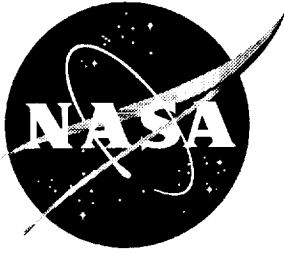# PIV/HPIV Film Analysis Software Package

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*ViGYAN, Inc., Hampton, Virginia*

December 1997

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NASA/CR-97-206286

PIV/HPIV Film Analysis Software
Package

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# PIV/HPIV Film Analysis Software Package

## Abstract

A PIV/HPIV film analysis software system was developed that calculates the 2-dimentional spatial autocorrelations of subregions of Particle Image Velocimetry (PIV) or Holographic Particle Image Velocimetry (HPIV) film recordings. The software controls three hardware subsystems including 1) a Kodak Megaplus 1.4 camera and EPIX 4MEG framegrabber subsystem, 2) an IEEE/Unidex 11 precision motion control subsystem, and 3) an Alacron i860 array processor subsystem. The software package runs on an IBM PC/AT host computer working either under Microsoft Windows v3.1 or Windows 95 operating systems. It is capable of processing five PIV or HPIV displacement vectors per second, and is completely automated with the exception of user input to a configuration file prior to analysis execution for update of various system parameters.

# Acknowledgments

# Contents

# PIV/HPIV Film Analysis Software Package

## 1.0    Introduction

The IBM PC/AT PIV/HPIV film analysis software system calculates the 2-dimentional spatial autocorrelations of subregions of PIV or HPIV film recordings using the Alacron i860 array processor subsystem. It runs on an IBM PC/AT host computer working either under Microsoft Windows v3.1 or Windows 95 operating systems. The system is capable of processing five displacement vectors per second, and is completely automated with the exception of user input to a configuration file prior to analysis execution for update of various system parameters. The executable program file is named **PIV54.exe** with a configuration text file called**KODAK54.cfg**.

## 2.0    Hardware and Software Interface Description

The hardware used in the analysis system includes three basic subsystems. They include 1) the Kodak Megaplus v1.4 digital camera and Epix frame grabber 4MEG video subsystem for transfer of the individual subregion areas to PC memory, 2) the National Instruments IEEE/GPIB NI-488.2 interface card and Aerotech Unidex 11 precision motion control subsystem for transfer of the film frame to the adjacent image correlation regions, and 3) the Alacron FT200-AT array processor subsystem for calculating the 128x128 2-dimensional autocorrelation of the image subregion. The hardware and software versions used in the software development for each subsystem include:

| | | **DATE** |
|---|---|---|
| 1) | Kodak Megaplus Digital Camera System v1.4 | 1992 |
| | Epix Framegrabber Object Library m4obm7wl.lib v1.7 | 1992 |
| | Epix Framegrabber Image Processing Library pxipm7wl.lib v1.7 | 1992 |
| 2) | IEEE/GPIB NI-488.2 interface card | 1992 |
| | IEEE/GPIB NI-488.2 function Library gpib.lib v2.1.1 | 1992 |
| | Aerotech Unidex 11 Motion Controller | 1988 |
| 3) | Alacron FT200-AT array processor board | 1995 |
| | Alacron FT200-AT RT860 Slave Mode Library w3slv860.lib v1.7 | 1995 |
| | Portland Group Compiler package v2.3 | 1995 |

## 3.0    Software Description

## 3.1    General Software Description

The software is modular in nature and applies the various hardware and software control functions in a sequential manner. The order of program execution typically involves the following steps:

1) system initialization
2) read in configuration file parameters
3) initialize the i860 array processor and load i860 program
4) calculate the FFT weight functions on the i860
5) initialize the IEEE/GPIB and Unidex 11 systems
6) initialize the EPIX framegrabber and Kodak Megaplus systems
7) send analysis parameters to i860
8) move Unidex system to start position and zero coordinates
9) Begin main analysis loop which involves:
   a) capture subimage using framegrabber
   b) transfer position information to i860
   c) transfer image data to i860
   d) move Unidex to next analysis subregion
   e) calculate the 2-d autocorrelation of the 54 subimages which involves:
      I.) compute and apply active threshold on raw image data
      II.) check for totally white or black image field
      III.) apply default peak values
      IV.) calculate forward 2d fft
      V.) autocorrelate the 2d fft field
      VI.) center the final correlation field
      VII.) calculate the inverse 2d fft
      VIII.) zero out DC peak region
      IX.) scale output correlation field to 0-255
      X.) apply search box thresholding
      XI.) calculate the top three centroid positions
      XII.) write the results to output file
   f) retrieve the final correlation number 54 and display on monitor
10) return Unidex 11 to zero position
11) free up memory and close hardware

The user provides various analysis parameters through the kodak54.cfg configuration file. Image and correlation field threshold levels, Unidex shift amounts and sizes, DC peak extent, file output name, magnification levels, laser pulse separation level, Kodak camera exposure level, correlation field search box extents, and default peak positions are required. Once the configuration parameters are setup, the program is executed using the user parameters provided. Analysis at this point is automated, with interaction with the user limited to display of the current analysis position on the computer screen, and display of the most recent correlation field on the RS170 monitor. An update of the approximate time remaining in the analysis is also provided. The top three centroid positions and relative intensity levels are written out for each analyzed position in the image field in ASCII text format.

## 3.2    Detailed Software Description

The program is made up of three 'c' source files, and three resource files. The program is of a Windows 'quickwin' type which allows it to be run in Windows 3.1 or Windows 95, but allows minimal user interaction. Interaction and control of various program execution parameters is provided by a configuration file as described in the previous sections. The user edits the configuration file before program execution, and when the program is run, the configuration parameters are read in from that file. The program then displays the parameters on the monitor in a quickwin window and begins the analysis with no further user input.

The source file PIV54c.C is the primary 'control' program, and the source file PIV54p.C is a 'slave' program run on the i860 array processor. Each of these will be detailed in the following section. The source file PIV54w.C develops and displays the quickwin window and will not be detailed here. The user is referred to the commented listing provided. The three additional resource files will also not be detailed here.

The source file PIV54c.C contains seven modular functions that perform the various initialization operations for the system. The main() function begins and ends program execution and performs memory allocation, initialization, and control functionality. Its first task is to call the read_config() function which reads the configuration file parameters into global variables for use later in the program. The main() function then continues on and prints the configuration parameters in the quickwin windows, followed by data array memory allocation calls.

The Alacron i860 array processor board is then initialized and opened with the functions alopen() and aldev(), respectively. The i860 slave program 'piv54p' is then

loaded into i860 memory using the function almapload(). Memory is then initialized and allocated using the function i860malloc() and malloc() functions. A call to the i860 slave function dowts() is then made using the master function alcall(). This function calculates the FFT weight functions needed for the autocorrelation routine. The function alwait() prevents further program execution until the alcall() function returns from the i860.

The IEEE/Unidex 11 system is then initialized using the ibfind(), ibdev(), ibclr(), and ibconfig() functions. The EPIX 4MEG video framegrabber and Kodak Megaplus systems are then initialized and opened using the do_open() and pxd_m4open() functions. An initialization image is then captured using the pxd_videkset() and pxd_videkdo() functions.

The correlation analysis parameter set is then sent to the i860 using the functions alsetla() and alsetba() functions. This includes 12 long integer values and a character string containing the output filename. A master call to alcall() and alwait(), in turn, calls the i860 slave function filetransfer() which reassembles the filename from individual characters into a character string name for the file.

The IEEE/Unidex system is then positioned to its initial analysis system position using the functions ibrsp() and ibwrt(). The main analysis looping sequence is then begun, which involves:

1) capturing a low resolution Kodak Megaplus image of a subregion in the film,
2) transferring the image data to the i860 memory,
3) performing the autocorrelation of the image in 128x128 sections,
4) finding the centroids of the top three correlation peaks,
5) writing the results out to file,
6) and moving the film to the next position for the process to repeat.

The low resolution image capture is performed with the pxd_videkdo() and pxd_video() functions. The camera exposure level for the pxd_videkdo() function was provided by the user in the configuration file. The pxd_video() function controls the digitize/display/blank control functionality of the framegrabber and is set to image blanking to speed up processing here. Image data is sent from the framegrabber to PC memory, and then from the PC memory to the i860 memory in a piece-wise manner, based on the fact that the EPIX function pxd_io() and Alacron function alsetba() are limited to transferring 32000 bytes of information at a time. This requires the transfer of image data in nine pieces 50 rows by 640 pixels long. Image transfer from the framegrabber buffer to the PC memory is accomplished with the buf_to_array() function, which in turn calls the

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EPIX functions pxd_iopen() and pxd_io(). Transfer from the PC memory to i860 memory is then done with the Alacron alsetba() function. A call to the i860 slave function transfer() is then required to reassemble the image field to a full 640x448 from its nine transferred pieces.

Once the image and analysis parameter set has been sent to i860 memory, the i860 slave function dofft() is called. This function breaks up the image into 54 128x128 subimage regions, and perform the autocorrelations of each. The 54 subimage regions represent a 9x6 grid of adjacent regions in the full 640x448 image field. Each subimage is 128x128 pixels and 50% oversampling of the data results in an x, and a y, shift of 64 pixels in each direction between adjacent subimage region. This ultimately results in 9 available 128x128 images in the x direction (out of 640 image pixels in that direction), and 6 available images in the y direction (out of 448 image pixels in that direction), which finally results in 54 autocorrelations for each captured image field in the analysis.

The autocorrelation process begins with a determination of the weighted mean pixel level for the 128x128 subimage region being evaluated:

$$Weighted\ Mean = \frac{(\sum_{i=0,j=0}^{i=128,j=128} I_{pixel}) \times Weight}{16384}$$

where $I$ is the 8-bit pixel intensities (0-255), and weight is the user input weighting amount usually set to between 0.65 and 1.25. If a pixel value is found to be greater than the weighted mean value it is set to zero, and if found less than or equal to the weighted mean value it is set to its compliment value. This produces an image field of bright white particle image dots on a black background.

A count of bright and dark levels in the current image field is kept so that if excessive bright or dark areas are present the frame can be zeroed out for easier data validation efforts later. This condition typically occurs in boundary regions, image flair regions, or non-seeded regions. On a similar theme, a default correlation peak set is introduced into the image field to aid in data validation efforts later. This is done by setting a series of six pixels to a intensity level of 20 corresponding to a set of three particle image pairs that will correlate if the entire image field is black. The user elects to introduce these default peaks and chooses their relative locations. The minimal 20 pixel intensity level causes no adverse affects on a legitimate PIV image field, which has particle image peak intensities near 255 and contrast levels in excess of 50:1.

Following the active threshold (weighted mean) implementation, the forward 2-dimensional Fourier transform is applied to the data set using the Alacron provided function cfft2d(). The 2d FFT is then autocorrelated with itself:

$$\Im[R(\alpha,\beta)] = \Im[f^*(x,y) \otimes f(x,y)] = |F(p,q)|^2$$

which basically reduces to squaring the real and imaginary parts of the FFT and adding them together:

$$|F(p,q)|^2 = A_F(p,q)e^{i(px+qy)} \times A_F(p,q)e^{-i(px+qy)} = \{\mathrm{Re}[F(p,q)]\}^2 + \{\mathrm{Im}[F(p,q)]\}^2$$

where F(p,q) is the complex 2d forward FFT of the image field. The correlated image field is then centered in the image field by taking advantage of the translation property of the Fourier transform which sets the origin of the Fourier transform of f(x,y) to the center of its corresponding NxN frequency square by multiplying f(x,y) by $(-1)^{x+y}$. This is coded up by multiplying the x and y frequency components values of f(x) and f(y) by $(-1)^x$ and $(-1)^y$ respectively. Mathematically, this is represented by:

$$f(x,y)(-1)^{x+y} \Leftrightarrow F(u-N/2, v-N/2)$$

The inverse Fourier transform is then obtained to produce the desired PIV autocorrelation pattern, which takes the form of a self-correlation peak centered in the image field, and symmetric satellite correlation peaks about the center of the image field representing the average particle image displacement present in the field.

Following the successful completing of the autocorrelation processing steps, a determination of the locations of the satellite peaks needs to be conducted. This first involves applying a filter to the self correlation peak centered in the image field. The DC peak extent value provided by the user is used to zero-out values extending from the center of the image field out to the peak extent level. This basically zeroes out a square box pattern centered around pixels (64,64). The correlation field is then scaled to 8-bit levels (0-255) for display and storage later. This involves calculating the minimum and maximum pixel intensity values in the image field and applying:

$$Scaled\ Pixel\ Intensity = \frac{Pixel\ Intensity + (-1.0* Minimum)}{Maximum + (-1.0* Minimum)} \times 255$$

The user supplied search box values are then used to apply a hard threshold level within the search box boundaries. An additional 0-255 scaling operation is done before the hard threshold to enhance the dynamic range levels within the search box. The hard threshold level is then applied so that if the pixel value is less than the user threshold it is zeroed.

A custom set of image centroid functions are then applied to the search box region. This begins by calling the i860 slave function main_search() from within the dofft() function. A series of three dynamic centroid storage arrays are used to store potential centroid values, of which the top three intensity levels will be saved away. The main_search() function checks the pixel intensity levels from the top left portion of the search box to the bottom right, and calls blob_search() if it finds a pixel above the threshold level. The blob_search() function in turn looks for connected neighbors that are above the threshold level and stores away the (x,y) positions and the intensity value for each pixel associated with a given blob. Once the entire blob extent has been determined, its centroid is evaluated using the i860 slave function find_centroid() which uses a weighted mean average routine to determine the x, y, and intensity levels of the blob. A comparison of its weighted mean intensity level is then made with the top three centroids, and if it beats any of the three, it is placed ahead of them in the final centroid arrays.

Returning to the main_search() function, and following the determination of the top three centroid positions within the search box, the centroid x and y positions are scaled relative to the center of the image field, to give the relative displacement away from the self-correlation peak (which is the average displacement of the particle pairs in the field). The magnification and laser pulse separation are then taken into account using the user defined values to transform the final centroid pixel displacements to velocity according to:

$$Velocity\ Level = \frac{(Pixel\ Displacement\ Level)*(Analysis\ Scale\ Factor)}{(Acuisition\ Magnification\ Level)*(Laser\ Pulse\ Separation)}$$

where the analysis scale factor, acquisition magnification level, and laser pulse separation are determined by, and supplied by the user. The x and y position is also scaled at this point in the program according to:

$$Scaled\ Position_{x,y} = \frac{[Position_{x,y}*(Analysis\ Scale\ Factor)]}{(Acquisition\ Magnification\ Level)} + (Unidex\ Shift\ Amount)_{x,y}$$

where the (Unidex Shift Amount)$_{x,y}$ represents the amount of x or y shift between image capture frames applied by the Unidex film translation system.

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The top three autocorrelation centroid positions are then written out to file along with the 8-bit (0-255) correlation peak intensity level, and the x and y position. The output file format takes the following form of eleven columns of data across:

| column 1 | column2 | column3 | column4 | column5 | column6 | column7 | column8 | column9 | column10 | column11 |
|---|---|---|---|---|---|---|---|---|---|---|
| x position | y position | $1^{st}$ u | $1^{st}$ v | $1^{st}$ peak | $2^{nd}$ u | $2^{nd}$ v | $2^{nd}$ peak | $3^{rd}$ u | $3^{rd}$ v | $3^{rd}$ peak |

where u and v are the u and v velocity components, respectively, and peak is the relative centroid correlation peak height recorded during the analysis process. The $1^{st}$, $2^{nd}$, and $3^{rd}$ designations represent the strongest, $2^{nd}$ strongest, and $3^{rd}$ strongest correlation peak heights, respectively.

Following the autocorrelation analysis and data write-out to file for a single captured (640x448) image field, the program returns to the master program's control and the main() function. The next image position (defined by the Unidex film translation away from the previous adjacent position) is then captured, transferred to i860 array memory, and analyzed in an identical way. This process continues until the entire film frame is analyzed, which is defined by the number of Unidex film x/y translations provided by the user.

Following the analysis of the entire film frame, the Unidex is repositioned at the original (0,0) position. Memory is also freed up, and hardware/output data files are closed.

## 4.0    Analysis Procedures

The basic analysis process includes three steps which include 1) aligning the film in the film holder, 2) setting up the configuration file, and 3) running the analysis program. Each of these will be detailed in this section of the document. Some additional preliminary analysis setup procedures are also required before analysis can commence, but will not be covered. They include 1) determination of acquisition and analysis magnification levels, 2) determination of an adequate registration point on each film frame, 3) determination of Unidex x and y shift amounts, 4) determination of the number of Unidex x and y shifts to cover the entire film frame, and 5) determination of the origin (0,0) position to begin each analysis. (NOTE: the starting position of the analysis should be the top- and left-most position of the data field, in that positive motion increments of the Unidex system will move the film field-of-view to the right and downward).

The first step in the analysis procedure involves loading the film in the film holder properly. This basically involves three steps. First, the film must be loaded in the film holder and aligned so that the horizontal and vertical film positions are lined up accurately

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with the Unidex motion directions. This is typically done using the front panel controls of the Unidex control box is slew mode, and using the edges of the film frame field or other horizontal and vertical lines on the film, to line up the field with the Unidex motion. Once this first step is done, the film is repositioned at a user defined registration point on the film. The Unidex control box is again used here to move the film to this position. The Unidex system is then zeroed out at this registration point. The film must finally be positioned at the film analysis start position by moving a predetermined amount away from the registration point in both the x and y directions. This is typically in the extreme upper left corner of the film frame's field of view, so that positive x/y Unidex motion results in film motion to the right and downward. The Unidex control box is again used to move this predetermined amount using jog/step instead of slew control. The Unidex system is again zeroed out, so that this position acts as the analysis origin (0,0) position. IEEE computer communication control of the Unidex system is then enabled.

The second analysis step involves setting up the configuration file KODAK54.CFG. An example configuration file input is provided below:

| | |
|---|---|
| Software_Version_Number | 1.2 |
| Camera_Exposure_Level(ms) | 90 |
| #steps_Xdimension | 10 |
| #steps_Ydimension | 15 |
| Image_Active_Threshold_Scale(0.65-1.25) | 1.0 |
| FP_DC_Peak_Extent(1-20 pixels) | 10 |
| Search_Box_Xmin(0-128 pixels) | 35 |
| Search_Box_Xmax(0-128 pixels) | 79 |
| Search_Box_Ymin(0-128 pixels) | 10 |
| Search_Box_Ymax(0-128 pixels) | 39 |
| Default_Peak_Xpos(0-64 pixels) | 0 |
| Default_Peak_Ypos(0-64 pixels) | 38 |
| Centroid_Threshold_Level(0-255) | 250 |
| Analysis_Pixel_Scale_Factor($\mu$m/pixel) | 10.0628 |
| Acquisition_Magnification | 0.93066 |
| Laser_Pulse_Separation(microsec) | 0.60000 |
| Unidex_Xshift_Amount(microns) | 5796 |
| Unidex_Yshift_Amount(microns) | -3864 |
| Output_Datafile_Name | f71r7.dat |

PIV analysis system configuration file: **KODAK54.CFG**

The file supplies various analysis system parameters needed for processing. The user provides four basic types of information. First, the user must provide various setup parameters such as acquisition magnification, analysis magnification, and laser pulse separation timing. Second, the user must provide Unidex film positioning and motion

information including the amount of x/y shift in each direction, and the number of shifts. The third type of information includes autocorrelation analysis parameters. These are determined on a trial by error basis using test correlations and varying the parameters to enhance and maximize the correlation image fields SNR. The exposure level of the Kodak Megaplus camera (in milliseconds) needs to be determined first, where test correlations are used at various exposure levels to optimize the exposure level for a typical frame on a given roll. Image and centroid threshold levels are also evaluated with respect to test correlations. The image threshold factor applies a threshold to the raw image before FFT processing based on the average pixel intensity (weighted mean) in the image. The centroid threshold level limits the centroid search to pixel intensity values above a certain level. The self-correlation peak extent also needs to be determined in pixel units based on an evaluation of its radial extent out from the correlation image center. Correlation search box limits also need to be set, allowing for movement of the correlation peak at various positions across the field. And finally, a default peak correlation position can be inserted in the event of a totally black or totally white image field.

Once the configuration file is properly setup, it is saved away, and the analysis system program is run. This process starts the automated autocorrelation analysis routine that moves the film in a stepwise manner, and analyzes 54 correlation subregions for each translation position in the flow. The analysis parameters that were read in from the configuration file are displayed in the 'quickwin' box supplied by the program, and an approximate time period remaining in the processing. The system is currently capable of 5 vector correlations per second, which translates to approximately 30-40 minutes of analysis time for a standard 70 mm film frame

## 5.0    Software Development Issues

The PIV/HPIV film analysis software was written in a Microsoft 'quickwin' format, which allows the program to be run in Windows 3.1 or Windows 95, but which doesn't allow any user interaction with the program while it is running. Five separate files are required during the compile and link process:

1) Piv54c.c    -    The analysis program's 'master' control source file
2) Piv54p.c    -    The analysis program's i860 'slave' source file
3) Piv54w.c    -    The quickwin source file
4) Piv54.def   -    The definition file for the program
5) Piv54.rc    -    The resource file for the program

# REPORT DOCUMENTATION PAGE

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| 1. AGENCY USE ONLY (Leave blank) | 2. REPORT DATE | 3. REPORT TYPE AND DATES COVERED |
|---|---|---|
| | December 1997 | Contractor Report |

**4. TITLE AND SUBTITLE**
PIV/HPIV Film Analysis Software Package

**5. FUNDING NUMBERS**

C NAS1-19505

WU 538-03-12-04

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**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

National Aeronautics and Space Administration
Langley Research Center
Hampton, VA 23681-2199

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

NASA/CR-97-206286

**11. SUPPLEMENTARY NOTES**
Langley Technical Monitor: Dr. Richard R. Antcliff
Final Report

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**

Unclassified-Unlimited
Subject Category 36          Distribution: Nonstandard
Availability: NASA CASI (301) 621-0390

**12b. DISTRIBUTION CODE**

**13. ABSTRACT (Maximum 200 words)**

A PIV/HPIV film analysis software system was developed that calculates the 2-dimensional spatial autocorrelations of subregions of Particle Image Velocimetry (PIV) or Holographic Particle Image Velocimetry (HPIV) film recordings. The software controls three hardware subsystems including 1) a Kodak Megaplus 1.4 camera and EPIX 4MEG framegrabber subsystem, 2) an IEEE/Unidex 11 precision motion control subsystem, and 3) an Alacron I860 array processor subsystem. The software runs on an IBM PC/AT host computer running either the Microsoft Windows 3.1 or Windows 95 operating system. It is capable of processing five PIV or HPIV displacement vectors per second, and is completely automated with the exception of user input to a configuration file prior to analysis execution for update of various system parameters.

| 14. SUBJECT TERMS | 15. NUMBER OF PAGES |
|---|---|
| Particle Image Velocimetry; PIV; HPIV | 19 |
| | **16. PRICE CODE** A03 |

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| Unclassified | Unclassified | Unclassified | |

6) Piv54.ico  -  The bitmap icon for the program

In addition, a command line batch file has been used to control the compile, link, and resource compiler stages of the build process. This files name is Piv54.bat. The program was compiled with Microsoft C compiler version v8.00, linker version v5.5, and resource compiler v3.11.

Editing of the code to add new functionality, or to change existing capabilities is relatively straight forward. The modular nature of the code allows this. The quickwin source file Piv54w.c, definition file Piv54.def, resource file Piv54.rc, and icon file Piv54.ico should not require any changes and should be left alone if possible.

A copy of the compile/link batch file listing is provided below:

```
pgcc -Mreentrant -o piv54p piv54p.c i860lib.a pgcnl.a libm.a
cl -c -AL -Gsw -Zpe -DC_MSC -Dmain=Cmain piv54c.c piv54w.c
link /NOD /NOE piv54c+piv54w,,,w3slv860 libw Llibcew m4obM7WL pxipM7WL gpib,piv54.def
rc -K piv54.rc piv54c.exe
```

It calls the Portland Group Compiler for compiling on the i860 processor board, and the Microsoft compiler, linker, and resource compiler, with various switches setup for a quickwin application.

This software package was developed under contract to NASA. Requests for copies of the source and executable codes described in this report should be directed in writing to one of the following:

NASA Langley Research Center
Technology Applications Group
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Hampton, Virginia 23681-0001

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