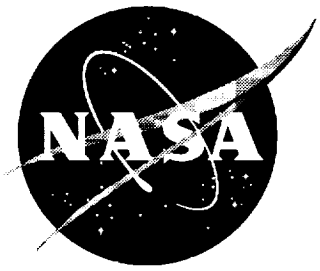

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National Aeronautics and
Space Administration

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Overview

Description

The Video Model Deformation (**VMD**) software package (**MDef.exe** or **MDef**) was written as an MS-DOS application for use with an **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 XYZ displacements for each target. When enabled, MDef can also compute the amount of twist along specified rows of targets.

Minimum System Requirements

IBM PC style computer (80286 processor or better)
Motherboard with two, adjacent, full-length card slots with no obstructions
Epix Model 12 video capture card
Epix type video breakout connector (1DB25)
Video camera (pixel-clock output recommended) with power supply
Black and white (**B&W**) or color monitor for viewing video output from the Epix card
Two RG-59 cables (one for video signal from camera to Epix card, the other for video signal to monitor)
Retro-reflective material or paint for targets

Optional Parts

IBM PC style computer (80286 processor or better)
Mounting hardware for camera
RG-59 cable for pixel-clock signal from camera to Epix card (if this signal is available)
B&W or color monitor for viewing video input to Epix card
RG-59 cable for 2nd monitor
Light source (variable intensity recommended) such as fiber optic bundle
Variable power supply for controlling light source remotely
Cable for connecting power supply to light source
Ethernet card and cable for network connection

Other parts may be needed depending on if wind-tunnel data is being sent to the VMD system, and the method of transfer (such as by RS-232 or a network connection).

Hardware Connections

All video and pixel-clock signals are routed through RG-59 (75 ohm) co-axial cable. Connect the Video output from the camera to the video input of a B&W monitor then connect the output from the monitor to the video input lead of the Epix card (labeled **VIN**). If the camera has a pixel-clock output (a continuous signal of approximately 14.318MHz), it is connected to the external clock input lead of the Epix card (labeled **CLOCK_IN**). The video output lead of the Epix card (labeled **GREEN**) is connected to the video input of the second B&W monitor.

Trigger Connection

The Epix card has a trigger input lead (labeled **EXT_IN**) that can be used to trigger data taking. The trigger is a **TTL** level signal with a high to low transition. Since EXT_IN floats high (~5V), a simple short to ground (0V) is all that is needed as a trigger signal.

An alternate method of triggering data taking is via a network connection to the Data Acquisition System (**DAS**) at the facility where the test is being held. A network connection requires the computer to have an Ethernet card installed, and network addresses to be assigned to the computer 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.

Data Acquisition System (DAS) Interface

The serial port on the computer can be used to receive wind tunnel data through a standard RS-232 cable. An external program is written to open the port, read the data stream, close the port, write the data to a copy of Video.dat (See Appendix), and then return to the calling program. The batch file GetFile.bat is used to call the external program.

RS-232 Connection

The serial port on the computer can be used to receive wind tunnel data through a standard RS-232 cable. An external program is written to open the port, read the data stream, close the port, write the data to a copy of Video.dat (See Appendix), and then return to the calling program. The batch file GetFile.bat is used to call the external program.

Network Connection

An Ethernet connection can be used to receive wind tunnel data as well as triggering data taking. After the computer has been assigned an IP address on the network, MDef.exe can be called with the appropriate IP address and Port number for the Data Acquisition System server.

Software Setup

The VMD code (MDef.exe) is normally stored (along with other useful programs) in a directory named **Facility\Code** off the root directory of one of the hard drives (Ex.: C:\Facility\Code). This directory is usually added to the search path in **Autoexec.bat**. A **Facility\Plates** directory is also used as a place for storing the calibration plate data files. Directories are created in the Facility directory named after the facility where a test is being held (such as **TDT** for the Transonic Dynamics Tunnel). Work (or test) directories are created in the appropriate facility directory.

If the test number was 542 and a conventional wing was being tested at the Transonic Dynamics Tunnel (**TDT**), the work directory might be:

C:\Facility\TDT\T542.CON

Since MDef.exe was written as a DOS application, all file names and directory names need to be kept short (8 characters for a name, a period, and 3 characters for an extension). MDef.exe creates special directories for it's output files within the work directory, as they are needed for the output files.

Necessary Files

	MDef.exe	The main VMD program
	Param.dat	The test configuration file; See Appendix for sample
*	**FlapAngl.ini**	Flap and wing angle configuration file

Miscellaneous Files

Note: * denotes a file or program that may not be needed for the normal operation of MDef
** denotes a file that may be needed by the DAS

*	**GetFile.bat**	DOS batch 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**	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

Param.dat

The configuration file **Param.dat** is a simple text file containing information about the placement and orientation of the video camera, the image size to be used, the maximum and minimum target sizes, the number of targets to search for, and other information needed by MDef. Most of the lines in Param.dat can contain comments (which are ignored by MDef).

FlapAngle.ini

The flap and wing angle configuration file **FlapAngl.ini** is a simple Windows® type INI file specifying which targets are grouped into 'rows' for computing wing twist or angle-of-attack (**AOA**). FlapAngl.ini also identifies the row to be used as a reference and the correction values used in the computations.

GetFile.bat

MDef calls GetFile.bat when it needs to retrieve the wind tunnel data. GetFile.bat is either set up to copy a file off a shared drive to Video.dat (in the current work directory) or it calls another program (such as **FOR-A.exe**) to read the tunnel data from an **RS-232** stream and write the data to a copy of Video.dat.

For-A.exe

When the wind tunnel data is being sent to MDef over an RS-232 cable, FOR-A.exe (or a similar program) can be called by **GetFile.bat.** **For-A** reads a stream of RS-232 data and uses it to create a copy of Video.dat in the current directory.

For-A.ini

The configuration file For-A.ini is used by **For-A** to identify what characters (or words) in the RS-232 stream to use to identify the wind tunnel data. **For-A** can be used as a stand-alone program to continuously read and display the wind tunnel data. Labels can be added to For-A.ini to be used when displaying the data.

Work Directory Structure

When the VMD code (MDef.exe) is run, sub-directories are created in the work directory for the output files but only when data is to be written. The directories that MDef creates and uses are:

Centroid	Centroid data files are saved here (Centxxxx or Cerrxxxx)
XYZ	XYZ data files are saved here (XYZxxxxx)
ZSLP	Z-Intercept/Slope files are saved here (ZSLPxxxx)
Images	RAW and TIFF image files are saved here

The use of 'xxxx' in a file name designates a number that is padded with leading zeros so that the file name is eight characters long and the numeric part appears right justified such as **Cent0025**. If MDef is triggered to take data but the point number has not advanced, padded numeric extensions are added to the file names to prevent overwriting previous data. Example: If MDef were triggered to take data for point number 25 a second time, the new centroid file would be named **Cent0025.001**. The XYZ and ZSLP files are named similarly. The reason for padding the file names with zeros is to make sorting easer.

Output Files

MDef creates several output files. When wind-tunnel data is read, a copy of the data is written to **Tunnel.log**. When data is taken, the centroid locations within the image plane (in pixels) are written to the temporary file **Blobs.dat**. If any row of targets does not contain the proper number of targets, Blobs.dat is copied to a **Cerr** type file (ex: Cerr0025) in the **Centroid** directory. Any 'good' rows are written to a **Cent** type file (ex: Cent0025) in the **Centroid** directory.

Computations are made to using the 'good' centroid locations to determine the X, Y, and Z locations of the targets in 3-dimensional space; the results are written to a **XYZ** type file in the **XYZ** directory. Averaged X, Y, and Z values for all fields are written to **XyzMean.dat** in the work directory. The slope (or angle-of-attack) of each row is calculated, along with the Z-axis displacement and standard-of-deviation values, and written to **Zintslpe**. Sample output files can be found in the appendix.

Initial Setup

Before **MDef** can be used for a new test, the configuration file **Param.dat** must be created. The following is a line-by-line description of the file.

Line	Value (Ex.)	Parameter	Description
1	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 done; otherwise, MDef defaults to a Zintslpe display. If the ASCII character 124 ('I') is placed on this line, the text following the character is used as a title for the test.
2	752	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.
3	0	Horizontal offset	Normally 0, use -1 to center the captured region.
4	240	Vertical pixels	Maximum = 2401, 480 if interlace is ON.
5	0	Vertical offset	Normally 0, use -1 to center the captured region on the screen.
6	0.026	Vertical pixel spacing of camera in mm	The spacing of the camera's pixels in millimeters. For a Hitachi model KP-M1U CCD camera, the numbers are approximately 0.026 vertical, and 0.011 horizontal.
7	0.011	Horizontal pixel spacing of camera in mm	
8	363.2	Pixel x principal point	To be measured during configuration.
9	100.5	Pixel y principal point	To be measured during configuration.
10	362	Pixel x symmetry point	Measured by zoom symmetry on image.
11	101	Pixel y symmetry point	Measured by zoom symmetry on image.
12	0.0	k1 radial distortion mm^-2	The K1 radial distortion factor in mm^2. If any of the variables K2, K3, P1 or P2 are needed, they can be inserted between this line and the next. The extra variables are added in order. Any unneeded variables in the set MUST be inserted and set to zero. If only K2 and P1 are needed, values for K2 and K3 **must** be included.
13	1.0	Unitless sh_ratio locked/unlocked	
14	0	Pixel x shift unlocked to locked	
15	0	Pixel y shift unlocked to locked	
16	2	Delta_x	How much to increase the target bounding box over the default minimum of 4.
17	2	Delta_y	How much to increase the target bounding box over the default minimum of 2. When targets (or blobs) are found, a rectangular area surrounding the target is determined. The background level is measured along the top and bottom edges and is subtracted from the entire rectangle. The box size can be adjusted with the values Delta_x and Delta_y.
18	12.7	Camera constant c in mm	
19	57.9047	Deg omega	Camera's rotation (orientation) about the X-axis within the wind tunnel.
20	180.1271	Deg phi	Camera's rotation about the Y-axis within the wind tunnel.
21	89.0504	Deg kappa	Camera's rotation about the Z-axis within the wind tunnel.
22	-5.4308	Inch Xc	Camera's position in relation to the model in inches (along air flow axis).
23	28.5556	Inch Yc	Camera's horizontal position in relation to the model in inches.
24	-27.3561	Inch Zc	Camera's height in relation to the model in inches.
25	1	White-on-black	0 = Dark targets on light background, else Light targets on a

			dark background.
26	12	Minimum_blob_mass	Minimum number of pixels in a valid target.
27	4	Fields delay	If <= 0, get tunnel data AFTER scanning for blobs. Some video capture cards require a few fields to be skipped after a hardware trigger before images are captured. The fields delay determines the number of fields to skip. The sign on this number is used to control when the wind tunnel data is read.
28	60	Target threshold	Gray-scale level for detecting targets; see White-on-black.
29	10	Maximum buffers to process	When set to 0, MDef computes this value based on the image size and size of the Epix card's memory.
30	0	Skip buffer offset	When set to 0, MDef processes every buffer. A value of 5 would cause MDef to process the fields in the sequence: 1, 7, 13, etc.
31	0	Row orientation	If less than 0, MDef does not sort the targets into rows. If set to 0, MDef sorts the targets into vertical rows, else horizontal.
32	2	Number of rows of targets	The targets are aligned as rows running parallel to the model's center axis. This number sets the number of rows for sorting, etc.
33	Row 1 Information		Start of information describing the target rows. This line is plain text.
34	11	Number of targets on Row 1	
35	1.0	Y/b/2 (Row 1)	The normalized semi span offset.
36	0.0	z ref offset (Row 1)	See equation below
37	0.0	AOA ref offset (Row 1)	See equation below
38	1.0	Z ref slope (Row 1)	See equation below
39	1.0	AOA ref slope (Row 1)	See equation below
40	3	Ref point (Row 1)	Point within a row to use to determine z_int; can be a fraction to specify a position between two targets.
41	Row 2 Information		
42	11	Number of targets on Row 2	
43	2.0	Y/b/2 (Row 2)	The normalized semi span offset.
44	0.0	z ref offset (Row 2)	See equation below
45	0.0	AOA ref offset (Row 2)	See equation below
50	1.0	Z ref slope (Row 2)	See equation below
55	1.0	AOA ref slope (Row 2)	See equation below
60	3	Ref point (Row 2)	Point within a row to use to determine z_int; can be a fraction to specify a position between two targets.

When targets (blobs) are found, a rectangular area surrounding the target is determined. The background level is measured along the top and bottom edges and is subtracted from the entire rectangle. The box size can be adjusted with the values Delta_x and Delta_y.

Some video capture cards require a few fields to be skipped after a hardware trigger before images are captured. The fields delay (line 27) determines the number of fields to skip. The sign on this number is used to control when the wind tunnel data is read: before or after the captured images are processed.

After targets are found within an image, they are sorted to determine their order. When multiple regions are used, sorting may not be required.

The information in the 'ROW x INFORMATION' tables is used to compute the angle of the 'row' and the z-displacement of a specific target. The equations are:

z_int = (intercept - zref) * zref_slope
angle = (aoa - aoaref) * aoaref_slope

After all of the Row tables is found a table of miscellaneous information starting with a header line.

```
Thres nw.x nw.y minx miny maxx maxy     yref[] compl bac_sub add_sub         X
100    35    30    4    2   21   11   0.00000     0       1       3   0.00000

      Z Mtar se.x se.y
0.00000    3  182  240
```

Columns 8, 12, and 13 are used to specify the locations of each target in the order that they are placed in after located and then sorted. The rest of the columns are used to specify information for the search region(s). If the entire image is to be used as the first and only region, the first threshold value in this table is set to a negative value. The default threshold value on line 28 will be used instead but columns 4 through 14 will be used as usual.

The columns are:

Column	Label	Description
1	Thres	The threshold value for a search region (region of interest) within an image. A positive value here overrides the default threshold (line 28 above). A negative value marks the end of the search region information within this table. The number of consecutive positive threshold values determines the number of regions.
2, 3	nw.x, nw.y	The area of interest boundaries, in pixel numbers for a search region within an image. nw.x and nw.y designate the "north-west" or upper-left boundary. sw.x and sw.y designate the "south-west" or upper-left boundary.
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 set of these values is used as the default
8	y-ref	The target's Y-reference value. Each target's y-ref is indicated. This value is the distance of each target from the centerline of the model, in inches.
9	compl	This value determines if the pixels within the rectangle bounding a target are to be complemented.
10	bac_sub	This value determines if the background is to be subtracted from every pixel in the target rectangle.
11	add_sub	An additional value to subtract from the pixels in the target rectangle.
12	X	The targets' X-reference value in inches.
13	Z	The targets' Z-reference value in inches.
14	Mtar	The maximum number of targets to be found in this search region. When this number is reached, MDef begins searching for targets in the next region.
15, 16	se.x, se.y	The location (in pixel numbers) defining the boundary of the "south-east" corner of a search region.

MDef Operation

When started, MDef reads Param.dat. If the number on the first of Param.dat is negative, MDef reads FlapAngl.ini. MDef then sets the Epix card to the configuration specified in Param.dat. If the network address and port number are given, MDef attempts to establish a connection to the Data Acquisition System. MDef next reads the current wind-tunnel information, and sets up the normal operation display (See Figure 1).

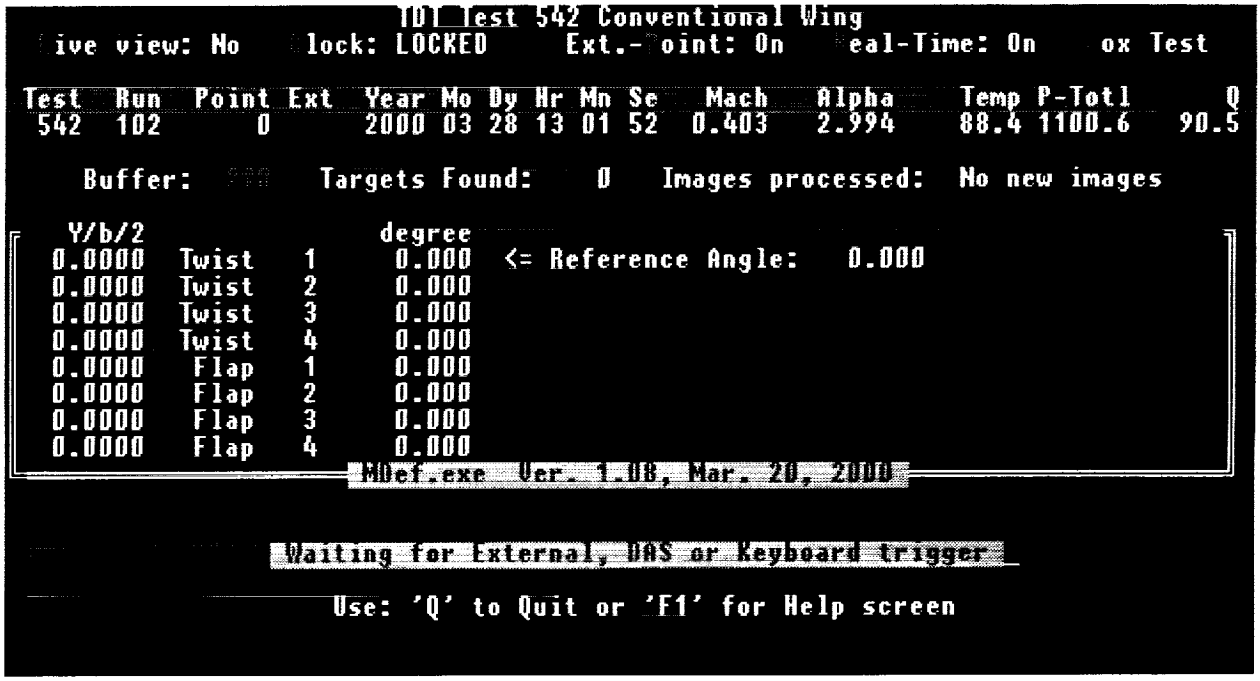

Figure 1 – Sample Start-up Screen Showing the Flap-Angle Display

MDef can be started with various command-line options. A list of command-line options can be obtained by starting MDef with a command-line option of '**?**' or '**-?**' (Ex.: **MDef.exe ?**). The command-line options are:

- **-F** - Load a still image File for processing instead of capturing and processing new images
- **-A** - IP Address for network access to the Data Acquisition System (**DAS**)
- **-P** - Port number for network access to the Data Acquisition System (**DAS**)
- **-E** - Disable External Triggers (can be enabled and disabled from within MDef)
- **-U** - Disable Pixel-Clock Lock (**U**nlock; can be enabled and disabled from within MDef)
- **-1** - One-Shot operation, Take one (**1**) data point and quit
- **?** - Display a list of command-line options

The **-F**, **-A**, and **-P** options are followed by colons and the appropriate information, such as:

MDef -F:Sample.raw -F:Sample2.raw -A:255:255:255:255 -P:50001

It should be noted that MDef only loads 8-bit grayscale image files that are uncompressed and have no header such as the images that MDef creates with the Save-Image command (**ALT-S**). Consecutive image files are loaded into consecutive image buffers starting with buffer one.

Some of the user controllable options are displayed on the second line of the screen with 'hot keys' highlighted. Function key **F1** can be used to pull up a scrollable help screen. Normal data taking can be manually triggered be pressing the letter **T**. A sample image can be captured and processed without writing to any of the append files by pressing the letter **B**; this is what is referred to as a 'B' test as 'Boxes' are drawn around any regions of interest after the targets are located. The 'B' test also numbers the targets and the regions (See Figure 7). The 'B' test is frequently used to confirm that the targets are within the proper image search region(s), the maximum and minimum blob sizes are set correctly, and the thresholds are set correctly for each search region.

B:	Do a 1-Shot Blob Test, number the targets found, draw boxes around each search region
C:	Toggle Pixel-Clock Lock
E:	Toggle External trigger enable
F:	Toggle between Flap-Angle data display and AOA data display
I:	Toggle Independent blob tracking
K:	Toggle Blob tracking (not normally used in this version of MDef)
L:	Toggle Live video mode
P:	Toggle Auto increment of Point number
Q:	Quit this program
R:	Toggle Real-time image capture
T:	Take data (Manual trigger)
W:	Walk (Step) through the image buffers
Z:	Zero the Wing and Flap-Angle data
ALT-F:	Toggle Flap-Angle computations enable
ALT-L:	Change LUX (threshold) setting for any region
ALT-S:	Save current image buffer as a raw image file and as a TIFF file
ALT-U:	Update the parameter file

The up and down arrow keys can also be used to change the image buffer being viewed.

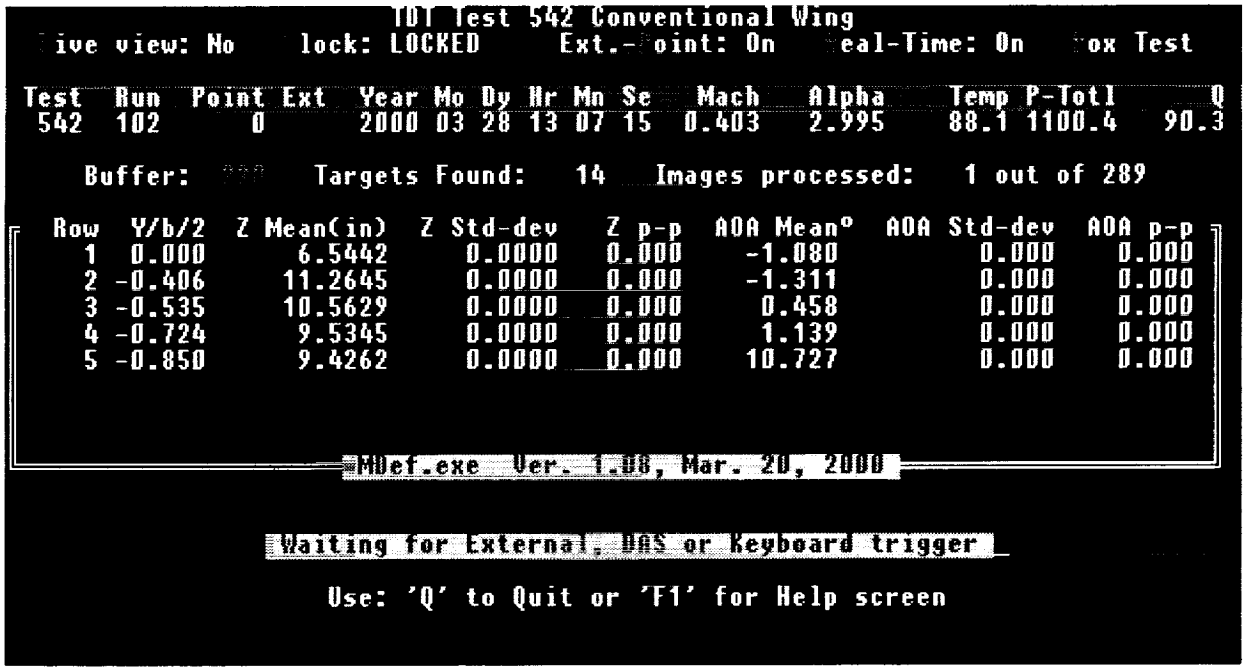

Figure 2 – Sample Zintslpe Display

When MDef runs, two types of result displays are available for viewing. One display is the newer Flap-Angle display (as shown in Figures 1 and 3), and the other display is the older Z-Intercept / Slope (**Zintslpe**) display (as shown in Figure 2).

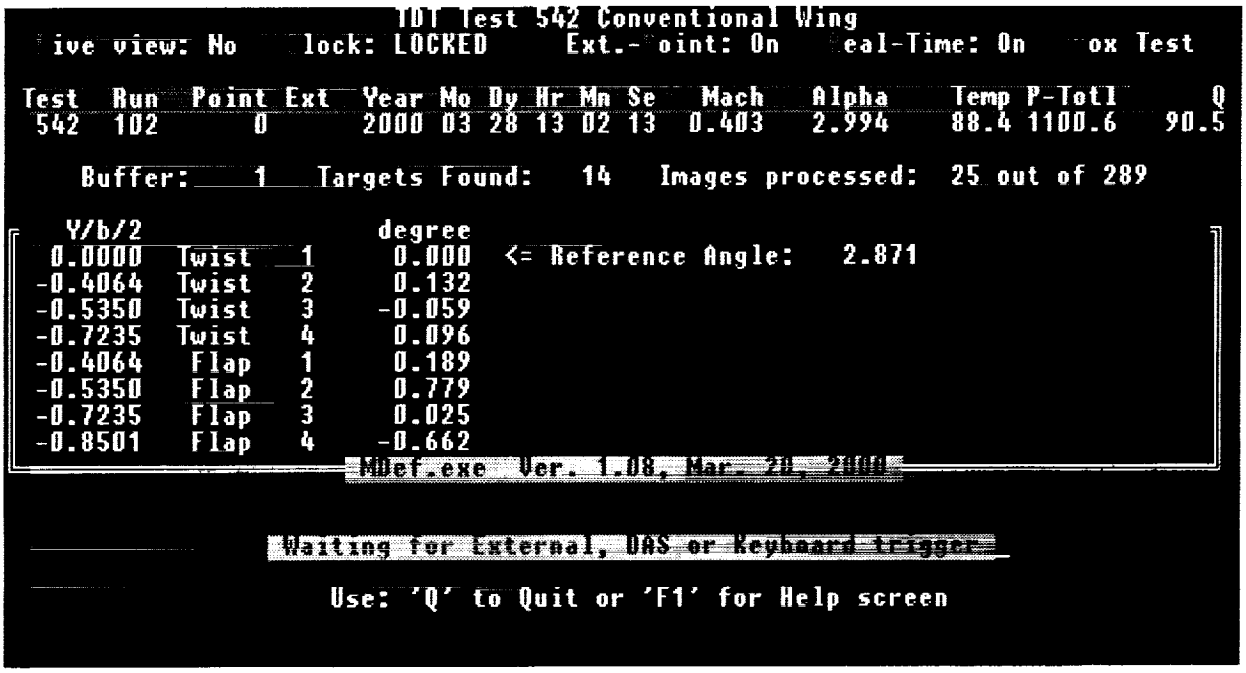

Figure 3 – Sample Flap-Angle Display

The green bar on the screen, and the text on the line immediately below it, displays some of the information from the wind tunnel's Data Acquisition System (**DAS**). The wind tunnel data can be obtained by accessing a file on a shared drive, reading serial data from an RS-232 stream from the DAS, or by a network connection to the DAS. MDef can also read the tunnel directly from the DAS by a '**socket**' connection over the network.

Serial Connection

If a serial connection is used, the DAS must be set up to send data continuously over an RS-232 cable to the computer that is running MDef. A copy of **GetFile.bat** is written that calls a program, such as **For-A.exe**, which can read the RS-232 stream and write the data that it receives to a copy of Video.dat in the work directory of the MDef computer. A configuration file (For-A.ini) must be set up for the program to know how to interpret the RS-232 stream in order to write Video.dat.

Network Connection

The computer on which MDef is being used must be set up with an Ethernet connection and properly configured (local IP address, etc.). If the wind tunnel data is being written to a shared drive, the data must be in the same format as Video.dat. A copy of GetFile.bat is written that copies the data file from the shared drive to Video.dat in the work directory of the MDef computer.

Socket Connection

The MDef computer is set up the same way as for a simple network connection. MDef must be run with the command-line options for the DAS IP address and a valid port number to talk directly to the DAS. The DAS must also be set up to send the required data in a specific order (See MDef.send in the Appendix).

Figure 4 – Sample 'Step' Calibration Plate

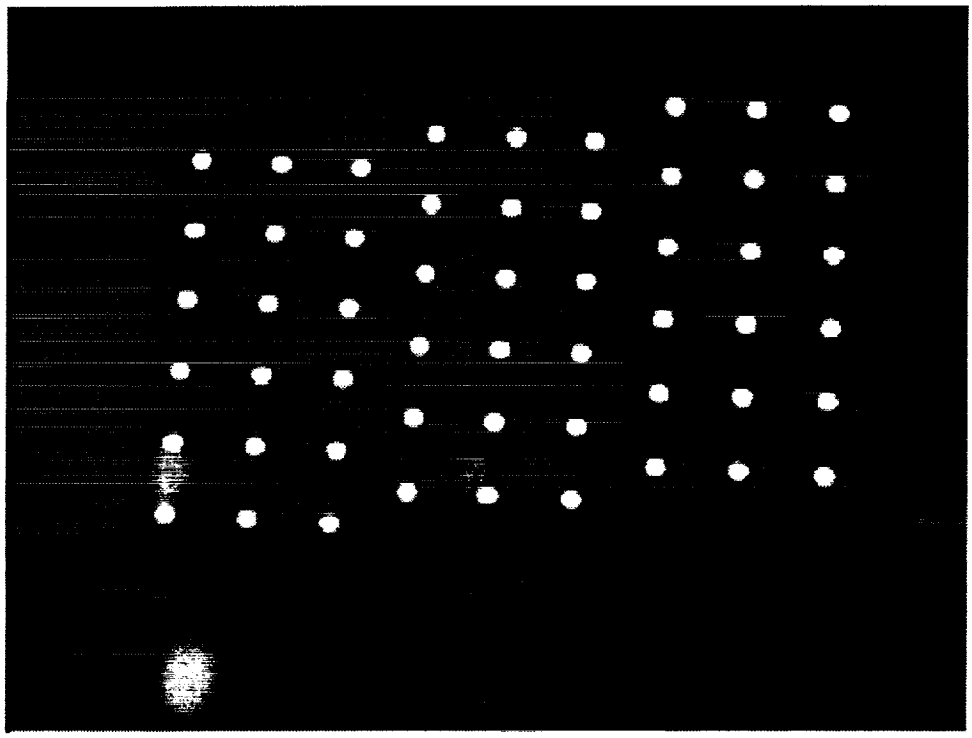

Figure 5 – Sample 'Step' Calibration Plate with Illumination

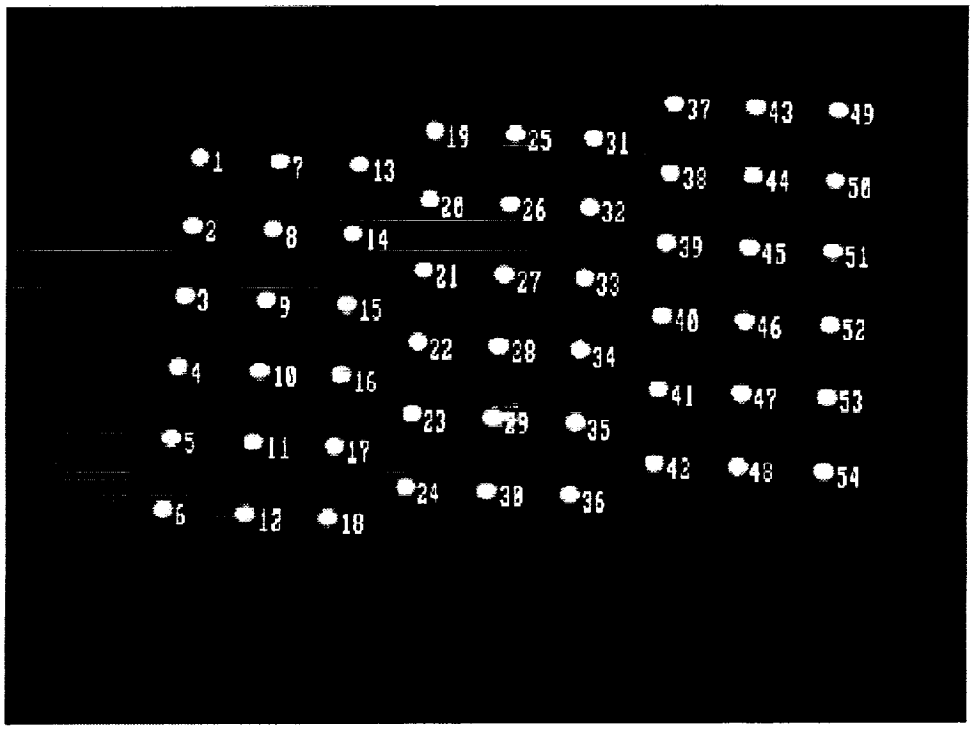

Figure 6 – Sample Image with Targets Located by 'B' Test Using a Single Region

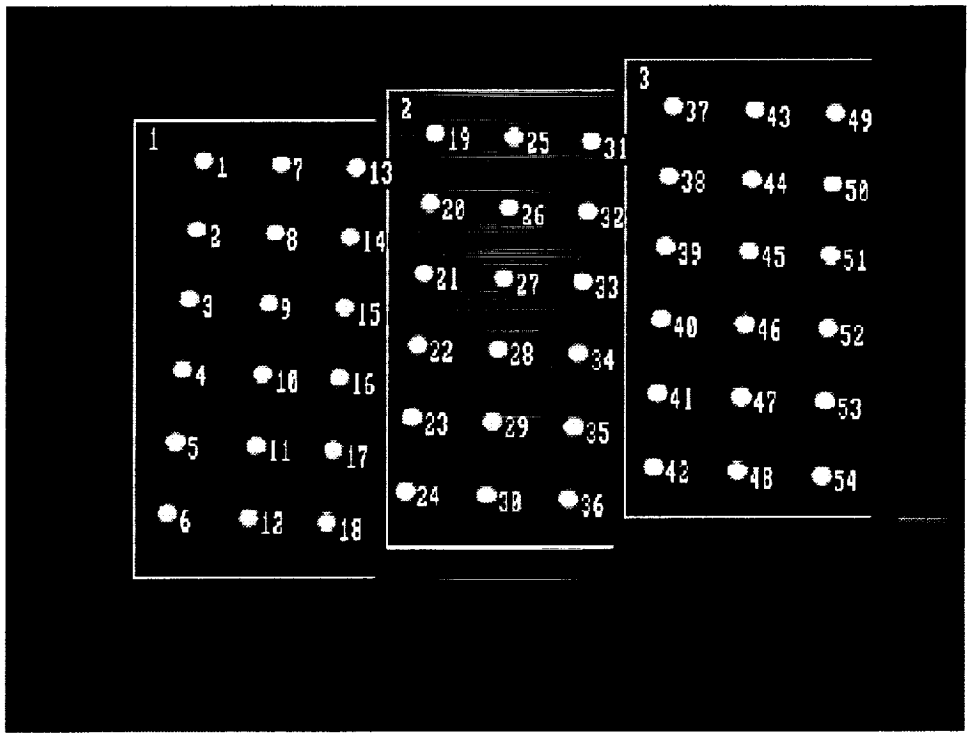

Figure 7 – Sample Image with Targets Located by 'B' Test Using Multiple Regions

Setup Procedure

Camera Setup and Orientation

The video camera is mounted on a fixed bracket or pan-tilt mechanism behind the wall of a wind tunnel's test section so that it views the model through a window. The camera is rotated 90 degrees so that the flow direction is vertical on the image plane as seen on the monitors. A variable intensity light source is usually placed near the camera to illuminate the retro-reflective (or white) targets and is adjusted, along with the aperture setting on the camera, to produce a high-contrast image of the targets on the monitors. In addition to the usual bright targets on a dark background, MDef can be set up for dark targets on a light background. Set **White-on-black** (line 25 in Param.dat) for the default, or set the flags in the **compl** column (lines 42+) for each region.

Configuration

Initial values for the camera's location are obtained by measuring the camera's location with respect to the model. The Y value (line 22 of Param.dat) is the distance (in inches) from the camera to the model along a horizontal line perpendicular to the centerline of the wind tunnel. The sign of Y is positive if the camera is on the right side of the model (air flow is to the left when viewed by someone standing next to the camera facing the model). The Z value (line 23 of Param.dat) is the vertical displacement of the camera from the centerline of the model. A positive value of Z implies that the camera is above the centerline of the model. The X value (line 21 of Param.dat) is the distance the camera is behind target number one on the model and is frequently less than ten inches.

Since the camera is usually rotated 90 degrees along it's line of sight, the initial value for kappa is (line 21 of Param.dat) set for 90. Omega (line 19) is the camera's rotation around the axes parallel to the wind tunnel's airflow (or the centerline of the model). Phi is the camera's rotation around a vertical axis.

A target plate (whose target locations have been measured) is placed near the model, within the field of view of the camera (see figure 4), and oriented parallel to the main axes of the wind tunnel. The target plate is usually mounted on a tripod such that the target plate can be translated (moved) at least one inch in along of the three axes. A copy of the target plate's reference file is created with the targets arranged in the order that they will be detected by MDef. The target nearest the top left corner of the images on the monitors is referred to as target 1, with the target below it referred to as target 2. If horizontal sorting is selected in Param.dat, the target to the right of target 1 is target 2. The X, Y and Z columns in the reference file are arranged to reflect any changes in the target plate's orientation. One or more columns may need their signs reversed. The values from the new target reference file are copied to the columns in Param.dat labeled **yref[]**, **X**, and **Z**.

After the initial values are placed in Param.dat, a 'B' (Box) test is performed. Confirm that the targets are being identified properly and that the target plate's orientation angle is near zero. If some of the targets are not found, any of the following may need to be changed:

1) The lighting (the targets may not be bright enough)
2) The aperture of the lens (there should be sufficient contrast between targets and background)
3) The threshold level(s) in Param.dat (line 28 or column 1 in the region table)
4) The maximum and/or minimum target size(s) in Param.dat (columns 4-7 in the region table)
5) The camera's orientation (all of the targets must be in the field of view for the entire range of angles the model is to be set during the test)
6) The focal length of the lens (See item #5)

Distortion

Additional software is available that can process data files created by MDef (when using a pre-measured target plate) that will calculate the pixel principal point (lines 8 and 9), the pixel symmetry point (lines 10 and 11), as well as the distortion correction value k1 (line 12) for use in Param.dat. Although k1 is placed on line 12 of Param.dat, if the other correction values are needed, they can be added immediately after k1 in the order: k2, k3, p1, and p2.

```
-1.113e-003 k1 radial distortion mm^-2  ( Put K2, K3, P1 & P2 after this …
0.0         k2 radial distortion mm^-4
1.0000000   Unitless sh_ratio locked/unlocked
```

Appendix

All output files (with the exception of the image files) are plain text files with header and comment lines prefixed with a percent sign. This allows the files to be loaded into Matlab ® for generating special plots.

Sample Param.dat File

```
-48             Tab Point               |TDT Test 542 Smart Wing
752             Horizontal pixels       ( Must be divisible by four, Max=752 )
0               Horizontal offset       ( -1 to center )
240             Vertical pixels         ( Max = 240, 480 if interlace On )
0               Vertical offset         ( -1 to center )
0.02599700      Vertical   pixel spacing of camera in mm
0.01099700      Horizontal pixel spacing of camera in mm
 370.00         Pixel x principal point ( To be measured during cal )
 108.00         Pixel y principal point   "     "
 374.30         Pixel x symmetry point  ( Measured by zoom symmetry on image )
 107.60         Pixel y symmetry point    "        "
-1.113e-003     k1 radial distortion mm^-2      ( Put K2, K3, P1 & P2 after
                this line if needed )
1.0000000       Unitless sh_ratio locked/unlocked
  0.00          Pixel x shift unlocked to locked
  0.00          Pixel y shift unlocked to locked
1               Delta_x  ( how much to increase the box over min of 4 )
1               Delta_y  ( how much to increase the box over min of 2 )
  12.8950       Camera constant c in mm
-151.4449156222003      Deg omega
-3.079673156343532      Deg phi
-83.94443400192141      Deg kappa
-1.627920426876803      Inch Xc
80.248  42.51402182382443     Inch Yc
-86.09295102229963      Inch Zc
1               White-on-black          ( 0 = Dark targets, else Light )
12              Minimum_blob_mass
4               Fields delay  ( if <= 0 get tunnel data AFTER scanning for
                blobs )
100             Target threshold        ( difference for White-on-black )
60              Maximum buffers to process      ( 0 to let it compute number )
5               Skip buffer offset              ( 0 to process every buffer )
0               Row orientation ( <0 = No sort, 0 = vertical, else horizontal
                )
5               Number of rows of targets    ( See: Ames54b.tdt in plates
                directory )
ROW 1 INFORMATION
3         Number of targets on Row 1
0.0000          Y/b/2           (Row 1)
  0.0000        Z ref offset    (Row 1)         z_int = (intercept - zref) *
                zref_slope
 0.0000         AOA ref offset  (Row 1)         angle = (aoa - aoaref) *
                aoaref_slope
 1.0000         Z ref slope     (Row 1)
 1.0000         AOA ref slope   (Row 1)
```

```
 2.0000          Ref Point        (Row 1) (x.y -> .y after point x)
ROW 2 INFORMATION
3          Number of targets on Row 2
 0.406          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)
 2.0000         Ref Point        (Row 2) (x.y -> .y after point x)
ROW 3 INFORMATION
3          Number of targets on Row 3
 0.535          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)
 2.0000         Ref Point        (Row 3) (x.y -> .y after point x)
ROW 4 INFORMATION
3          Number of targets on Row 4
 0.724          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)
 2.0000         Ref Point        (Row 4) (x.y -> .y after point x)
ROW 5 INFORMATION
2          Number of targets on Row 5
 0.850          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)
 1.5000         Ref Point        (Row 5) (x.y -> .y after point x)
Thres nw.x nw.y minx miny maxx maxy    yref[] compl bac_sub add_sub          X
                Z Mtar se.x se.y
  100    35    30    4     2    21    11    0.00000      0        1        3    0.00000
                0.00000     3  182  240
  100   185    10    7     3    21    11    0.00000      0        1        3    0.00000
                0.00000    11  750  238
 -128     0     0    7     3    21    11    0.00000      0        0        0    0.00000
                0.00000     0  752  240
 -128     0     0    7     3    21    11   22.47000      0        0        0    0.00000
                0.00000     0  752  240
 -128     0     0    7     3    21    11   22.47000      0        0        0    0.00000
                0.00000     0  752  240
 -128     0     0    7     3    21    11   22.47000      0        0        0    0.00000
                0.00000     0  752  240
 -128     0     0    7     3    21    11   29.58000      0        0        0    0.00000
                0.00000     0  752  240
 -128     0     0    7     3    21    11   29.58000      0        0        0    0.00000
                0.00000     0  752  240
 -128     0     0    7     3    21    11   29.58000      0        0        0    0.00000
                0.00000     0  752  240
 -128     0     0    7     3    21    11   40.00000      0        0        0    0.00000
                0.00000     0  752  240
 -128     0     0    7     3    21    11   40.00000      0        0        0    0.00000
                0.00000     0  752  240
```

```
-128    0    0    7    3   21   11  40.00000     0       0       0   0.00000
              0.00000    0  752  240
-128    0    0    7    3   21   11  47.00000     0       0       0   0.00000
              0.00000    0  752  240
-128    0    0    7    3   21   11  47.00000     0       0       0   0.00000
              0.00000    0  752  240
```

Sample FlapAngl.ini File

```
; FlapAngl.ini
;
Test=           542
B_2=            55.285
RefAngle=       1  ; Angle to be subtracted from all angles after corrections

; Target numbers defining the angles to calculate
;
Angle1=          1,  2,  3
Angle2=          5,  6
Angle3=          8,  9
Angle4=         11, 12
FlapAngle1=      4,  5
FlapAngle2=      7,  8
FlapAngle3=     10, 11
FlapAngle4=     13, 14
; AileronAngle1=  1,  1

; Polynomial fits for angle calibrations
;               Order:   0,    1,    2,    3,    4,    5
;
Angle1Cal=          4.3977,    0.99426,  -0.0004268,  0.000010877, 0, 0
Angle2Cal=          5.3510,    0.98482,  -0.0008244, -0.000011196, 0, 0
Angle3Cal=          1.4440,    0.99731,   0.0006800, -0.000041889, 0, 0
Angle4Cal=          1.1188,    0.99789,  -0.0002240, -0.000011629, 0, 0
FlapAngle1Cal=      4.3569,    1.00410,   0.0001892, -0.000015192, 0, 0
FlapAngle2Cal=      6.0283,    0.99658,  -0.0005375, -0.000009915, 0, 0
FlapAngle3Cal=      7.7215,    0.99007,  -0.0002878,  0.000022040, 0, 0
FlapAngle4Cal=     -5.0332,    1.03268,  -0.0025317,  0.000062695, 0, 0
; AileronAngle1Cal=      0,    1,    0,    0,    0,    0

; Zeroing values to be subtracted from all angles after corrections
;
ZeroPoint=      0         ; The angles were Zeroed at this point
;
Angle1Off=      0
Angle2Off=      0
Angle3Off=      0
Angle4Off=      0
FlapAngle1Off= 0
FlapAngle2Off= 0
FlapAngle3Off= 0
FlapAngle4Off= 0
```

Sample Video.dat File (Numbers only, text in italics added for identification only)

92	*Point number*
-0.002	*Alpha (Angle-of-Attack of Model or Wing)*
0.0000	*Alpha2,*
0.0000	*DPitch*
0.0000	*Pitch2*
4	*ID*
0.0000	*Roll (Roll angle of Model)*
0.0000	*Arcsec*
9.998	*Mach (9.998 usually indicates **no flow**)*
69.5	*Total Temperature in Wind tunnel in degrees Fahrenheit)*
0.30	*Total Pressure in PSI*
9	*Q*
542.6	*Test number*
902	*Run number of test*
03-09-2000	*Date of test*
12:20:54	*Time point was taken*

Sample MDef.send File (Text in italics added for identification only)

P TEST 0	Test Number
P RUN 0	Run Number of Test
P POINT 0	Tab/Point/Sequence Number
P ALPHA -3	Angle-of-Attack of Model or Wing
P MACH -3	Wind speed in tunnel
P TEMP -1	Total temperature (°F)
P PRESSURE -2	Total pressure (PSI)
P Q -1	
P ROLL -2	Roll angle of Model or Wing under test
P HOUR 0	Time point was taken
P MINUTE 0	
P SECOND 0	
P YEAR 0	Date point was taken
P MONTH 0	
P DAY 0	
P ID 0	Optional data
P Alpha2 -3	Optional data
P DPitch -3	Optional data
P Pitch2 -3	Optional data
P Arcsec -3	Optional data

The file above is only an example of what the Data Acquisition System may require for sending the data to MDef. In this example, the negative numbers represent the number of decimal places for formatting the values to be sent.

The following file samples have too many columns to print properly, the extra columns have been split off and are printed a section at a time; some columns have been dropped. The comment lines have been highlighted for readability.

Sample Tunnel.log File

% Test	Run	Point	Ext	---Date---	--Time--	TTemp	TPres	Mach
542	902	90		2000 03 09	11 19 43	67.7	0.30	9.998
542	902	91		2000 03 09	12 11 02	69.1	0.30	9.998
542	902	+91.001		2000 03 09	12 12 18	69.3	0.30	9.998
542	902	+91.002		2000 03 09	12 12 30	69.3	0.30	9.998
542	902	+91.003		2000 03 09	12 12 40	69.3	0.30	9.998
542	903	92		2000 03 09	12 20 54	69.5	0.30	9.998

Qinfft	Alpha	TwistSLI	TwistSLO	TwistSRI	ID	Roll	TwistSRO
999.9	-0.085	542.000	903.000	90.000	13	0.47	9.998
999.9	-0.002	542.000	903.000	91.000	4	0.00	9.998
999.9	-0.002	542.000	903.000	91.000	4	0.00	9.998
999.9	-0.002	542.000	903.000	91.000	4	0.00	9.998
999.9	-0.001	542.000	903.000	91.000	4	0.00	9.998
999.9	-0.002	542.000	903.000	92.000	4	0.00	9.998

Sample Log.dat File

% Test	Run	Point	Ext	---Date---	--Time--	xdim	xpos	ydim	ypos
542	902	90		2000 03 09	11 19 43	752	0	240	0
542	902	91		2000 03 09	12 11 02	752	0	240	0
542	903	+91.001		2000 03 09	12 12 18	752	0	240	0
542	903	+91.002		2000 03 09	12 12 30	752	0	240	0
542	903	+91.003		2000 03 09	12 12 40	752	0	240	0
542	903	92		2000 03 09	12 20 54	752	0	240	0

camvpix	camhpix	xp_pixel	yp_pixel	xs_pixel
0.0259970	0.0109970	370.0000000	108.0000000	374.3000000
0.0259970	0.0109970	370.0000000	108.0000000	374.3000000
0.0259970	0.0109970	370.0000000	108.0000000	374.3000000
0.0259970	0.0109970	370.0000000	108.0000000	374.3000000
0.0259970	0.0109970	370.0000000	108.0000000	374.3000000
0.0259970	0.0109970	370.0000000	108.0000000	374.3000000

ys_pixel	k1	sh_rat	xshift	yshift	de_x	de_y	c
107.6000000	-0.0011	1.0000	0.0000	0.0000	1	1	12.90
107.6000000	-0.0011	1.0000	0.0000	0.0000	1	1	12.90
.							
.							
.							
107.6000000	-0.0011	1.0000	0.0000	0.0000	1	1	12.90
107.6000000	-0.0011	1.0000	0.0000	0.0000	1	1	12.90

omega	phi	kappa	Xc	Yc	Zc	wonb	minm	maxm
-151.4449	-3.0797	-83.9444	-1.63	80.25	-86.09	1	12	4
-151.4449	-3.0797	-83.9444	-1.63	80.25	-86.09	1	12	4
.								
.								
.								
-151.4449	-3.0797	-83.9444	-1.63	80.25	-86.09	1	12	4
-151.4449	-3.0797	-83.9444	-1.63	80.25	-86.09	1	12	4

thresh	num_b	skip	ro	r_c	ntr[1]	yb2[1]	zref[1]	aref[1]	zslp[1]
100	60	5	0	5	3	0.000	0.000	0.00	1.00
100	60	5	0	5	3	0.000	0.000	0.00	1.00
.									
.									
.									
100	60	5	0	5	3	0.000	0.000	0.00	1.00
100	60	5	0	5	3	0.000	0.000	0.00	1.00

aslp[1]	zrp[1]	ntr[2]	yb2[2]	zref[2]	aref[2]	zslp[2]	aslp[2]
1.00	2.0	3	0.406	0.000	0.00	1.00	1.00
1.00	2.0	3	0.406	0.000	0.00	1.00	1.00
.							
.							
.							
1.00	2.0	3	0.406	0.000	0.00	1.00	1.00
1.00	2.0	3	0.406	0.000	0.00	1.00	1.00

zrp[2]	ntr[3]	yb2[3]	zref[3]	aref[3]	zslp[3]	aslp[3]	zrp[3]
2.0	3	0.535	0.000	0.00	1.00	1.00	2.0
2.0	3	0.535	0.000	0.00	1.00	1.00	2.0
.							
.							
.							
2.0	3	0.535	0.000	0.00	1.00	1.00	2.0
2.0	3	0.535	0.000	0.00	1.00	1.00	2.0

ntr[4]	yb2[4]	zref[4]	aref[4]	zslp[4]	aslp[4]	zrp[4]	ntr[5]
3	0.724	0.000	0.00	1.00	1.00	2.0	3
3	0.724	0.000	0.00	1.00	1.00	2.0	3
.							
.							
.							
3	0.724	0.000	0.00	1.00	1.00	2.0	3
3	0.724	0.000	0.00	1.00	1.00	2.0	3

```
yb2[ 5] zref[ 5] aref[ 5] zslp[ 5] aslp[ 5] zrp[ 5]
  0.850    0.000     0.00     1.00     1.00     1.5
  0.850    0.000     0.00     1.00     1.00     1.5
    .
    .
    .
  0.850    0.000     0.00     1.00     1.00     1.5
  0.850    0.000     0.00     1.00     1.00     1.5
```

Sample Centxxxx File

```
% Cent0091
%
% 2000-03-09 12:11:02
%
% F    X[  1]  Y[  1]    X[  2]  Y[  2]    X[  3]  Y[  3]    X[  4]
  1   122.013 109.209   102.832 153.226    83.836 211.054   319.082
  7   122.021 109.201   102.818 153.238    83.817 211.050   319.076
 13   122.018 109.211   102.780 153.242    83.819 211.058   319.070
    .
    .
    .
 49   122.014 109.209   102.811 153.228    83.819 211.062   319.041
 55   122.019 109.214   102.798 153.241    83.814 211.059   319.041

 Y[  4]    X[  5]  Y[  5]    X[  6]  Y[  6]    X[  7]  Y[  7]
159.382   304.557 201.709   294.208 230.292   394.056 118.416
159.377   304.567 201.706   294.210 230.292   394.050 118.427
159.382   304.541 201.691   294.210 230.301   394.068 118.425
    .
    .
    .
159.370   304.558 201.707   294.199 230.284   394.059 118.420
159.380   304.554 201.702   294.221 230.293   394.076 118.429

 X[  8]  Y[  8]    X[  9]  Y[  9]    X[ 10]  Y[ 10]    X[ 11]
377.663 163.299   359.569 228.071   510.581  59.691   495.904
377.672 163.308   359.564 228.069   510.583  59.696   495.914
377.672 163.308   359.556 228.073   510.578  59.696   495.908
    .
    .
    .
377.664 163.310   359.586 228.065   510.579  59.695   495.896
377.673 163.306   359.596 228.070   510.582  59.696   495.904

 Y[ 11]    X[ 12]  Y[ 12]    X[ 13]  Y[ 13]    X[ 14]  X[ 14]
100.631   472.642 189.700   566.210 127.815   555.970 186.196
100.623   472.621 189.712   566.188 127.812   556.011 186.193
100.621   472.638 189.706   566.202 127.816   555.996 186.186
    .
```

```
   .
   .
100.623   472.642 189.697   566.210 127.814   555.983 186.191
100.633   472.638 189.699   566.187 127.816   555.979 186.181
```

Sample Cerrxxxx File

(The plus signs in front of the field numbers indicate that the sample was manually triggered)

```
% Cerr0702
%
% 2000-03-09 12:11:02
%
%  F    X[  1]  Y[  1]    X[  2]  Y[  2]    X[  3]  Y[  3]    X[  4]
+1     153.780 159.814   134.681 212.532   383.696  34.329   360.506
+13    153.776 159.816   134.655 212.539   383.716  34.317   360.509
+25    153.766 159.821   134.679 212.534   383.722  34.327   360.517
   .
   .
   .
+265   153.765 159.815   134.656 212.532   383.716  34.327   360.539
+277   153.777 159.818   134.647 212.522   383.710  34.323   360.526
+289   153.771 159.811   134.669 212.549   383.715  34.322   360.523

 Y[  4]    X[  5]  Y[  5]    X[  6]  Y[  6]    X[  7]  Y[  7]
 85.555   241.557 108.912   444.761 119.857   218.499 165.079
 85.546   241.559 108.916   444.776 119.861   218.519 165.090
 85.560   241.561 108.913   444.779 119.850   218.521 165.099
   .
   .
   .
 85.552   241.567 108.912   444.776 119.865   218.518 165.096
 85.558   241.566 108.917   444.769 119.846   218.498 165.085
 85.558   241.573 108.915   444.761 119.857   218.508 165.092

 X[  8]  Y[  8]    X[  9]  Y[  9]    X[ 10]  Y[ 10]    X[ 11]
432.735 194.979   329.550 199.117
432.755 194.979   329.549 199.112
432.757 194.982   329.544 199.111
   .
   .
   .
432.735 194.979   329.575 199.120
432.738 194.986   329.550 199.122
432.736 194.975   329.556 199.113

Y[ 11]    X[ 12]  Y[ 12]    X[ 13]  Y[ 13]    X[ 14]  X[ 14]
```

The normal header line was created but no data was written past X,Y pair #9 as only 9 targets were found.

Sample XYZxxxxx File

% Field	X[1]	Y[1]	Z[1]	...
1	1.851992	0.000000	7.792948	...
7	1.854060	0.000000	7.793869	...
13	1.851581	0.000000	7.793826	...
.				
.				
.				
49	1.852007	0.000000	7.793107	...
55	1.850867	0.000000	7.794113	...

X[14]	Y[14]	Z[14]
-10.533415	47.000000	12.494166
-10.533283	47.000000	12.505107
-10.531616	47.000000	12.500552
-10.532515	47.000000	12.497359
-10.530348	47.000000	12.495591

Sample XYZMean.dat File

% Test	Run	Point Ext	X[1]	Y[1]	Z[1]	...
542	902	90	1.84496	0.00000	7.82568	...
542	902	91	1.85174	0.00000	7.79470	...
542	902	+91.001	1.85219	0.00000	7.79480	...
542	902	+91.002	1.85135	0.00000	7.79395	...
542	902	+91.003	1.85218	0.00000	7.79414	...
542	903	92	1.85439	0.00000	7.79420	...

X[14]	Y[14]	Z[14]
-10.54488	47.00000	12.49333
-10.53257	47.00000	12.49853
-10.53194	47.00000	12.49800
-10.53085	47.00000	12.49463
-10.53147	47.00000	12.49630
-10.52955	47.00000	12.49413

Sample ZSlp File

% Field	z_int[1]	angle[1]	x_tmp[1]	z_crs[1]	...
1	7.525	-4.4076	-9.042	6.828	...
7	7.525	-4.4166	-9.045	6.827	...
13	7.523	-4.4140	-9.046	6.825	...
.				...	.
.				...	.
.				...	.
43	7.526	-4.4083	-9.046	6.829	...
49	7.524	-4.4125	-9.042	6.826	...
55	7.524	-4.4169	-9.046	6.826	...

z_int[5]	angle[5]	x_tmp[5]	z_crs[5]
11.591	4.9000	-4.477	11.975
11.587	4.9798	-4.477	11.977
11.590	4.9406	-4.477	11.977
.		...	
.		...	
.		...	
11.589	4.9101	-4.479	11.974
11.592	4.9156	-4.477	11.977
11.586	4.9368	-4.476	11.973

Sample ZIntSlpe File

% Test	Run	Point Ext	yb2[1]	mean_z[1]	mean_aoa[1]	sigma_z[1]
542	902	90	0.0000	6.8406	-4.507	0.0010
542	902	91	0.0000	6.8271	-4.413	0.0013
542	902	+91.001	0.0000	6.8274	-4.411	0.0006
542	902	+91.002	0.0000	6.8265	-4.414	0.0010
542	902	+91.003	0.0000	6.8272	-4.412	0.0011
542	903	92	0.0000	6.8270	-4.416	0.0011

SEE_z[1]	sigma_aoa[1]	SEE_aoa[1]	pp_z[1]	pp_aoa[1]	...
0.0020	0.0051	0.0065	0.0037	0.0153	...
0.0022	0.0046	0.0070	0.0038	0.0152	...
0.0017	0.0060	0.0056	0.0037	0.0167	...
0.0013	0.0065	0.0042	0.0037	0.0177	...
0.0008	0.0046	0.0025	0.0034	0.0146	...
0.0029	0.0084	0.0093	0.0062	0.0237	...

yb2[5]	mean_z[5]	mean_aoa[5]	sigma_z[5]	SEE_z[5]
0.8500	11.9802	4.844	0.0037	0.0000
0.8500	11.9757	4.935	0.0017	0.0000
0.8500	11.9750	4.936	0.0034	0.0000
0.8500	11.9734	4.920	0.0024	0.0000
0.8500	11.9739	4.931	0.0022	0.0000
0.8500	11.9718	4.930	0.0029	0.0000

sigma_aoa[5]	SEE_aoa[5]	pp_z[5]	pp_aoa[5]	---Date---	--Time--
0.0199	0.0001	0.0111	0.0640	2000 03 09	11 19 43
0.0252	0.0001	0.0055	0.0799	2000 03 09	12 11 02
0.0319	0.0001	0.0101	0.0898	2000 03 09	12 12 18
0.0328	0.0001	0.0117	0.0989	2000 03 09	12 12 30
0.0280	0.0001	0.0062	0.0978	2000 03 09	12 12 40
0.0221	0.0001	0.0091	0.0694	2000 03 09	12 20 54

TTemp	TPres	Mach	Qinfft	Alpha	Alpha2	DPitch	Pitch2
67.7	0.30	9.998	999.9	-0.085	542.000	903.000	90.000
69.1	0.30	9.998	999.9	-0.002	542.000	903.000	91.000
69.3	0.30	9.998	999.9	-0.002	542.000	903.000	91.000
69.3	0.30	9.998	999.9	-0.002	542.000	903.000	91.000
69.3	0.30	9.998	999.9	-0.001	542.000	903.000	91.000
69.5	0.30	9.998	999.9	-0.002	542.000	903.000	92.000

ID	Roll	Arcsec
13	0.47	9.998
4	0.00	9.998
4	0.00	9.998
4	0.00	9.998
4	0.00	9.998
4	0.00	9.998

The last seventeen columns of this file (**---Date---** through **Arcsec**) can also be found in **Tunnel.log**.

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13. ABSTRACT (Maximum 200 words)
The program MDef.exe was created to take images in wind tunnels of models under test, identify targets, compute the target's centroids, compute the target's real-world X-Y-Z coordinates and the model's deformation (vertical displacement and wing twist).

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