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COMPUTER-AIDED DIGITIZATION OF GRAPHICAL MASS FLOW DATA FROM THE 1/5-SCALE MARK I BWR PRESSURE SUPPRESSION EXPERIMENT

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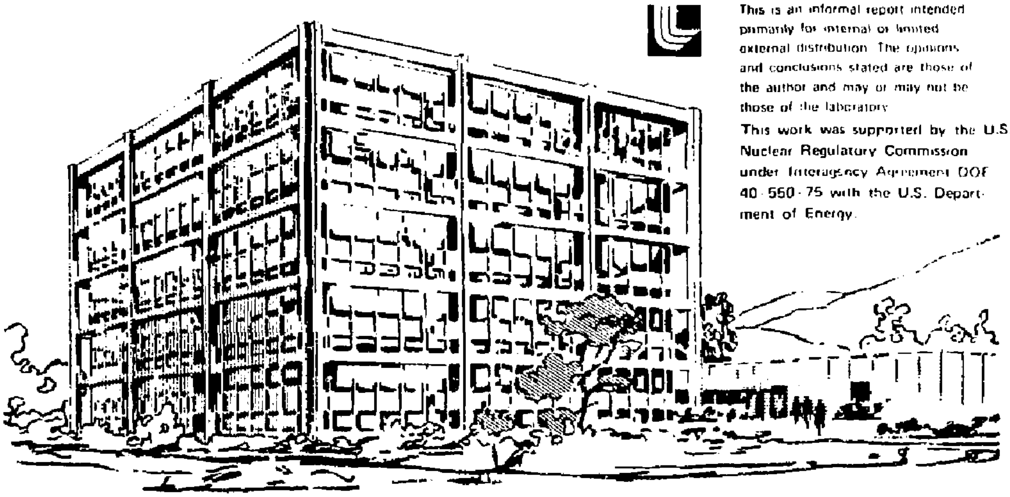

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ABSTRACT

Periodically in the analysis of engineering data, it becomes necessary to use graphical output as the solitary source of accurate numerical data for use in subsequent calculations. Such was our experience in the extended analysis of data from the 1/5-scale Mark I boiling water reactor pressure suppression experiment (PSE). The original numerical results of extensive computer calculations performed at the time of the actual PSE tests and required for the later extended analysis program had not been retained as archival records. We were therefore required to recover the previously calculated data, either by a complete recalculation or from available computer graphics records. Time constraints suggested recovery from the graphics records as the more viable approach.

This report describes two different approaches to recovery of digital data from graphics records. One, combining hard and software techniques immediately available to us at LLL, proved to be inadequate for our purposes. The other approach required the development of pure software techniques that interfaced with LLL computer graphics to unpack digital coordinate information directly from graphics files. As a result of this effort, we were able to recover the required data with no significant loss in the accuracy of the original calculations.

Because of the specific nature of the PSE extended analyses and the time constraints placed on their completion, this graphics software in itself has no general application beyond the PSE task. It does, however, provide a basis for possible future development of a truly generic data recovery capability for the LLL computer graphics system.

Introduction

As part of an extended analysis of data from the 1/5-scale Mark I boiling water reactor pressure suppression experiment (PSE)[1,2], "enthalpy flux" into the two test sections was calculated for each of twenty-four air blowdown tests. Enthalpy flux is calculated by convoluting time-dependent mass flow ($\dot{m}$) and temperature (T) data according to the relationship

$$\dot{m}h = \dot{m}c_pT \qquad (1)$$

where c_p denotes the constant pressure specific heat of the working fluid. Mass flows for the 7.5° (2D) and 45° (3D) test section vent pipes were originally calculated by Pitts [3] shortly after the completion of the final air test series, using pressure differential data recorded during each test. Temperatures were measured directly at each of the three vent pipes.

Results of the mass flow calculations, essential to the calculation of enthalpy flux, were retained in graphical form both as hardcopy plots (Ref. [3]) and as computer graphics ("FR80") files. Unfortunately, the corresponding original mass flow data were not saved in numerical form as required for the enthalpy flux calculations. We were therefore forced to consider three alternate methods for recovery of this data:

- regeneration of the mass flows from the original PSE raw data tapes.
- "hand" digitization of the hardcopy mass flow plots, based on available hard-and software techniques in use at LLL.
- making use of the available computerized graphics files, i.e., unpacking the coordinate data directly and converting to engineering units; no known software existed at LLL to accomplish this.

Clearly, it can be argued, regeneration of the mass flows from the raw data tapes is "best" because original data is used. However, the analog-to-digital computer routine used to process the PSE data [a] requires on the order of twenty-five instruction and calibration files to process data from any one test. Although these files were available in archival (photostore) storage, each would have to have been checked to assure duplication of the original mass flow calculations. Within the time constraints on the completion of the PSE extended analyses, the manipulation and examination of some 625 individual files was not regarded as practical. It was concluded that the mass flow data would have to be recovered from the available graphics output.

Digitization of Mass Flow Curves

Of the two remaining options for data recovery, unpacking coordinate information from the available computerized graphics files was viewed as preferable, but was not immediately pursued because the necessary computer software was not available.

Instead, the computer routine PPLOT[4,5] was initially used to digitize hardcopy data plots from Ref. [3]. The PPLOT program interfaces a mechanical stylus with the CDC 7600 computer and allows the user to digitize hardcopy curves into packed-ASCII computer disk files. Digitized data are recorded as x-y coordinate pairs and may be arbitrarily spaced at user option, depending on the complexity of the particular plot. Therefore, additional software had to be developed to convert the PPLOT output into the uniformly incremented "WL" format [1] used for PSE data.

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[a] Data processing techniques for the PSE are described in detail by Ref. [1]

Typically, the processing of one mass flow plot in this manner (Fig. 1, for example) involved four basic steps:

- physically pick points along the curve using a mechanical stylus and the PPLOT program.
- numerically fit a uniformly incremented curve to the PPLOT output data.
- inspect the fitted curve and reject PPLOT output points which are clearly unacceptable. Points which reverse in time, for example, fall into this category.
- refit a uniformly incremented curve to the corrected PPLOT output data and write to disk in "WL" format.

Curve fitting to the PPLOT output data was performed by CURVFIT, a computer routine developed specifically for the PSE extended analysis task[b]. CURVFIT fits a uniformly incremented curve (i.e., using a user-specified time step) to an arbitrary set of x-y coordinate pairs by means of a stepwise algorithm based on Lagrangian polynomial interpolation. Linear interpolation between PPLOT output points was generally found to be acceptable, although second-order interpolation was used if the higher-order fit appeared more reasonable. In addition to generating numerical coordinates, CURVFIT also produces plots of the fitted data which may be overlaid on the original mass flow plots to check replication.

A sample mass flow digitization, using original data shown in Figure 1, is outlined by Figures 2 through 5. For the sample problem, mass flow data between 2.0 and 5.0 sec were desired; the corresponding set of data points taken from Figure 1 using PPLOT and the mechanical stylus is shown in Figure 2. The subset of PPLOT output points bounding the specified time window is then used to define a new curve as shown in Figure 3. Note that the CURVFIT algorithm combines PPLOT points less than one time step apart by taking a simple mean, and rejects any

[b]Details of CURVFIT and other undocumented computer routines developed by this task may be obtained from the authors.

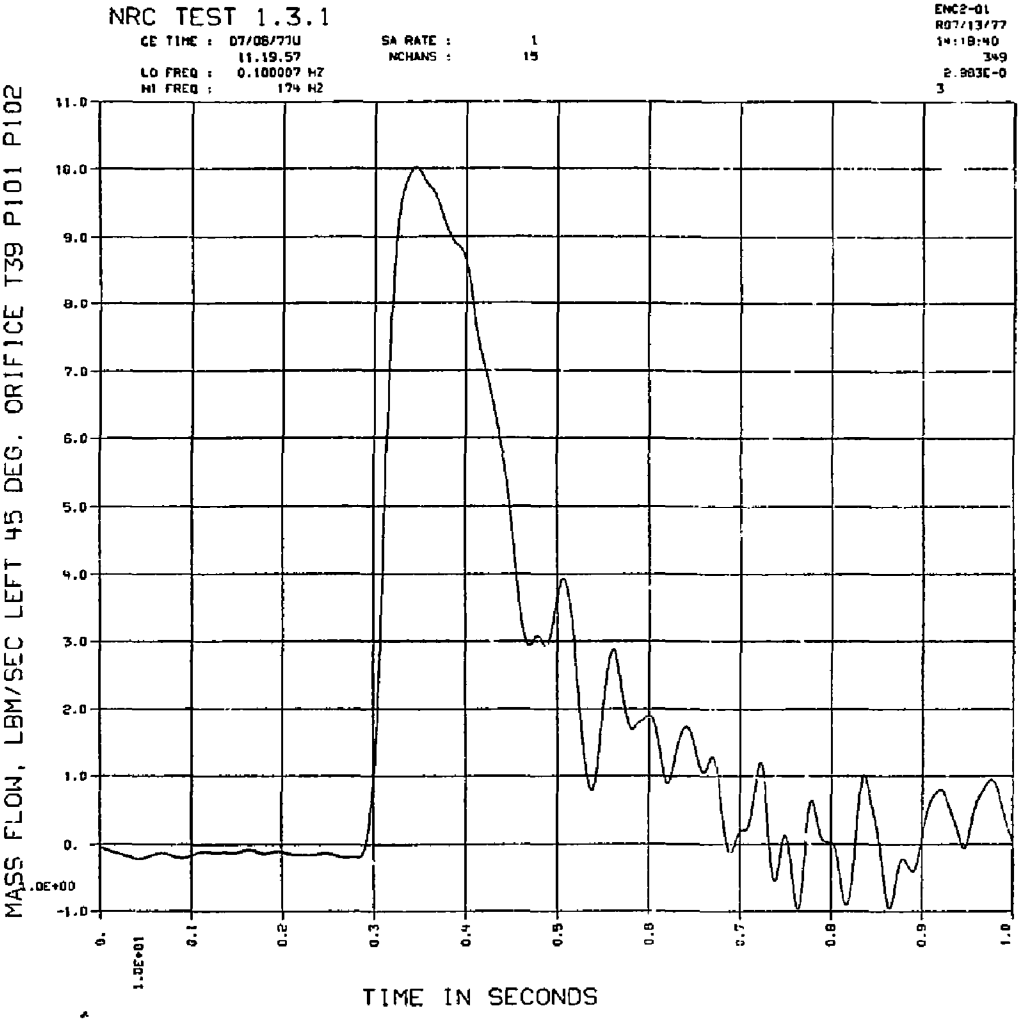

Fig. 1. Time-dependent mass flow in left 3D vent pipe[3]

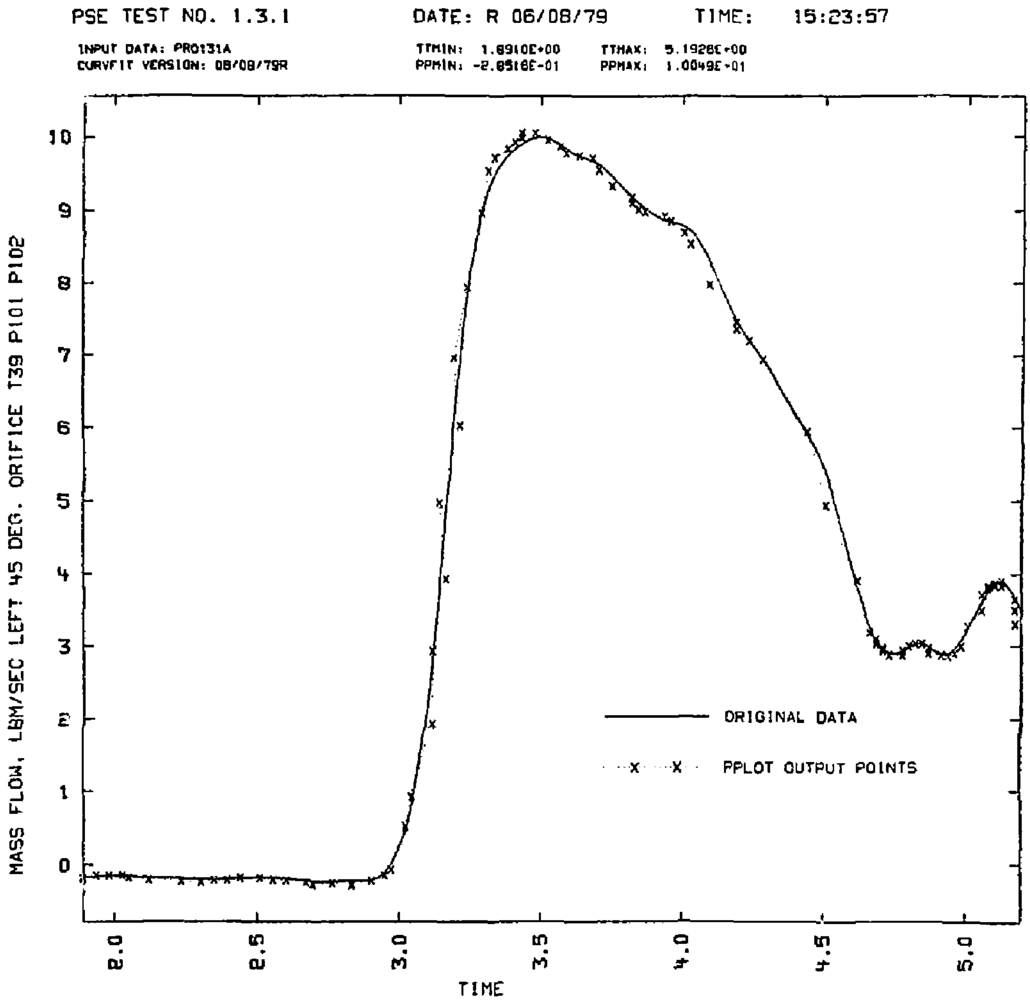

Fig. 2. PPLOT output points taken from Fig. 1 for the indicated time window.

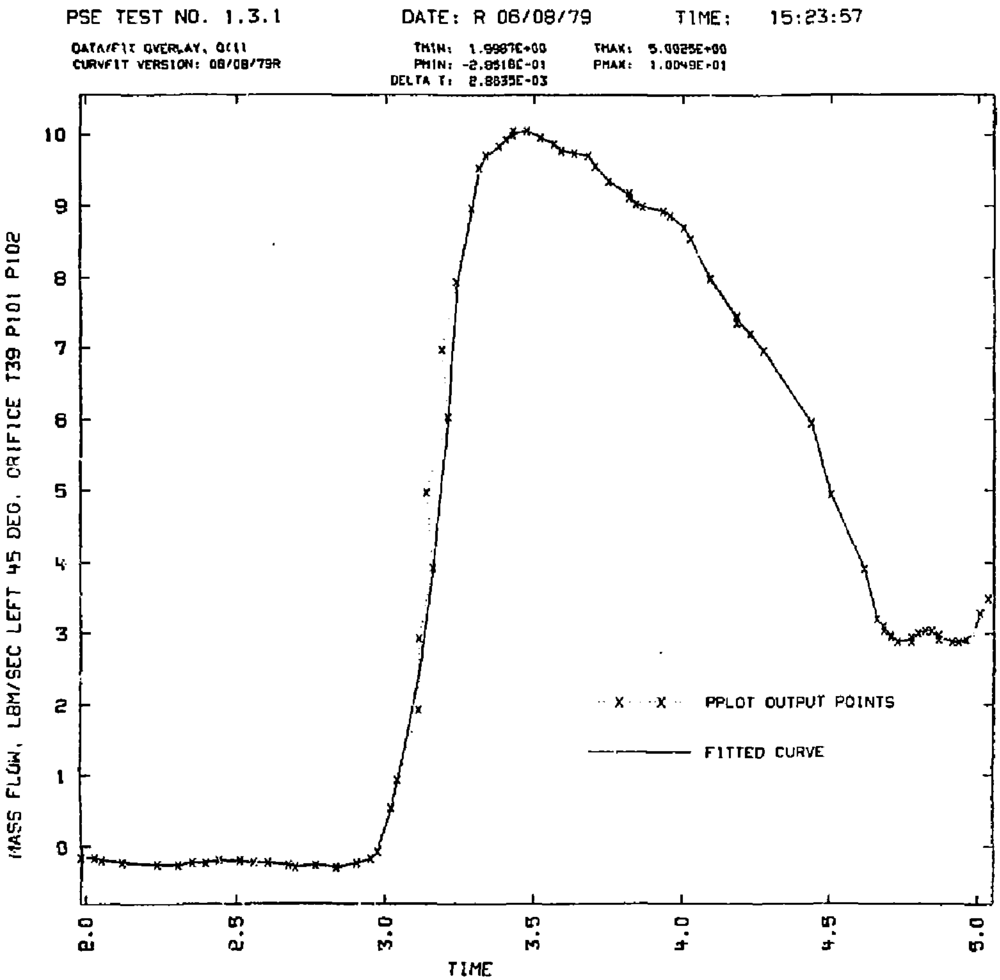

Fig. 3. Initial fit to PPLOT mass flow data points using CURVFIT.

points determined to reverse in time by more than one time step. A final fit to the PPLOT output data, following rejection of "unacceptable" points by the user, is shown in Figures 4 and 5. Figure 5, which is plotted within the coordinate limits of the original mass flow curve, indicates close replication when overlaid on Figure 1.

Although this method gave reasonable results, several aspects made it unsuitable for production purposes. First, the operation is rather tedious and time-consuming, especially if several iterations are required to produce an "acceptable" plot result. Secondly, heavy reliance is placed on the human factor, particularly with regard to the ability of the user to accurately trace the original curve with the mechanical stylus. This is clearly evident from Figure 3, where even a small (less than 0.25% of full scale) tracing error in the independent variable can result in a large (approximately 10% of full scale) error in the dependent variable[c]. Furthermore, the judgment of PPLOT coordinate acceptability by the user is also highly subjective.

Therefore, as the unacceptability of hand digitization become apparent, a concurrent effort was initiated to develop the software required to extract coordinate information directly from the available computer graphics output. The result of this effort was PSECLUGE, a UXdd80 routine developed by Blair [6] to digitize the PSE mass flow graphics files. Basically, PSECLUGE translates the plot raster coordinates included in a UXdd80 graphics file into normalized coordinates in local ("CRT") space. If the bounds on the coordinate axes in real ("engineering") space are known in combination with the limits on the mapping in CRT-space, translation of the raster coordinate pairs $(X,Y ; Y = F(X))$ into corresponding coordinate pairs in engineering units $(x,y; y = f(x))$ is a

[c]Here "full scale" refers to the plot from which the original tracing was made, i.e., Fig. 1.

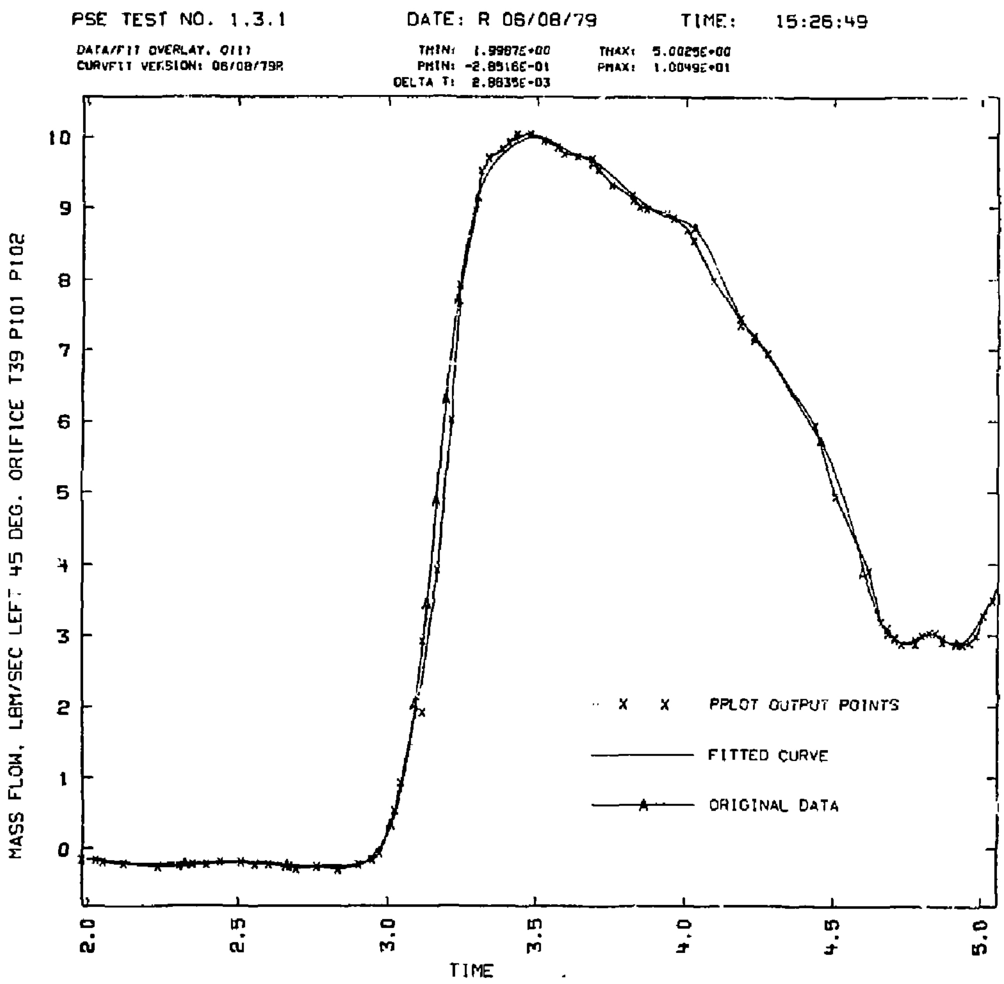

Fig. 4. Final fit to PPLOT data points after discarding unsuitable points.

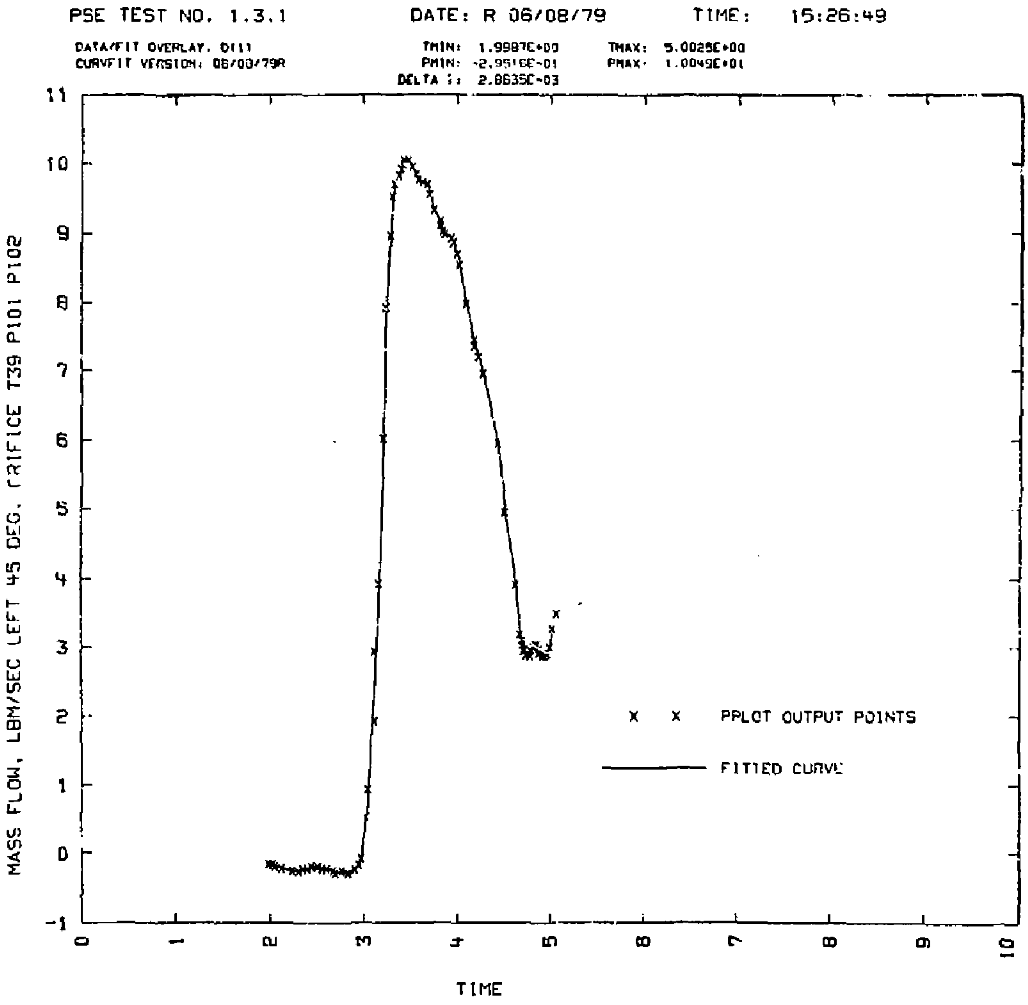

Fig. 5. Final fit to PPLOT digitized data plotted within the coordinate limits of Fig. 1.

simple process. Given a general linear UXdd80 mapping established by the FORTRAN statement[7]

```
CALL MAP (xmin, xmax, ymin, ymax, xmi, xma, ymi, yma)
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the mapping of coordinate pairs in CRT-space to engineering space is defined by

$$x = xmin + (xmax - xmin) \cdot \frac{X - xmi}{xma - xmi} \qquad (2)$$

$$y = ymin + (ymax - ymin) \cdot \frac{Y - ymi}{yma - ymi} \qquad (3)$$

where

$$\begin{aligned} xmin &\le x \le xmax \\ ymin &\le y \le ymax \\ 0. \le xmi &\le X \le xma \le 1.0 \\ 0. \le ymi &\le Y \le yma \le 1.0 \end{aligned} \qquad (4)$$

Using PSECLUGE, the processing of one mass flow plot typically involved the following steps;

- extract the desired frame from the available FR80 graphics output file and convert to UXdd80 format using the computer routine FRUX[8].
- use PSECLUGE to obtain the normalized coordinate data pairs in CRT-space.
- convert normalized data to engineering units.
- fit a uniformly incremented curve to the converted coordinate data to convert to the standard PSE data format.

These last two steps were performed using UX80FIT, a routine evolved from CURVFIT that takes the PSECLUGE output data, converts it to engineering units, and then used the converted data to define a uniformly incremented set of data in the standard PSE format.

The advantages of using computer-aided techniques instead of mechanical digitization to recover the PSE mass flow data are plain. The high density ($65636_{10} \times 65636_{10}$) of raster points in CRT-space yields numerical accuracy to four decimal places in replication of the original curve. Additionally, the coordinate pairs output by PSECLUGE very closely (but not identically, due to integer arithmetic truncation) represent the individual data points used to generate the original curve. While a fit to the digitized data is still required to convert to the desired "WL" format, the resolution of the fitted curve is essentially identical to that of the original.

Figures 6, 7, and 8, show respectively, the representation of Figure 1 in CRT-space, in engineering space, and in engineering space converted to the uniform PSE time step (2.8635 msec). An overlay of Figures 1 and 8 (Fig. 9) indicates excellent replication of the original data, particularly in the higher frequency regions that are for all practical purposes untreatable by PPLOT (see Fig. 10).

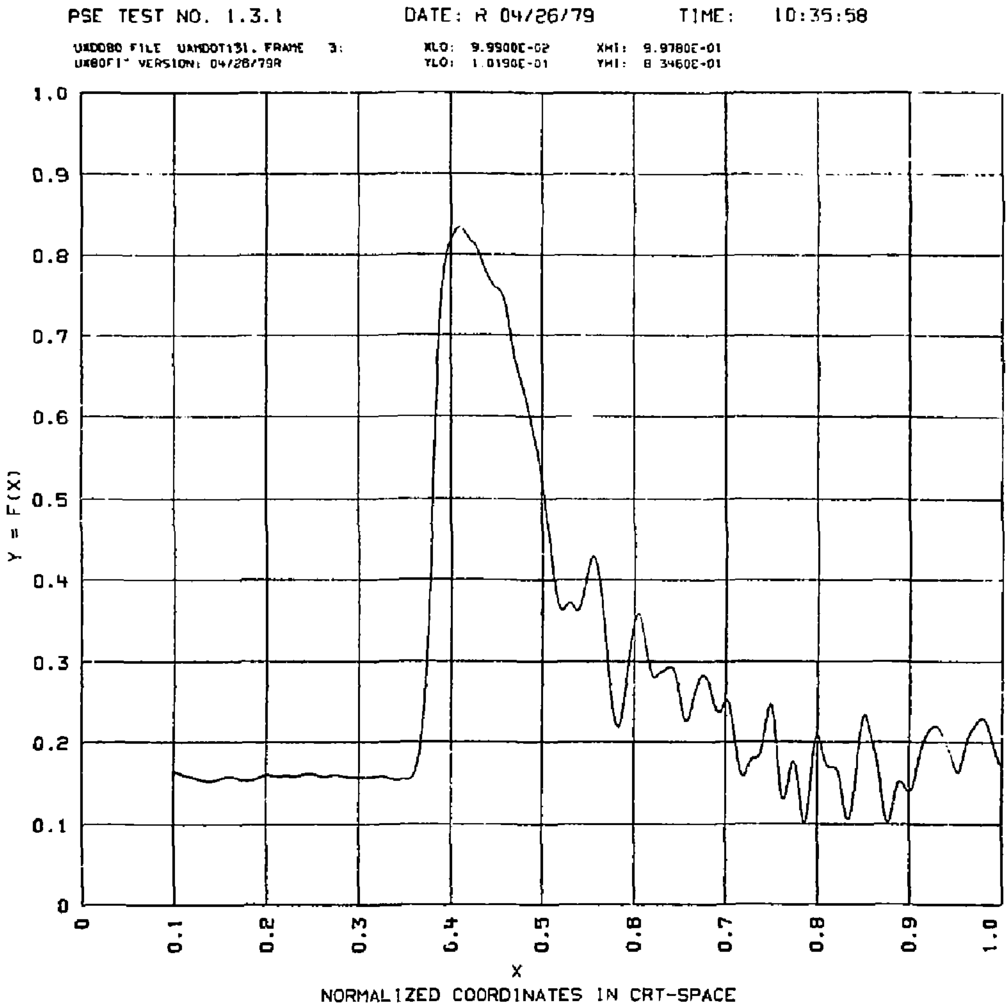

Fig. 6. Plot of Fig. 1 in CRT "raster" coordinate space.

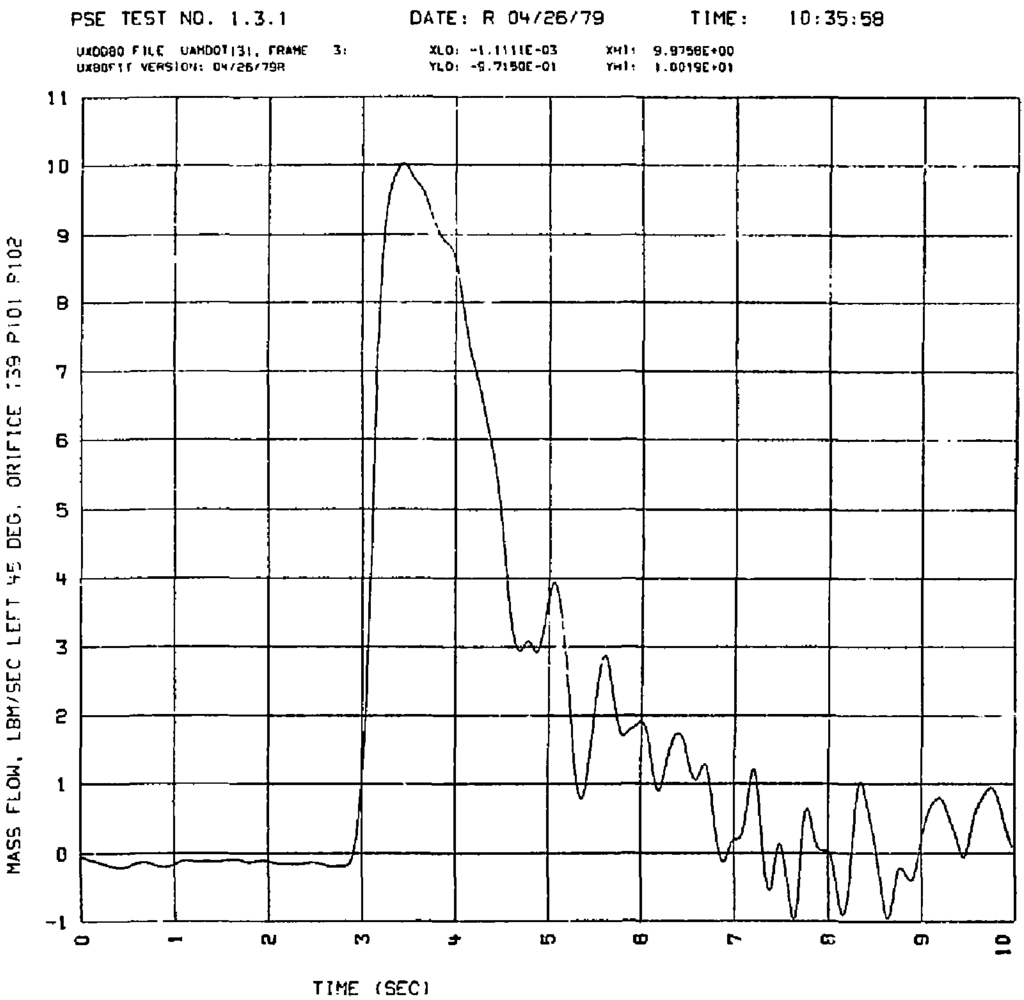

Fig. 7. Data in Fig. 6 converted to engineering units and plotted within the coordinate limits of Fig. 1.

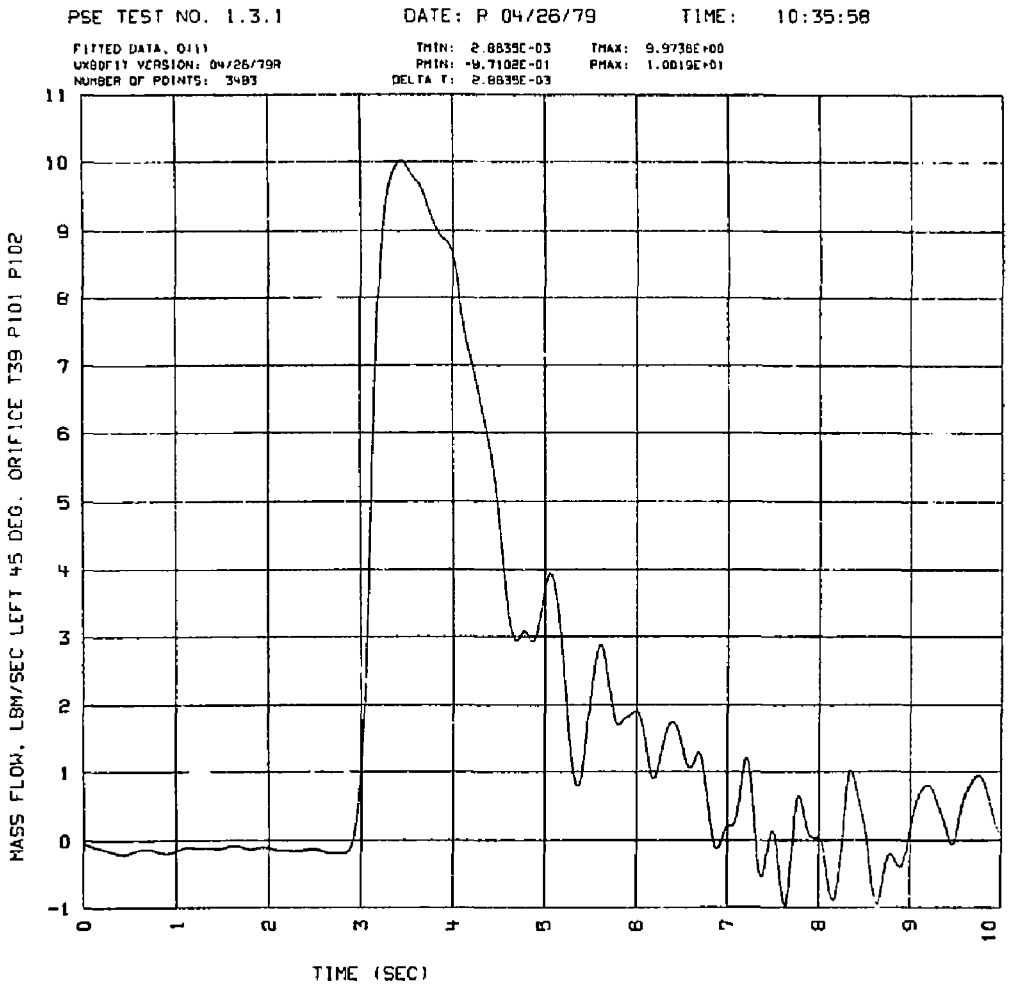

Fig. 8. Data in Fig. 7 fit using standard uniform PSE time step (2.8635 msec).

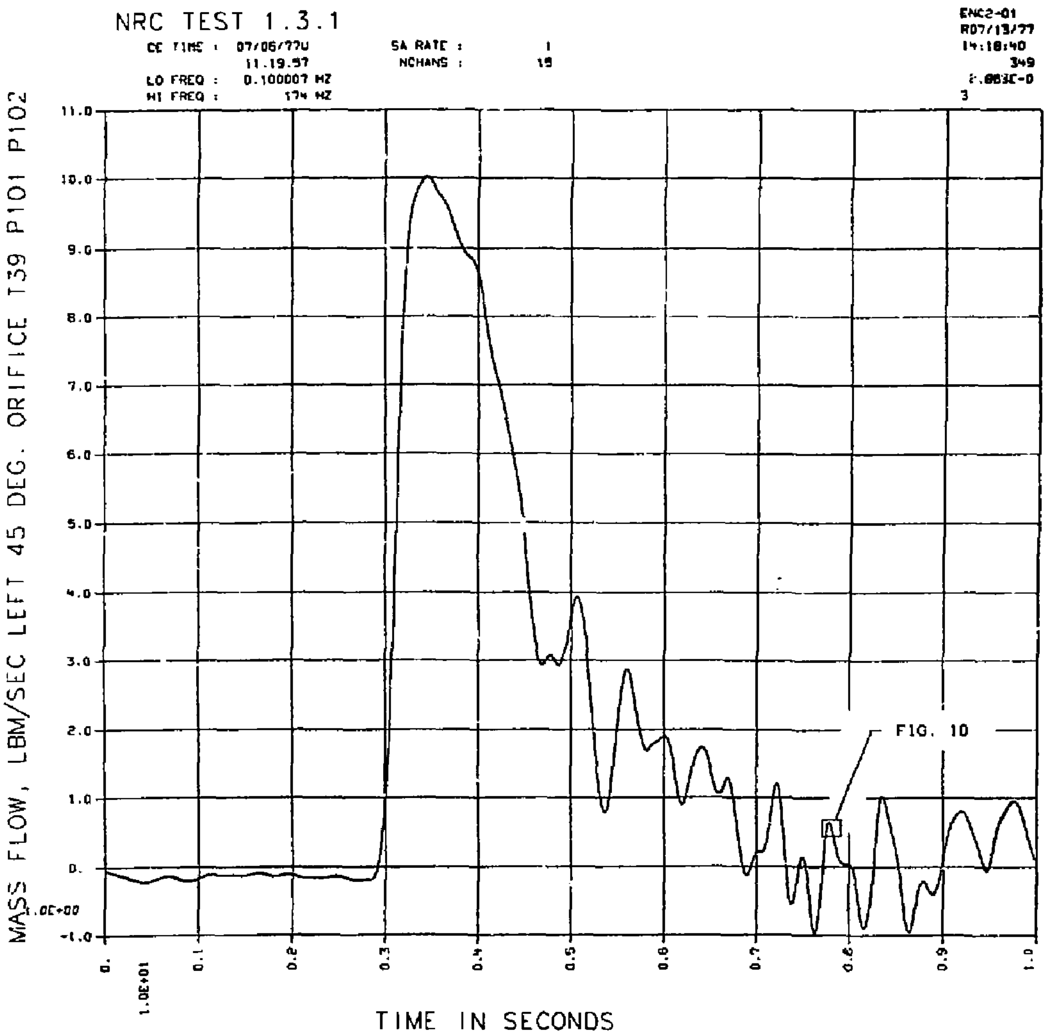

Fig. 9. Overlay plot of original mass flow data and data recovered using PSECLUGE and UX80FIT.

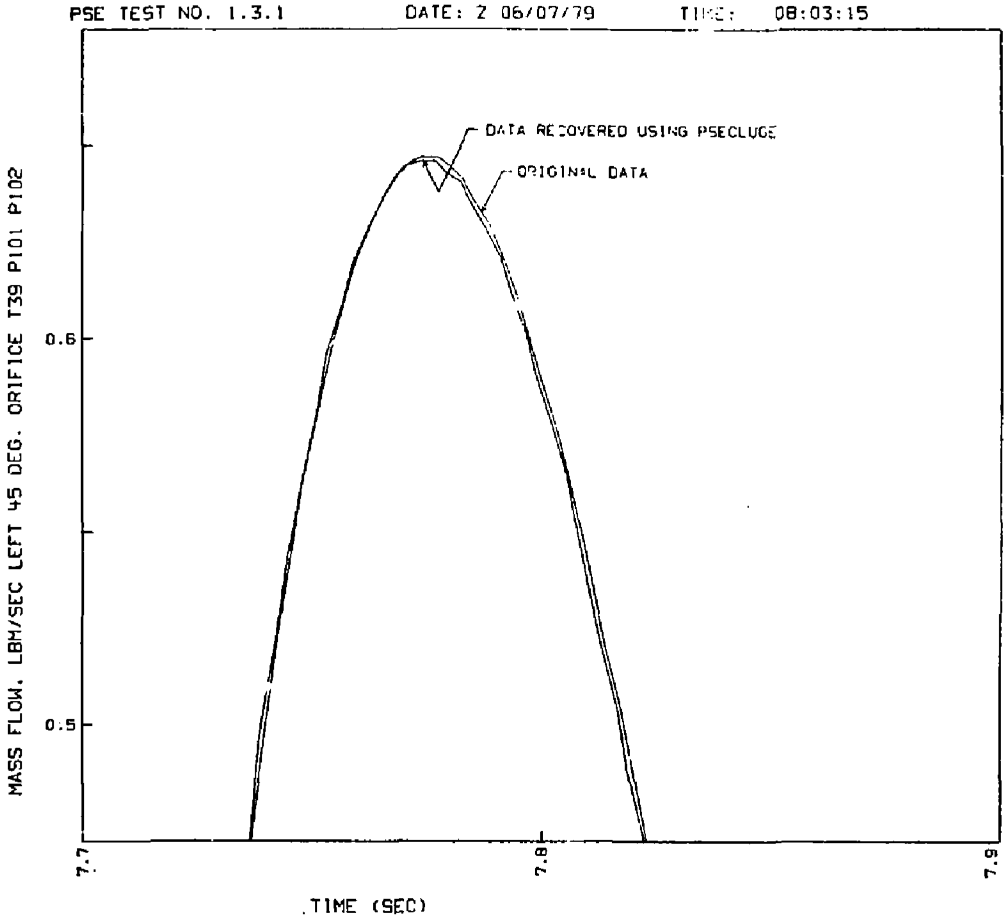

Fig. 10. Expanded section of Fig. 9 illustrating excellent replication of original data by PSECLUGE.

Conclusions

The primary goal of this exercise --- accurate recovery of previously generated engineering data from available graphics records --- was successfully achieved through the development of pure computer techniques to digitize the available computer graphics files. By using PSECLUGE and other routines interfacing with it, we were able to digitize the individual data points of the mass flow curves within a degree of accuracy that was over two orders of magnitude better than the seven to eleven percent relative error estimated in the original mass flow calculations. As a result, no additional statistically significant error in mass flow was propogated through the subsequent enthalpy flux calculations beyond that associated with the original mass flow data.

It is important to emphasize that, as its name implies, PSECLUGE itself has no general application beyond the PSE task for which it was written. Nor is this report intended to imply that recovery of digital data from graphics output be viewed as a general substitute for the storage of original data. The techniques discussed here do, however, form one basis for the potential development of more general recovery tools to interface with LLL graphics, should a widespread need for such a capability be perceived in the future.

Acknowledgements

If the efforts of any one individual can be regarded as crucial to the success of this task, that individual is certainly Mark Blair. His timely development of PSECLUGE in response to our requests for a UXdd80 digitizer and his aid in understanding UXdd80 file structure are gratefully acknowledged.

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