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Videotape Analysis of a CAD System User Interface: A Case Study

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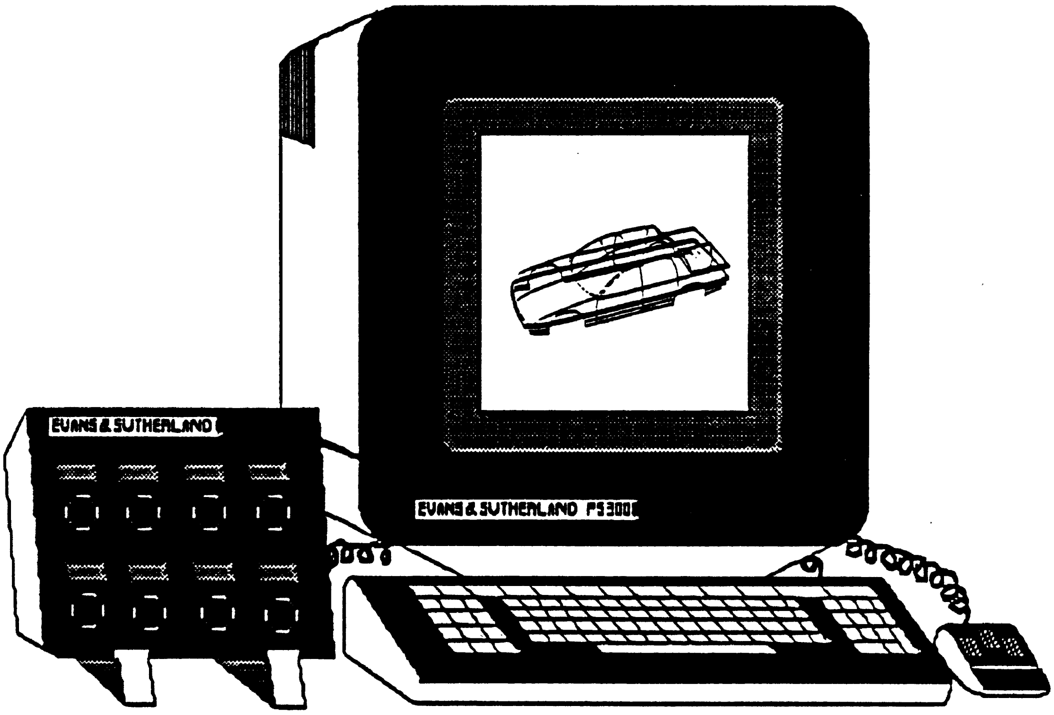

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16. Abstract

This report analyzes the user interface for the Chrysler Designer Workstation, a wire-frame CAD program that runs on an Evans and Sutherland PS 350 workstation connected to a CDC Cyber 825 mainframe. The data for the recommendations came from time-stamped videotapes of a person learning to use the software. The time for each mouse pick, each typing action, and other actions was obtained from those tapes to determine how the user spent his time, which errors occurred (and when), and how often the user shifted between menus.

The report suggests about a dozen modifications/enhancements to the user interface (adding mirror-imaging and menu bypass features, making dial actions compatible with user expectations, etc.) to make the software easier to use. The report also describes several tools (CAD prototypers, automatic logging software, task analysis utilities) that are required to support usability analysis.

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PREFACE

This report, the second in a series, concerns a subject learning to use the Chrysler "Designer Workstation," a Computer Aided Design (CAD) system being developed at the Chrysler Design Center in Highland Park, Michigan. Those activities are described on a second-by-second basis for two test sessions.

The bulk of this research was supported by the Chrysler Corporation through the Chrysler Challenge Fund. The purpose of the Challenge Fund is to promote technology transfer from leading American universities to the Chrysler Corporation and make students aware of engineering employment opportunities.

This work is part of a larger project (originally titled "User Interface for Robot Programming") directed by Klaus-Peter Beier of the University of Michigan Department of Naval Architecture and Marine Engineering. Its original goal was to develop a computer graphics routine to run in concert with Chrysler's Interactive Parts Programming System to perform off-line programming of a clay-modeling robot.

At the outset of the program, Chrysler identified a higher priority problem, the design of a Computer Aided Surfacing System, and directed our efforts there. While the robot program problem could be solved using the Wizard of Oz Prototyper (Wesselman and Green, 1986) as described in the project proposal, that was not true of the CAD problem. Furthermore, the CAD problem was much more complicated than the robot problem, and not as well understood. Therefore, more background work was required.

To design a system for people, one needs to know quite specifically who they are. Early on it became clear that quantitative data on users were not available. This led to the first report in this series (Green and Adams, 1987).

The next step in this project was trying to identify what CAD users do. As described in the literature review that follows, there is very little information on that subject. For that reason, a user being trained on the current Chrysler Designer Workstation was videotaped to identify what users do now. This information should lead to improvements in the current system and ideas about how a surface oriented system should be designed. Throughout this effort the Chrysler staff has strongly encouraged the research team to look beyond the immediate application of the results. They have repeatedly stated they were not just interested in the data, but the methods and techniques as well. This is an unusual attitude as most contractors are primarily interested in the data.

- *PREFACE* -

At the end of this project, it became clear that this work had implications far beyond the design of a particular CAD system and for that reason, NCR funding was used to extend the scope of the work. NCR's primary interests are in user interface architectures and methods for studying human-computer interaction.

EXECUTIVE SUMMARY

Bos, T., Green, P., and Boreczky, J., (1987). Videotape Analysis of a CAD System User Interface: A Case Study (Technical Report UMTRI-87-49). Ann Arbor, MI.: The University of Michigan Transportation Research Institute, December.

This report examines the user interface for the Chrysler Designer Workstation, a wire-frame based geometric CAD program that runs on an Evans and Sutherland PS 350 connected to a CDC Cyber 825 mainframe. The purpose of the research was to determine how the user interface might be improved, how new CAD interfaces should be structured, and how the process of reviewing a user interface might be improved.

One person was videotaped learning to use the software. There were two one-hour plus sessions. During the first, the user worked on the dome light diffuser, trying to make the left and right halves symmetrical. During the second, the user worked on developing the glove box opening and surrounding instrument panel.

The videotapes were recorded using a portable two-camera system with a time and date generator. The time for each mouse pick, each typing action, and other user actions was obtained from those tapes.

During the first taping session, the user spent 28 minutes (36% of total time) trying to make the top of the drawing look identical to the bottom, 14 minutes smoothing a curve to the lip of ridge (18%), and 13 minutes smoothing the crown of the dome light (17%). During the second taping, he spent 15 minutes (22%) creating the instrument panel contour lines and checking the accuracy of their locations. The rest of his time was spent doing smaller tasks which took less than 10 percent of his time. It was found that approximately 4% of the user's actions resulted in errors, over half of which were using the control dials incorrectly (i.e., turning one the wrong way or using the wrong dial). It was also found the when the user exited a menu, 39% of the time he exited more than one level, accounting for 62% of the exits performed.

The report suggests about a dozen modifications and enhancements to the user interface (adding mirror-imaging and menu bypass features, making dial actions compatible with user expectations, etc.) to make the software easier to use. The report also describes several tools (CAD prototypers, automatic logging software, task analysis utilities) that are required to support usability analysis. These tools will aid future CAD system design and analysis and help move CAD interface technology into the 1990's.

PREVIOUS RESEARCH

General Human Factors Texts

Very little information is available on how to design and evaluate CAD user interfaces. Some indirectly useful information can be obtained from general human factors texts. Sanders and McCormick (1987), now in its sixth edition, presents basic human factors concepts such as information processing, CRT displays, and anthropometry. First printed in 1957, it is somewhat outdated because it does not discuss computer interfaces.

Bailey (1982) focuses on computers and discusses several relevant issues such as input methods, display characteristics, and some general guidelines for interface design. However, he does not support his guidelines with methods to make decisions and evaluate the user interface.

More specific information on user interfaces can be obtained from several quality sources. Card, Moran, and Newell (1983) describes two models (Model Human Processor and the Keystroke-Level Model) for predicting human behavior with computer interfaces. Using these models should decrease the number of experiments needed to evaluate a user interface.

Shneiderman (1987) gives a general overview of the human factors aspects of interface design. It includes discussions of different models, theories, interaction styles, menu structures, and assessment methods. However, it does not provide enough detail to actually perform any assessments.

Pew and Green (1987) provides several articles on specific topics related to user interfaces. These include articles about the Wizard of Oz prototyper (Green and Wei-Haas, 1985), the Trillium user interface (Henderson, 1986), the Keystroke Model mentioned above (Card, Moran, and Newell, 1980), and an analysis of design practices among designers (Rosson, Maass, and Kellogg, 1987).

Specific Studies on CAD systems

Some specific studies have been done on CAD systems but are generally not very useful. Van der Heiden (1984) did a work sampling study on CAD workstations and found two differences between CAD operators and other computer operators. He found that the dynamic working methods of CAD operators results in less constrained postures, and the CAD operators spend more time (46-68% of working hours) looking at the video display than the average data or word processing operators.

Majchrzak, Chang, Barfield, Eberts, and Salvendy (1987) present an overview of current features and functions of CAD system. It does not make any useful suggestions about CAD design and is mentioned here primarily because it alerted the authors to the van der Heiden paper.

Eberts (1987) identifies the differences in the design process between novice and expert CAD users. Experts tended to have function-related goals (with respect to the CAD commands available) while novices tended to be object oriented (i.e., draw an object using whatever combination of commands required). The function-oriented goal structure reduced back-tracking, indicating that CAD users should be educated about the benefits of using different goal structures.

Price (1982) compares user performance on a G.E. Calma CAD system using small changing menus and large menus with the entire menu on it. Price found that small changing menus provide better performance. This paper is important because the results are based on data logging of user sessions, although not much else comes out of the data.

In general, data on interface design (e.g., Shneiderman) and modeling (e.g., Card) exist but very little CAD-specific data is available.

TEST PLAN

Test Participants

One 32 year-old Chrysler studio engineer was observed learning the Chrysler Designer Workstation on two occasions. He had 20/20 vision. He completed 2 years at an engineering trade school and had a B.A. in Mechanical Engineering Technology and Business Administration & Management (double major). He had a 1 week short course in CADCAM and 1 week of experience on the CAD system before the first session, and 1-1/2 additional weeks training before the second. He did not own a personal computer and had no other computer experience other than his training at Chrysler.

During the first taping session, a second Chrysler employee answered questions from and provided guidance to the trainee, but did not perform any actions on the CAD system. The trainer was age 29, with a slight astigmatism corrected with glasses. He had a B.S. in Drafting. He had worked on the development of the Chrysler CAD system for 3 years, had formal training on a General Electric Calma CAD system for 6 months and had taken a computer class at a community college. He did not own a personal computer.

A third person was observed during a preliminary taping session used to set camera angles and perform sound system checks.

Equipment and Materials

Computer System Examined

The Chrysler "Designer Workstation" software ran on a Cyber 825 mainframe computer driving an Evans and Sutherland PS 350 display at Chrysler's Computer Aided Design Office in Highland Park, Michigan. The software was used to construct wire-frame models of vehicle exteriors (body) and interiors (e.g., instrument panels). It allowed the user to create curves, smooth curves, draw fillets, hang data sections, and manipulate (insert, erase, move, intersect, etc.) curves and data points. (Readers who are unfamiliar with these terms should refer to Appendix A at this time for an explanation of the CAD terms used in this report.) The room was dimly lit and contained 3 PS 350s, along with several other workstations. (See Figure 1.) The PS 350 had 2 megabytes of local memory dedicated to the graphical display of data and was connected to a Control Data Corporation Cyber model 825 timesharing computer. The 19-inch color calligraphic display had 4096 x 4096 resolution and could display up to 45,000 3-dimensional vectors without flicker.

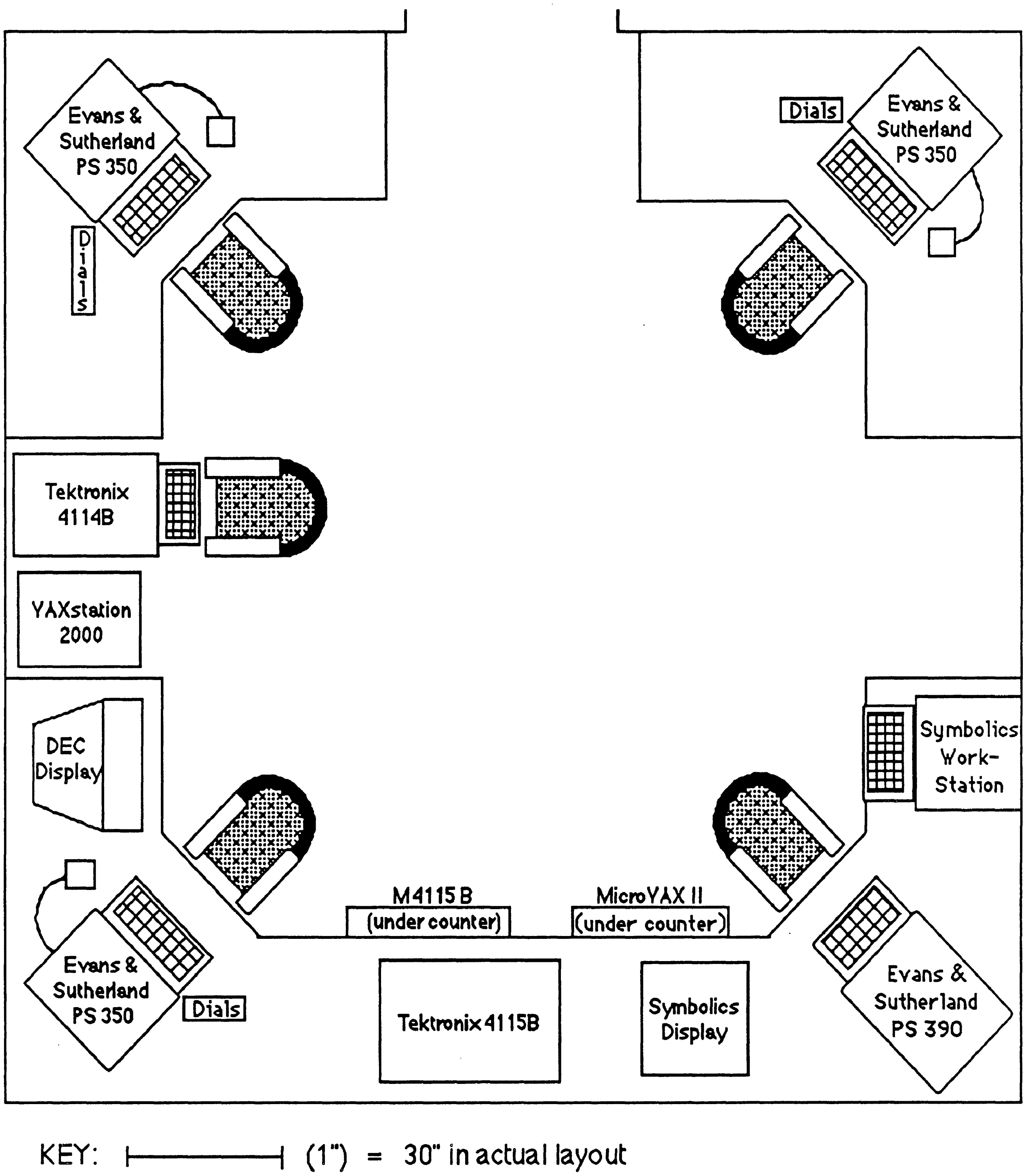

Figure - 1: Layout of CAD room containing Evans & Sutherland PS 350

The PS 350 components consisted of the display, a 95-key keyboard, a 3 button mouse, and 8 control dials. (See Figure 2.) The keyboard contained 12 software defined function keys which were present during various applications. They were (from left to right):
2) Interior/Exterior (mirror data around centerline),
3) Orthographic/Perspective view,
4) True/New view,
5) Clock (rotate data automatically),
6) Reference lines on/off,
8) Dots (data points) on/off, and
12) Reset view (unzoom, unrotate, untranslate data).
(Function keys 1, 7, 9, 10 and 11 were unused.)

The primary input device was the 3-button Logitech model R7-3S-ED mouse. All three buttons on the mouse performed identically, therefore it was used as if it were a 1-button mouse. The mouse was used to select points, lines, menu choices, 1 of 4 views, and zoom. The location of the mouse was indicated on the display by the intersection of vertical and horizontal lines spanning the screen which momentarily intensified when a button was pushed. (This gave the display the look of a Tektronix system.)

The control dials were arranged in 2 rows of 4 dials. Going from left to right, top to bottom, these knobs:
1) Rotated data around the X (horizontal) axis,
2) Rotated data around the Y (vertical) axis,
3) Rotated data around the Z (in and out) axis,
4) Scaled data in and out,
5) Translated data along the X axis,
6) Translated data along the Y axis,
7) Translated data along the Z axis, and
8) Cued the depth.

Scaling in or out moved the viewpoint closer or farther away and as a consequence enlarged or shrank the image. Depth cueing (a form of hidden line removal) adjusted the extent to which lines farther from the point of view faded from view.

Figure 3 shows an example of the display after choosing "smoothing" and "edit." (See Appendix B for entire command menu structure.) The "Whoops" choice was present in all menus. It allowed the user to undo the last operation and start it over. The "Exit" choice was also present in all menus. It allowed the user to end the current command and return to the menu from which it was chosen. Any of the four views could be chosen to take up the entire screen at any time. A part of this view could then be zoomed in on to see fine detail. Any typing done on the keyboard appeared on the top line of the menu.

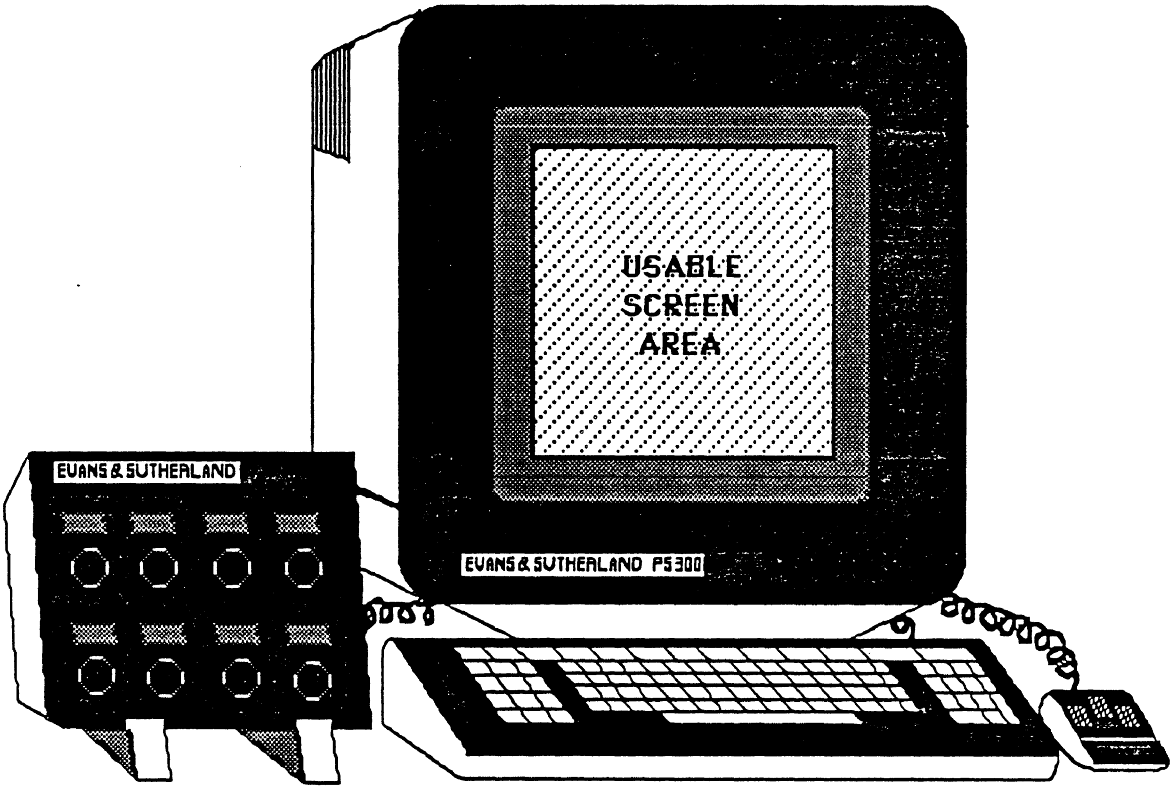

Figure - 2: Evans & Sutherland PS 350 System Configuration

Family Name:	PS 300
Model Number:	PS 350
3-Button Mouse:	Logitech model R7-3S-ED
Keyboard:	95 keys including 12 function keys
Display:	19" Color Calligraphic Display (13.4" x 13.4") 10.5" x 10.5" usable area
Resolution:	4096 x 4096 pixels
Refresh Rate:	60 Hz
Local Memory:	2 Megabytes

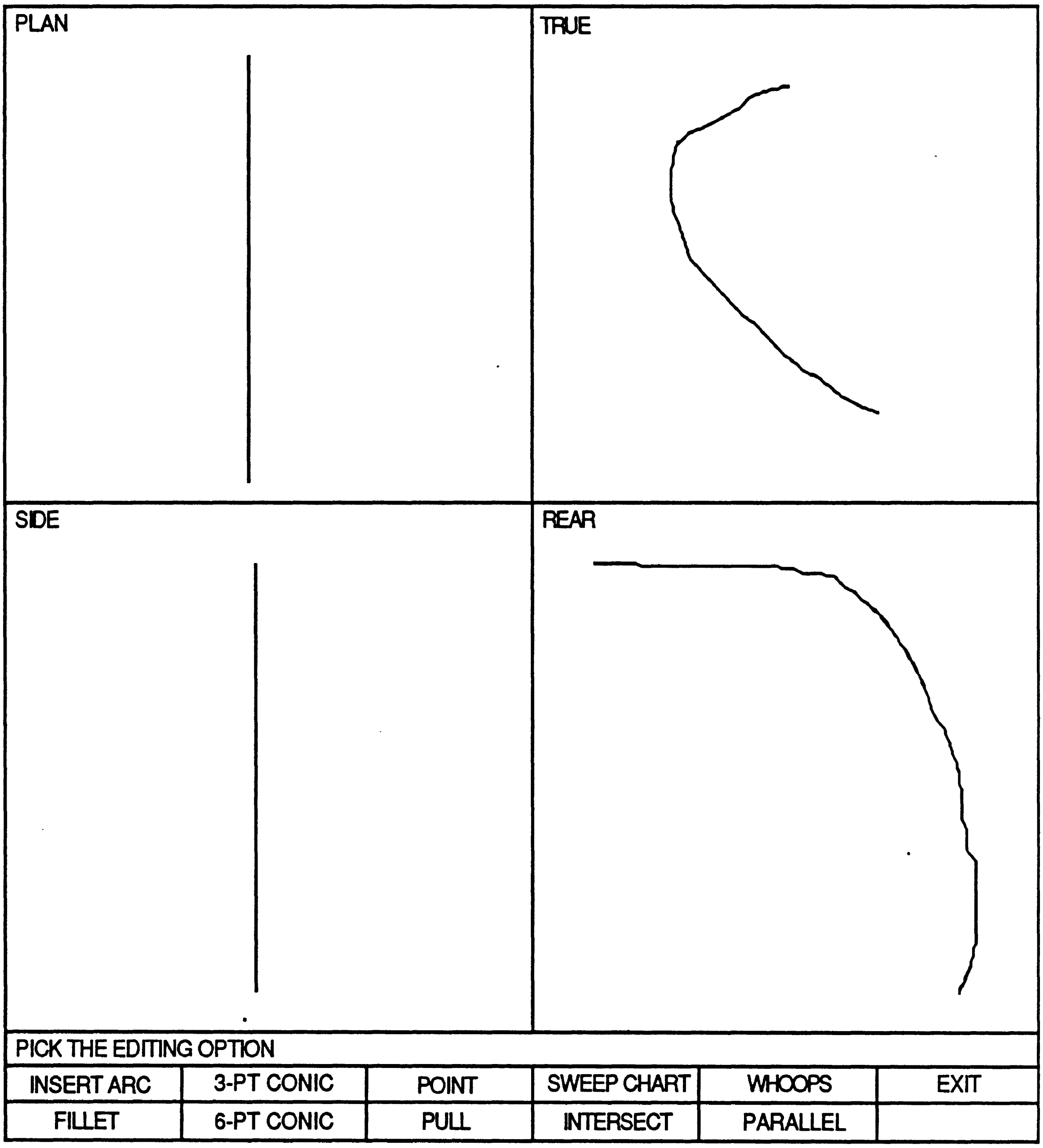

Figure - 3: Sample Screen from Designer Workstation after Choosing Smoothing-Edit

Video Equipment

The subjects were videotaped using two JVC color cameras (models S-100U and GX-S700U) connected to a Panasonic AG-6200 VCR through a JVC model KM-1200 color special effects generator. The special effects generator and a JVC model GN-C804 Sync. Coupler was used to mix both cameras "on the fly" without the need to edit the tape. A Thalner Electronics Portable time and date generator (model TD-426P) was also mixed onto the tape to aid data collection. A Panasonic 9-inch color video monitor (model BT-S700N) was used to display what was being recorded on tape. A Sanyo 9-inch black and white monitor (model VM4209) was used as a preview monitor during the first taping session.

The subjects wore Realistic FM Wireless Microphones (model 32-1221) during the first videotaping, and Audio-technica Miniature Omnidirectional Electret Condenser Microphones (model AT-805S) during the second. The audio signals were combined using a Shure Audio Mixer (model M267).

The audio-visual equipment was situated in a custom made framework on a 4-wheel cart set about ten feet in front of the CAD workstation. One camera was focused on the menu at the bottom of the display by shooting directly over the subject's shoulder. The second camera captured the entire display, the control dials, and some of the function keys by shooting from the right of the subject. The two signals were mixed (using a horizontal split screen) so that the menu from camera one appeared at the very bottom of the image from camera two.

Test Activities

A trial user session was videotaped on June 29, 1987. While the subject used the Designer Workstation, cameras and microphones were set up to determine sound levels, camera angles, how the two cameras should be mixed onto one screen, and the best location for the time-date generator. About 15 minutes of tape was collected but was not analysed.

CAD users were videotaped on June 29, 1987 for 1 hour 16 minutes and on August 18, 1987 for 1 hour 8 minutes. The users were first asked their name, age, job title, educational background, the amount of experience on the Designer Workstation, and the amount of computer experience in general. Then they were instructed to use the CAD system as they would normally. During the first session, the dialog between the CAD user and his instructor was recorded on videotape. During the second session, an observer asked the user questions about what he was trying to do at various times. These comments were recorded on the videotape for later analysis.

During the first session, the user worked on a dome light. His tasks included smoothing (rounding) the light and trying to make the right and left halves symmetrical. During the second session, the user worked on the passenger side of a dashboard including the glove box opening. His tasks included creating the surface lines for the dashboard, attaching the surface lines to the glove box opening, and drawing the depth of the opening.

In addition to the videotaping sessions, on October 9, 1987, the first author visited the Chrysler Computer Aided Design Office and spent about an hour using the system. The insights gained by using the system appear in the results section.

- TEST PLAN -

RESULTS AND DISCUSSION

Data Analysis Procedures

Prior to analysis of data, screen dumps from the Designer Workstation were studied to determine the command menu structure. As mentioned before, Appendix A contains a glossary of CAD terms used in this report. Appendix B shows the complete menu structure for the commands used during the two videotaping sessions.

From the two video tapes, lists of actions were compiled, along with the times when they were completed. (The user was taped early in the training process so his times may have been slower than a typical user.) These data appear in condensed form in Appendices C and D. An action constituted a click of the mouse (selecting a menu item or picking a point or view choice), a movement of a control dial, a press of a function key, a typed response, a discussion or decision, or a comment. Over 1400 actions were analyzed between the two taping sessions.

The data from the first tape were collected by hand, i.e., by starting and stopping the tape and writing down the action and time. These were later entered into the computer for analysis. This was a very time consuming process. The data from the second tape were collected using custom-written, undocumented, proprietary software. The first program (Bos, 1987c) recorded the times when actions occurred, appended a generic event name to the time and stored them in a file. The second program (Bos, 1987b) edited the generic names to better describe the action which occurred. Both programs were written in QuickBASIC 3.0 (Microsoft Corporation, 1987). These programs saved a considerable amount of time.

A third program (Bos, 1987a), also written in QuickBASIC 3.0, grouped the actions of both tapes, counted the frequency of each type of action and accumulated the time and number of errors associated with each type. These results appear in Appendix E. Tables 1 to 6 show the significant details from the data analysis. During the following discussion, refer to Appendix B for the detailed menu command structure.

How Did The User Spend His Time?

During the first session, the user worked on a dome light diffuser, designing one half and then trying to get the other half to look symmetrical. There were three main activities: working on the ridge around the dome light, smoothing the crown, and making it symmetrical about its centerline. During the second session, the user worked on the passenger side instrument panel and the location of the glove box opening, often jumping between the Sectioning-Hang and the Smoothing-

Edit-Point-Coordinate menus. The three main activities were: creating and checking the data sections, smoothing the glove box opening, and working on the depth of the glove box.

Table 1 lists the user's specific tasks and goals during the first design session. These data are condensed from Appendix C. The user spent 28 minutes (36% of total session time) trying to make the top half of the drawing look identical to the bottom half (i.e., mirror-imaging the top with the bottom). (A breakdown of the tasks involved appears later in this section.) The user spent 14 minutes (18%) trying to smooth the surface of the diffuser to the lip of the ridge around the cover. This proved to be difficult and caused the user to "whoops it out of there" (backtrack) four times. Another 13 minutes (17%) was spent smoothing the crown of the dome light cover. The major difficulty was joining two lines together. The user had to try several times before he was successful. Each of the remaining tasks took less than 6% of the total session time.

Table 1 - User Activities During First Design Session

Activity	Duration (h:mm:ss)	Task/goal
Work on ridge around dome light	:21	Figure out where they were
	2:18	Delete section of old data
	:51	Edit centerline to peak of groove
	2:05	Try again
	4:00	Edit grooves:rear end to front end
	3:04	Kill centerline section
	14:07	Smooth curve to lip of ridge
Smooth crown of dome light	2:36	Modify arc
	1:31	Modify arc
	2:15	Edit line
	1:02	Edit line again
	:43	Edit intersection of 2 lines
	12:40	Smooth crown of dome light
Make dome light symmetrical	27:40	Smooth top of drawing (mirror w/ bottom)
	1:00	Terminate system
	1:16:13	Total time of Session 1

* The total time for session 1 includes 154 seconds of comments not included in Appendix C.

Table 2 lists the user's specific tasks and goals during the second design session. These data are condensed from Appendix D. The user worked on the passenger side of a dashboard including the glove box opening. His tasks included creating the surface lines for the dashboard, attaching the surface lines to the glove box opening, and attaching sections to represent the depth of the opening. (See Table 2.)

Specifically, he spent 15 minutes (22% of session time) creating the surface of the dashboard and verifying the accuracy of the contour lines. Each of the remaining tasks took less than 10% of the total session time.

Table 2 - User Activities During Second Design Session

Activity	Duration (h:mm:ss)	Task/goal
Create and check data sections	1:09	Finish task started before session
	14:48	Create data sections
	5:14	Check locations of sections
	:41	Erase all but one section created
	2:27	Copy remaining data section
	4:31	Check locations of sections
	1:11	Erase lines not on a multiple of 50
Smooth glove box opening	5:45	Try to connect 3 sections to glove box
	1:44	Demonstrate use of reference lines
	6:11	Try to connect center section
	1:43	Smooth upper right corner of glove box
	1:51	Remove points to flatten top line of
	2:05	Try to connect center section
	1:20	Smooth upper left corner of glove box
	2:17	Smooth lower right corner of glove box
Work on depth of glove box opening	2:46	Try to hang depth off other 2 sections
	4:20	Copy depth to other sections
	1:09	Check it
	6:26	Try to connect new sections to opening
	:13	Finish up
	1:07:51	Total time of Session 2

* The total time for session 2 includes 71 seconds of comments not included in Appendix D.

As mentioned above, 28 minutes was spent during the first session trying to make the top and bottom of the diffuser symmetrical about its centerline. A series of 28 editing tasks (5 aborted, 1 an error) were required to succeed. (See Table 3.) The CAD system only allowed the user to mirror data around the centerline of the car for reference. It did not provide any service for creating a mirror-image of an existing piece of the drawing.

Table 3 - Functions Performed to Mirror-Image Dome Light

Function	Times performed	# aborted
Fillet	15	3
Insert Arc	8	3*
Pull point	2	0
Exchange 2 points	1	0
Move point	1	0
Insert point	1	0
Total	28	6

* One aborted because the user intended to pick fillet.

Notes:

These are functions, not just events; i.e., doing a fillet is selecting tangents, adjusting the fullness, etc., not just selecting the menu item "fillet." See Appendix C for the list of events performed during the first session.

Much can be learned by examining the individual actions the user performed during the design session. Appendix E lists the frequencies, durations, and error frequencies associated with each type of action for each tape. Table 4 shows two of the more key results of this breakdown. (Control dial results are discussed in the next section.) By far, the single command chosen most often was the exit command. Almost 17% of the user's time was spent exiting menus, accounting for almost 14% of all actions. In other words, every seventh action was an exit.

Table 4 - Key Results from Video Tape Analysis

Event	n (#)	t (s)	e (#)	n/N (%)	t/T (%)	e/E (%)	t/n (s/ev)
Exit (T1 - Tape 1)	79	620	0	11.4	14.0	0.0	7.8
Exit (T2 - Tape 2)	116	803	5	15.8	20.1	17.2	6.9
Exit (both - T1 & T2)	195	1423	5	13.6	16.9	9.6	7.3
Dials(T1)	116	718	15	16.7	16.2	65.2	6.2
Dials(T2)	139	814	15	18.9	20.4	51.7	5.9
Dials(both)	255	1532	30	17.6	18.2	57.7	6.0
All Events	**N**	**T**	**E**				**T/N**
Totals (T1)	695	4419	23				6.4
Totals (T2)	734	4000	29				5.4
Totals (both)	1429	4219	52				5.9

Notes:

n = frequency of action
t = accumulated durations
e = number of errors doing this action

N = frequency of all actions
T = total time of sessions
E = total number of errors

During these exit sequences, the user performed 1.6 consecutive exit commands. (See Table 5.) The mean was lower for the first taping session because the user never exited the smoothing menu. During the average multiple-exit sequence (a series of 2 or more exits in a row), the mean was 2.5 exits/sequence. (See Table 6.) The smoothing-edit menu was most commonly the last menu exited. The system did not have a function to exit more than 1 level at a time.

Table 5 - Exit Operations per Exit Sequence

Tape #	Exits/sequence	# Sequences	# Exits
1*	1	45	45
	2	11	22
	3	4	12
Sub total		60	79
2	1	30	30
	2	16	32
	3	14	42
	4	3	12
Sub total		63	116
1 & 2	1	75	75
	2	27	54
	3	18	54
	4	3	12
Total		123	195

Average exits per sequence (# Exits/# Sequences)

Tape 1:	1.3
Tape 2:	1.8
Both:	1.6

* During the first taping session, the user never exited out of the top level (smoothing). Therefore, 4 exits in a row was not possible.

Table 6 - Analysis of Multiple-Exit Sequences

Last exit	E	S	Ave	E	S	Ave	E	S	Ave
Edit	17	7	2.4	32	11	2.9	49	18	2.7
Point	10	5	2.0	8	4	2.0	18	9	2.0*
Utility	4	2	2.0	10	5	2.0	14	7	2.0*
Smoothing	3	1	3.0	21	6	3.5	24	7	3.4
Sectioning	0	0	0.0	15	7	2.1	15	7	2.1
Total	34	15	2.3	86	33	2.6	120	48	2.5

* Maximum possible for sequences ending with these exits.

Key: E Total number of exits in sequences.
S Number of sequences ending with this exit.
Ave Average number of exits in sequences ending.

When the user's CAD session was over, he had to write down on paper the filename he stored the data in and what he was working on to remember for his next CAD session. The CAD system did not allow the user to make notes about actions completed or future work plans.

What Errors Were Made?

Tables 4 (several pages back) and 7 give information about the errors made during the taping session. Approximately 4% of the user's actions resulted in errors. More than 57% of the errors made occurred while using the control dials, accounting for almost 13% of the dial actions. The most common error (44% of all errors) was turning the dial the wrong way. This was due in part to the 3-dimensional coordinate system used. The x-axis was represented horizontally, the y-axis was represented vertically, and the z-axis was perpendicular to the screen. Since the data must be displayed in 2 dimensions and often from 4 different viewpoints, it was not always obvious which way to turn a dial to produce the desired rotation, translation, cueing, or scaling. Compounding the problem, for at least one dial (Rotate y), turning it clockwise produced a counter-clockwise rotation of the drawing.

Table 7 - Summary of Errors

	Number of Errors		
Error Type	Tape 1	Tape 2	Total
Turned dial wrong way	15	8	23
Made selection too soon	2	10	12
Used wrong dial	0	7	7
Made invalid selection	4	2	6
Picked wrong line/point	2	0	2
Missed line/point	0	2	2
Totals:	23	29	52

Another 13% of the dial errors were caused by using the wrong control dial. Since the control dials were located to the left of the user, they were not in his direct line of sight. Not looking closely at the dials probably caused most of these errors.

Selections were made too soon in 23% of the error cases. This was caused by the user knowing where the desired menu item would appear and either clicking the mouse there before the menu was displayed, or clicking the mouse on the menu immediately after the menu appeared, but before the system was ready.

A total of 11.5% of the errors were invalid menu selections. All of these were caused by the user being confused about where he was in the menu structure. For example, at the 1 hour 9 minute mark in the first taping session, the user had just finished a fillet and wanted to do a pull. (See Appendix C for the list of events performed during the first taping session.) Pull was displayed on the menu so he selected it, without first exiting fillet (which was also displayed). He proceeded to pick the first two points required by a pull command before he realized his error. He was not given any visual or auditory signal of his error, nor was he given any clue to what command or menu was active at the time.

Twice the user picked the wrong line or point and twice he missed his line or point. The two wrong picks were cases where he decided he wanted something else after picking them. The missed points and lines were partially caused by the hidden line removal service of the CAD station. (See depth cueing description in Equipment and Materials for description of hidden line removal.) The lines and points of the wireframe drawing were so small that it was easy to click the mouse when it was not quite on the line. This was a problem by itself. But with hidden line removal, there may have been a line or point at that location on the other side of the drawing that was hidden from view. If so, then it was selected and an error occurred.

What Transitions Occurred?

During the second taping session, the user was creating data using the hang section function under the sectioning menu. (See Appendix D for the list of events performed during the second taping session.) To get the stations (point coordinates) required by hang section, he had to go to the coordinate function under the smoothing-edit-point menu. This involved a minimum of 9 actions to go from the hang section and get the station and 5 to get back. Multiplying by the average times per event shown in Appendix E, this involved 47 and 36.8 seconds respectively. For almost 10 minutes he bounced back and forth between these two functions. The system did not provide a way to jump back and forth between 2 functions.

RESULTS AND DISCUSSION -

RECOMMENDATIONS FROM CAD SYSTEM ANALYSIS

The data analysis identified several useful features that could be added to the Chrysler Designer Workstation software. For further discussion of why these features are recommended, see the Results section.

1. **Provide a mirror-imaging function.** This would allow the user to specify a center line and automatically create a mirror-image around that center line. During this study, this feature would have saved over a third of the total time of the first taping session!

2. **Provide a multi-exit menu choice to decrease the number of multiple-exit sequences.** A multi-exit would bounce the user up to the top or next-to-top level. (This is like a reverse menu-bypass.) The multi-exit command could save 1 or 2 menu choices per sequence, avoiding the additional screen updates as well. In addition, the system should give the user access to all major functions (Sectioning, Smoothing, Form 3D, and Utility) at all times.

3. **All control dials should cause the data to rotate or move according to population stereotypes for direction of motion linkages between controls and displays.** For example, rotating a dial to the right would rotate the data to the right. This could eliminate almost half of the errors currently being made when the dials are being used.

4. **Do not display a menu until the rest of the screen update is finished and the system is ready for a menu choice.** This would help eliminate confusion about when a menu item can be picked and therefore decrease the number of times menus were chosen too soon. When a menu selection is chosen too soon, an auditory signal should warn the user that the system was not ready.

5. **Display the menu chain to show the menu hierarchy and highlight the active menu choice.** This would eliminate confusion about which menu items can be selected. In addition, if a multi-exit function is implemented, the menu chain should indicate where it will take the user.

6. **Nesting commands could reduce the number of repeated commands.** It would allow the user to jump between commands repeatedly and very quickly. This would lead to time savings when hanging sections and verifying the section coordinates, for example.

7. **Provide a magnifying glass function using a mouse or function key.** The magnifying glass would act like a local zoom

by magnifying a small part of the screen for a brief period of time without affecting the rest of the screen. This would allow the user to pick lines and points more accurately. This would decrease the number of missed and incorrect picks.

8. **Provide a snap-to feature in conjunction with the magnifying glass.** Snap-to would automatically pick the nearest point to the location picked by the mouse. To warn the user that the system is making a guess, an auditory signal should be produced.

9. **Provide an on-line log to allow users to record what they were working on during a design session.** This might include an electronic "post-it" to provide for annotating design decisions and a facility for identifying work completed and future plans. This could be particularly useful when a single project is undertaken by more than one person. This would eliminate the pencil and paper method currently in use.

10. **Allow the user to redefine the edit and reference lines while remaining inside a lower menu choice.** This would be useful when the user needs to insert, delete, or check several lines or points which are not easy to deal with in a group.

11. **Provide a miniature perspective view which would show the overall orientation of the drawing.** This would help prevent users from becoming disoriented when they are zoomed in and/or when they have rotated the data.

12. **Show a miniature image of what the next higher-level screen is.** This would indicate what the screen would look like if the user backed up one level and increase the user's knowledge of where he or she is in the drawing and menu structure.

IMPLICATIONS FOR DESIGN OF CAS SYSTEM

The most immediate implication of this research to the design of the Computer Aided Surfacing system is that the biggest payoff will be realized at the menu level. Facilities should be provided which help the user remember his location within the command menu structure, the orientation of the drawing with respect to a reference, and the menu options currently available. Such facilities would eliminate back-tracking and errors, thus increasing the user's productivity.

While designing the CAS system, higher level tasks should be cultivated. For example, it would be useful to have an higher level command to "make this look like that except...." Maybe such a command would take the form of a macro. (A macro is a sequence of commands activated by a single user action.) It is not obvious whether these types of commands can be implemented, but is obvious they would save time.

It is also obvious that the CAS system should take into account the frequency with which task are performed and the transitions between tasks. Data are severely lacking in this area but expert guesses should be made to estimate. In addition, the CAS system should try to accumulate this type of data for future design projects.

IMPLICATIONS FOR DESIGN OF CAS SYSTEM-

LESSONS LEARNED ABOUT INTERFACE EVALUATION

Throughout this project the Chrysler project staff repeatedly emphasized that they were particularly interested in the methods used, possibly even more so than the final product. In many projects insight is gained into how research in engineering should be carried out, and that is especially true here. In addition, NCR is interested in identifying key features that advanced user interface architectures should incorporate. While CAD is not a primary business line of NCR, the lessons learned from this exercise generalize quite well to applications of interest to them. Below is a list of issues about videotaping and interface evaluation which were identified during this study.

Videotaping Procedures

Videotaping in the field produces large benefits but requires careful planning. The videotaping of users working in their own environment is the best way to study what they do. However, it requires portable equipment which most laboratories do not have, presents transportation problems, and times for set up and tear down must be taken into account. When developing portable equipment, doorway sizes, trunk sizes, and carrying aids (i.e., handles, carts) need to be considered. Each situation is different and must be planned for individually. Here are a number of issues identified during this study.

1. **How many cameras should be used and how should they be used?** The authors found that two cameras were required. One camera should be on a tripod, looking over the user's shoulder (perpendicular to the screen), and should show as much of the command menu as possible while still providing readability. This camera should remain fixed on the menu at all times. The second camera should be on a tall tripod to show the entire scene from an overhead viewpoint, i.e., the screen, the mouse, the dials, the keyboard, and the user's hands. This camera should remain stationary as well. Experimenters should not try to zoom or pan in on the screen or the user's hands because the events happen too quickly and will be missed. A third camera is not recommended because the playback screen would be too cluttered.

2. **What Sort of Lighting Is Required?** Most CAD rooms have subdued lighting to make the displays easy to see. Supplemental lighting is usually required to see the operator's hands, the mouse, the keyboard and the dials. A good solution is a directional desk lamp with a long neck because it is portable, minimizes heat, and takes up little space. White gloves with the fingers cut out (to aid typing) or white

adhesive tape on the backs of the hands make it easier to track the user's hands. Finally, if the user is wearing a white shirt, have a black robe or large shirt for the user to wear. Reflections from a white shirt can reduce the contrast of the display or decrease the scene luminance, making other items difficult to see.

3. **What Kind of Sound Equipment Is Required?** If the recording equipment is close enough to the workstation then it is best to use good quality lapel microphones which plug into the sound mixer. If this is not possible, wireless mikes will work but the user will partially block the signal and interference will be picked up from the surrounding computer equipment. A third possibility would be to use a boom mike suspended over the user. In addition, the equipment operators may want to have a microphone for voice-over comments and questions to the user.

4. **What Other Equipment and Procedures Are Required?** The images from the cameras, the audio, and a time and date signal should be mixed on location using a special effects generator (SEG). Two monitors should be used by the SEG operator, one to show the output (i.e., what is being recorded on tape), and one to preview cameras individually. Camera operators should be able to see the output monitor so they can position their cameras optimally. The output monitor should be used to aim and focus cameras, not the cameras' viewfinders. Most importantly, most CAD rooms will be crowded and video equipment will interfere with normal activities in the room, so the space equipment consumes should be minimized and well planned.

General Problems of Interface Evaluation

One of the critical lessons learned from this research was the need for new tools for human factors research. Without these tools, it was not possible to prototype a new user interface for the designer workstation. This was initially considered as a potential activity for this research. The following paragraphs identify the tools required to fulfill such a goal.

1. **Good general purpose prototypers do not exist for prototyping CAD interfaces.** The current recommended practice is to mock-up an interface and test it before committing to application code (Gould and Lewis, 1985). To do that, however, one needs the appropriate tools. Most prototypers (e.g., Dan Bricklin's Demo program (Software Garden, 1985)) are oriented toward handling screens, not objects. Hence, even simple actions such as rotating a view cannot be done. The ability to handle complex functions (e.g., generating a B-spline curve, fillets, etc.) is well beyond the state-of-the-art, making interface evaluation very difficult.

2. **Tools for capturing user interaction with CAD systems should be an integral part of their design.** For that matter, any system with which people interact should have the ability to log and timestamp every user action and every system response. In the system examined in this report, that was not possible. Hence, the only way to record user behavior was to videotape user sessions and then play the tape back to decipher what occurred using an on-screen time generator to establish event durations.

This was very time consuming. For every hour of tape, it took over 12 hours to isolate the various user actions (mouse picks, dial movements, etc.), and at least 3 to 4 times that length of time to analyze the data. Typically there was a user action every 6 seconds. The original method used for analyzing the data was to start the videotape, observe an event, stop the tape, write it down on paper, and then repeat the process. This is analogous to programming a computer by flipping toggle switches on the front panel of a computer to enter machine level instructions as binary values. Later, two computer programs based on an earlier UMTRI program used for timestudy (Green, Baker and Birdsall, 1985) were developed to timestamp and label the events (Bos, 1987c; Bos, 1987b). While this was a major advance, it still fell far short of the tools required. To continue the analogy, this method was like giving the programmer a keyboard to enter the machine code instructions. Hence, because the analysis had to develop the tools needed, it took weeks to analyze the data to produce only a relatively small report. Clearly, if user interface designers are to keep pace with system designers in the 1980's and beyond they will need new tools.

After the analysis for this project was complete, the authors learned of software that would have greatly facilitated this project. That software, the Observation Coding System (Triangle Research Collaborative, 1987) allows users to enter the time marks on a videotape and have real time closed-loop control of the time marked events. However, the software still lacks many capabilities necessary for this project. The development of software for this purpose should be aggressively pursued.

Ideally, a videotape system should be a backup for a system built into the operating system to log user and system actions. The logger should be able to record every action observable to the user, every key press, every mouse click, every mouse movement, every dial action, every character displayed, every disk access, and so forth. The user should be able to set the level of resolution. Sometimes the interface designer needs to know the text of what a user types in before hitting return, and the times when typing started and ended to the nearest second. In other instances, the time to the nearest millisecond when each key is depressed and released is required.

In designing such software, careful thought about how to record continuous actions is critical. For example, for cursor controlled devices (such as mice), one is primarily interested in the initial and final locations. But to have an operating system determine that without knowing the context (i.e., how to differentiate between a pause and an end of an action) is very difficult.

This problem was evident in another study to which the second author has contributed (Saldana, Elkerton, and Green, 1987) where mouse actions were collected while people edited and compiled a computer program on an Apollo. (The Apollo has a window interface.) In that instance each interrupt from the mouse was timestamped. Since each interrupt corresponded to a single pixel movement of the cursor, the amount of data collected from each mouse movement was overwhelming. While post-session data compression programs facilitated the analysis, most of the analysis was still done by hand using a calculator, a very time consuming process.

Further complicating such decisions, mouse actions can be used in parallel with other actions. For example, in this experiment there were several instances where the user turned a control dial while positioning the mouse cursor for a selection. Keeping the two (or more) actions distinct while they occurred simultaneously was not easy.

3. **Programs to automate the task analysis are needed.** Programs should give locations of menu items, display tree structures of menus and explain what some inputs mean (e.g., dial motions). They should also build indented structures of tasks and summarize times in a GOMS-like format (Card, Moran and Newell, 1983). For example,

```
00:00          begin session
02:35          clean up edge       &lt;-- task
     01:15          move line      &lt;-- subtask
          00:10          pick move line menu item
          00:17          pick one end of line
          00:32          click button and drag to other end
          00:33          release button
          00:55          point to one end location
          01:15          pull line to other end
     02:35          next subtask...
05:45          next task...
```

4. **Tools are needed for generic logging on a personal computer.** For example, the keyboard, mouse, etc., are plugged into an IO box. The output cables from the box get plugged into the system of interest (e.g., Apollo, PC, Sun, Evans and Sutherland, etc.). If a system configuration is being reused, then the IO definitions should be on file and contain all the pin information (what each pin connection is used for). If a

new system configuration is being used, it should tell the user what to do to configure the system correctly (e.g., hit the "a" key) and from the signals, figure out what each pin's function is.

Current human factors tools are inadequate to solve contemporary user interface design problems. The problems of the 1990's and beyond are being tackled with the tools of the 1960's. If human factors is to make a meaningful contribution, then problem solving tools are needed. Without such tools, the most appropriate tool for reshaping the user interface may well be a sledgehammer.

REFERENCES

Bailey, R.W. (1982). Human Performance Engineering. Englewood Cliffs, NJ: Prentice-Hall.

Bos, T. (1987a). COUNTUP.BAS - Event Counting Program, version 1.0. Ann Arbor, MI: The University of Michigan Transportation Research Institute, November.

Bos, T. (1987b). EV-EDIT.BAS - Event Editing Program, version 1.0. Ann Arbor, MI: The University of Michigan Transportation Research Institute, October.

Bos, T. (1987c). EVENTS.BAS - Event Recording Program, version 1.0. Ann Arbor, MI: The University of Michigan Transportation Research Institute, October.

Card, S.K., Moran, T.P., and Newell, A. (1980). The Keystroke-Level Model for User Performance Time with Interactive Systems. Communications of the ACM, July, 23(7), 396-410.

Card, S.K., Moran, T.P., and Newell, A. (1983). The Psychology of Human-Computer Interaction. Hillsdale, NJ: Lawrence Erlbaum Associates.

Eberts, R., Lang, G.T., and Gabel, M. (1987). Expert/Novice Differences with a CAD System. Proceedings of IEEE Systems, Man, and Cybernetics, October, 985-989.

Gould, J.D. and Lewis, C. (1985). Designing for Usability: Key Principles and What Designers Think. Communications of the ACM, March, 28(3), 300-311.

Green, P. and Adams, S. (1987). Who Are the Potential Users of a CAD System? (Technical Report UMTRI-87-15). Ann Arbor, Michigan: The University of Michigan Transportation Research Institute.

Green, P., Baker, D., and Birdsall, E. (1985). TS.BAS - Time Study Program, version 3.1. Ann Arbor, MI: The University of Michigan Transportation Research Institute, May 25.

Green, P. and Wei-Haas, L. (1987). The Rapid Development of User Interfaces: Experience with the Wizard of Oz Method. Proceedings of the Human Factors Society - 29th Annual Meeting, 470-474.

Henderson, D.A. (1986). The Trillium User Interface Design Environment. CHI '86 Conference Proceedings (Human Factors in Computing Systems). New York: Association for Computing Machinery, 221-227.

Majchrzak, A., Chang, T-C., Barfield, W., Eberts, R., and Salvendy, G. (1987). Human Aspects of Computer-Aided Design. Philadelphia, PA: Taylor and Francis.

Microsoft Corporation (1987). Microsoft QuickBASIC, version 3.0. Redmond, WA: Microsoft Corporation.

Orr, J. (1987). CADD Talk: An Illustrated Glossary of CADD Terminology. PC Magazine, December 8, 6(21), 98-100.

Pew, R.W. and Green, P. (eds.) (1986). Human Factors Engineering Short Course Notes (27th ed.). Ann Arbor, MI: The University of Michigan Chrysler Center for Continuing Engineering Education.

Price, L.A. (1982). Design of Command Menus for CAD Systems. ACM/IEEE 19th Design Automation Conference Proceedings, 453-459.

Rosson, M.B., Maass, S., and Kellogg, W.A. (1987). Designing for Designers: An Analysis of Design Practice in the Real World. CHI+GI 1987 Conference Proceedings (Human Factors in Computing Systems and Graphics Interface). New York: Association for Computing Machinery, 137-142.

Saldana, N., Elkerton, J., and Green P. (1987). User Memory Load and Procedural Manipulation with a Window Interface. Paper presented at Fourth Mid-Central Ergonomics/Human Factors Conference.

Sanders, M.S. and McCormick, E.J. (1987). Human Factors in Engineering and Design (6th ed.). New York: Wiley.

Shneiderman, B. (1987). Designing the User Interface: Strategies for Effective Human-Computer Interaction. Reading, MA: Addison-Wesley.

Software Garden, Inc. (1985). Dan Bricklin's Demo Program, version 1.0. West Newton, MA: Software Garden, Inc.

Triangle Research Collaborative, Inc. (1987). Observational Coding System Tools, Research Triangle Park, NC.

van der Heiden, G.H., Brauninger, U., and Grandjean, E. Ergonomic Studies on Computer Aided Design. Ergonomics and Health in Modern Offices. London: Taylor & Francis.

Wesselman, H. and Green, P. Wizard of Oz User's Manual, version 4.0. (Technical Report UMTRI-86-50). Ann Arbor, Michigan: The University of Michigan Transportation Research Institute.

APPENDIX A - GLOSSARY OF CAD TERMS

Below is a list of CAD terms used in this report and their meaning. These descriptions should help those readers who are not CAD experts. Some of these definitions are taken from a recent article in PC Magazine, "CADD Talk: An Illustrated Glossary of CADD Terminology" (Orr, 1987). Definitions not quoted from Orr are the authors' own descriptions, based on either a priori knowledge or observations of their use during the study.

B-spline:
A polynomial parametric function used to describe a curve.

Depth cueing:
Adjusting the extent to which data farther from point of view fade from sight. Also called hidden line removal.

Fillet:
"A rounded intersection between two curves that is used primarily in mechanical engineering. In 2-D design, a fillet is a curve connecting lines of arcs in such a way that they are tangent to it. The counterpart in 3-D design is called a 'fillet surface'." (Orr, 1987, p.99)

Hang Section:
A process to interpolate curved sections by repositioning an existing section; an existing section is selected and connected to the reference lines as often and at the increments specified.

Macro
"A collection of system commands that can be activated by a single code or button." (Orr, 1987, p.99)

Mirror:
"To create a reflected copy around an indicated axis." (Orr, 1987, p.99)

Orthogonal view:
"A drawing in which a face of the object is parallel to the drawing plane, and the projections lines are perpendicular (orthogonal) to the plane of the drawing." (Orr, 1987, p.99)

Pick:
Single out data using mouse. Examples include lines, tangents, points, pointsets, and sections.

Pixel:
"Picture element; also called pel. The smallest resolvable unit on a...display." (Orr, 1987, p.99)

Resolution:
"The number of pixels per unit of area or length, on a display...the number of addressable points per unit of area or length in a vector file." (Orr, 1987, p.100)

Scaling:
Adjusting the point of view close to or farther from the drawing. It enables the user to "move through" the drawing. As a consequence, scaling enlarges or shrinks the drawing.

Select:
Single out choices using the mouse. Examples include menu choices, view choices, zoom, and the corners for zoom.

Snap (snap-to):
"Snaps are like point placement magnets. A CADD user might want to snap a point to the end of a line, to a midpoint, or to the intersection of two lines, for example. Systems that have snaps usually allow the user to set the snapping range." (Orr, 1987, p.100)

Thinning Tolerance:
The number of points along the arc created by a fillet. The number of points are determined by chordal deviation.

Wireframe:
"A computer representation of 3-D objects in which only edges are represented." (Orr, 1987, p.100)

Workstation:
"A display and one or more input devices, usually coupled with a single-user computer." (Orr, 1987, p.100)

Zoom:
"Magnify the view, as when 'zooming in' on a critical part of the drawing." (Orr, 1987, p.100) The area magnified is determined by picking opposite corners of a rectangle (e.g., upper right and lower left corners). Unlike scaling, the viewpoint is not moved any close to the drawing (i.e., lines hidden due to hidden line removal remain hidden).

APPENDIX B - MENU STRUCTURE

Below is a detailed description of the menu structure for the Designer Workstation. Some notes about this appendix:

1. Menu hierarchy is indicated by indenting the subsequent menu choices.
2. Some menu choices are not completely filled in (e.g., FORM 3D choices) because they were not used by the subject during the videotaping.
3. Capitalized entries indicate menu choices which lead to a new menu. After each entry is the sequence of actions required to execute the given command.
4. At all times, the menu contains a "Whoops" choice and an "Exit" choice. The Whoops choice will undo the last command performed or undo the actions taken towards the current command. The Exit choice will get the user out of the current command, saving the work that has been completed and disregarding any unfinished functions.

```
FORM 3D
   Store . . . . . . .     {not examined}
   Erase . . . . . . .     {not examined}
   Locate Station . . .    {not examined}
   Limit 3D . . . . . .    {not examined}
   New SA1-23 . . . . .    {not examined}
   Erase True . . . . .    {not examined}
   To 3D . . . . . . .     {not examined}

SMOOTHING
   EDIT . . . . . . . .    Pick ptset to edit, ref. lines {0 or
                              more}, Select process
      Insert Arc
         Balance . . .     Enter station
         Non-Balance . .   Pick 3 pts.
      3 Pt. Conic . . .    Pick 2 tans., midpoint
      POINT
         Kill Point . .    Pick pt.
         Insert . . .      Pick pt.
         Move To . . .     Pick pt. to move, location
         Distance . . .    Pick 2 pts.
         Kill Special .    Pick 2 pts.
         On Line . . .     {not examined}
         Exchange . . .    Pick pt.
         Coordinate . .    Pick pt.
      Sweep Chart . . .    {not examined}
      Fillet . . . . .     Pick 2 tans., Adjust fullness,
                              Select ok/not ok, If ok Select
                              thinning tolerance
      6 Pt. Conic . . .    Select Tan./Nontan., Pick 3 pts.
      Pull . . . . . .     Pick 2 tans., pt. to be pulled,
```

```
                          location
    Intersect    . . .  Pick projection view, line to proj.
                          onto, line to project
    Parallel . . . .    {not examined}

  UTILITY
    Store Data   . . .  Enter file name, ID
    Distance .   . . .  Pick 2 pts.
    Erase .  .   . . .  Pick line to erase
    2-Pt. Move   . . .  Pick ptset to move, "from" pt., "to"
                          pt.
    Get Data .   . . .  Enter file name, ID
    Join Lines   . . .  Pick 2 lines
    Generate .   . . .  {not examined}
    Viewpoint    . . .  {not examined}
    Coordinate   . . .  Pick pt.

SECTIONING
  Hang Section   . . .  Select single or double axis, Pick
                          section to hang, ptsets 1 & 2,
                          Enter station 1, Select
                          single/multiple, If mult then
                          Enter station 2, increment
  UTILITY
    Store Data   . . .  Enter file name, ID
    Distance .   . . .  Pick 2 pts.
    Erase .  .   . . .  Pick line
    2-Pt. Move   . . .  Pick ptset to move, "from" pt., "to"
                          pt.
    Get Data .   . . .  Enter file name, ID
    Join Lines   . . .  Pick 2 lines
    Generate .   . . .  Enter 1st pt, Enter 2nd pt or Select
                          save pt/delete pt/quit ptset
  Hang Arc . . . . . .  Select constant section (x, y, z),
                          Pick 2 ptsets, Enter station 1,
                          Select single/multiple, If mult
                          Enter station 2, increment
  Xhang Section  . . .  Pick sect. to hang, 2 ptsets, Enter
                          station 1, Select
                          single/multiple, If mult Enter
                          station 2, increment
```

APPENDIX C - DATA FROM FIRST TAPING SESSION

```
Key: Menu and view choices are enclosed in single quotes (' ')
     Things users said are enclosed in double quotes (" ")
     Menu actions which are errors are preceded with a right
          arrow (>)
     Knob actions done in wrong direction first are errors are
          preceded with a squiggle (~)


TIME      TASK SUBTASKS/COMMENTS
----------------------------------------------------------------
-00:01:38 Start
-00:01:17 "Figure out where they were"
               Rotate data    Adj fullness

***Delete section of old data - use Edit menu
 00:00:07 Pick edit and reference lines and position drawing
               Discuss        'Edit'         Pick ptset
               Pick reference 'Process'      Turn dots on
 00:00:21 Kill section (wrong section)
               Discuss        'Point'        'Kill special'
               'Rear view'    Pick 1st pt    Pick 2nd pt
 00:01:32 Kill section
               Pick 1st pt    Pick 2nd pt
 00:01:01 Kill section (single pt)
               Pick 1st pt    Pick 2nd pt    Exit
               Exit pt        Exit edit

***Edit centerline section to peak of groove - use Edit menu
 00:01:52 Try to do 2 pt move in Edit menu
               Exterior on    Rotate Z       Dots off
               Discuss        >'edit'        Exit edit

***Try again - use Utility menu
 00:03:16 Execute 2 pt move
               'Utility'      ~Rotate Z      Pick ptset to move
               Scale in       Y trans        X trans
               Scale in       Pick from pt   Pick to pt
               'Exit 2 pt move
 00:03:57 Erase old ptset
               Dots off**     Discuss        >Exit utility
               >'Edit'        >Exit edit     'Utility'
               'Erase'        Pick line to erase
               Exit erase     Exit utility

***Edit rear end groove to front end groove - use Edit menu
 00:06:06 Pick edit and reference lines and position drawing
               Discuss        Scale in       Y trans
               X trans        ~Y trans       Rotate X
```

```
                 Rotate Z          Rotate Z          Discuss
                 'Edit'            Scale in          X trans
                 Y trans           Z trans           Rotate Z
                 Pick ptset to edit                  >Pick ref line
                 Pick ref line     'Process'         'Side view'
                 'Zoom'            Pick LRH crnr     Pick ULH crnr
                 Dots on
 00:07:13 Move point
                 Discuss           'Point'           'Move to'
                 ~Scale in         Z trans           Scale in
                 Pick pt to move                     Pick new loc
                 Exit move to
 00:07:33 Put new point on line
                 'On line'         Pick location     Exit on line
 00:07:57 Kill pt
                 'Kill pt'         Pick pt           Exit kill pt
                 Exit edit

***Kill centerline section - use Utility menu
 00:08:54 Erase centerline section
                 Discuss           'Utility'         'Erase'
                 ~Scale in         Z trans           X trans
                 Rotate Z          Pick line         'Stop'
 00:10:39 Execute 2 pt move
                 Hit 'reset'       Rotate Y          Rotate X
                 Rotate Z          Rotate Y          X trans
                 '2-pt move'       ~Scale in         X trans
                 ~Scale in         Pick pt to move
                 Pick from pt      Pick to pt        Exit 2 pt move
 00:11:01 Erase ptset
                 'Erase'           Pick pt to erase
                 Exit erase        Exit utility

***Smooth curve to lip of ridge - use Edit menu
 00:12:02 Pick edit and reference lines and adjust view
                 'Edit'            >Pick ptset to edit
                 'Whoops'          Pick ptset to edit
                 Pick ref line     Pick ref line     'Process'
                 'Rear view'       'Zoom'            Pick LRH crnr
                 Pick ULH crnr
 00:12:24 Move existing pt
                 'Point'           'Move to'         Pick pt to move
                 Pick new loc
 00:12:43 Move existing pt
                 Pick pt to move                     Pick new loc
                 "Try to extend arc by inserting pt"
                 Exit move to
 00:14:10 Insert pt on line
                 'Insert'
                 "(try to) extend arc out to blue line... imagine
                     (the line) running out and crossing that
                     blue line"
                 Hit reset         'Zoom'            Pick ULH crnr
                 Pick LRH crnr     Pick loc for pt
```

	Exit	Hit reset	Discuss
	Exit pt		
00:15:08	Insert arc (aborted)		
	'Insert arc'	'Non-balance'	Pick 1st pt
	Pick 2nd pt	Pick 3rd pt	'Zoom'
	Pick ULH crnr	Pick LRH crnr	Ref line on
	"Still doesn't look that smooth"		
	'Whoops'		
00:16:08	Execute 3-pt conic		
	Discuss	'3-pt conic	Pick 1st tan
	Pick 2nd tan	Pick mid-pt	Discuss
	'Stop'		
00:17:10	Execute fillet - not sure whether to use fillet/pull		
	'Fillet'	Pick 1st tan	Pick 2nd tan
	Ref line on	Adjust fullness	
	Ref line off	Ref line on	
	'Ok'	Pick thin tol	Exit
00:19:31	Inset arc		
	Ref line off	'Zoom'	
	Pick LRH crnr	Pick ULH crnr	'Insert arc'
	'Non-balance'	Pick 1st pt	Pick 2nd pt
	Pick 3rd pt	Ref line on	'Whoops'
	'Non-balance'	Pick 1st pt	Pick 2nd pt
	Pick 3rd pt	Re-pick 3rd pt	Ref line off
	Ref line on	Ref line off	
	"How do you know it's tangent down here?"		
	Exit insert arc		
00:21:17	Execute fillet		
	'Fillet'	Pick 1st tan	Pick 2nd tan
	Y trans	X trans	
	"You would think this line should lead down to here as if it were without the groove...it doesn't look like it does that"		
	Ref line on	Scale in	Ref line off
	'Ok'	Pick thin tol	Exit fillet
00:21:57	Kill pt (aborted)		
	'Point'	'Kill pt'	Pick pt to kill
	'Whoops'	Exit kill pt	
00:22:54	Move pt		
	'Move to'	Pick pt to move	
	Pick new loc	Z trans	Y trans
	Scale in	Scale out	Exit move to
	Exit pt		
00:23:46	Execute fillet		
	'Fillet'	Scale in	Pick 1st tan
	Pick 2nd tan	Ref,line on	'Ok'
	Pick thin tol	Exit fillet	
00:24:18	"Look at rest of pt set"		
	'Mult'	'Rear view'	'Zoom'
	Pick LRH crnr	Pick ULH crnr	
00:25:08	Execute fillet		
	'Fillet'	Pick 1st tan	Pick 2nd tan
	Adjust fullness		'Ok'
	Pick thin tol	Exit fillet	Exit edit

***Modify arc - use Edit menu
00:26:15 Pick edit and reference lines and position drawing
'Edit' X trans Z trans
Y trans Rotate Z Rotate Y
Rotate X Pick ptset to edit
Rotate X Pick ref line
"Did it grab it?" Re-pick ref line
Scale in Pick ref line 'Process'
00:27:44 Insert pt - lots of trouble positioning for view
~Scale out 'Rear view' 'Point'
Scale back 'Zoom' Pick LLH crnr
Pick URH crnr (missed) Scale out
Hit reset ~Scale out
"I think you'll have to do it manually"
'Insert' Pick loc 'Zoom'
Pick LLH crnr Pick URH crnr "Forget it"
Hit reset Exit insert Exit pt
Exit edit

***Modify arc - use Utility menu
00:28:34 Erase line
'Utility' 'Erase' Rotate Y
Rotate Z Rotate X Pick line to erase
Exit erase
00:29:15 Join lines (aborted)
'Join lines' Pick 1st line Pick 2nd line
"What the heck! Whoops that out of there quick!"
'Whoops' Exit utility

***Edit line - use Edit menu
00:29:41 Pick edit and reference lines and position drawing
'Edit' Pick ptset to edit
Pick ref line 'Process' 'Rear view'
"Does that cross the centerline? How would you want to make sure it hits the centerline section?"
00:31:30 Execute intersect
'Intersect' 'Mult' 'Whoops'
'Plan view' Scale back
Pick line to proj onto Pick line to proj
Exit >Exit edit

***Edit line again (exited Edit by mistake) - use Edit menu
00:32:10 Pick edit and reference lines and position drawing
'Edit' Rotate Z Rotate X
Pick ptset to edit Pick ref line
'Process' 'Rear view' 'Zoom'
Pick LRH crnr Pick ULH crnr
00:32:32 Kill pt
'Point' 'Kill pt' Pick pt to kill
"Let's try the join again" Exit
Exit point Exit edit

***Edit intersection of 2 lines - use Utility menu

00:33:15	Join 2 lines		
	'Utility'	'Join lines'	Rotate Y
	Rotate X	Pick 1st line	Pick 2nd line
	Exit	Exit utility	

***Smooth crown of done light - use Edit menu

00:34:20	Pick edit and reference lines and position drawing		
	'Edit'	Pick ptset to edit	
	Pick ref line	Pick ref line	Pick ref line
	'Process'	'Rear view'	'Zoom'
	Pick ULH crnr	Pick LRH crnr	Y trans
00:35:29	Kill 3 pts using "kill special"		
	Discuss	'Point'	'Kill special'
	Pick 1st pt	Pick 2nd pt	Scale back
	Z trans	Y trans	Scale back
	Y trans	Exit kill spec	
00:35:57	Insert pt		
	'Insert'	>Pick location	'Whoops'
	Pick location	Exit	
00:37:09	Insert arc		
	'Insert arc'	'Non-balance'	Pick 1st pt
	Pick 2nd pt	Pick 3rd pt	Ref line on
	'Zoom'	Pick ULH crnr	Pick LRH crnr
	Y trans	Discuss	
	"Let's re-evaluate what we have"		
	Hit reset	Exit	
00:37:58	Pull pt on line to new location		
	'Pull'	Pick 1st tan	Pick 2nd tan
	Pick pt to pull		Pick final loc
	Exit		
00:38:24	Insert arc		
	'Insert arc'	'Non-balance'	Pick 1st pt
	Pick 2nd pt	Pick 3rd pt	Exit insert arc
00:39:38	Insert arc		
	Discuss	'Insert arc'	'Non-balance'
	'Zoom'	Pick LRH crnr	Pick ULH crnr
	Scale back	Pick 1st pt	Pick 2nd pt
	Pick 3rd pt	Ref line on	Ref line off
	Exit		
00:40:57	Execute fillet		
	Y trans	Z trans	Scale out
	'Fillet'	Pick 1st tan	Pick 2nd tan
	'Ok'	Pick thin tol	Y trans
	Scale out	Discuss	Exit fillet
00:42:00	Check coordinates of pt		
	'Point'	'Coordinate'	'Zoom'
	Pick LRH crnr	Pick ULH crnr	Pick pt
	Discuss	Exit	
00:42:53	Intersect 2 lines		
	'Mult'	Exit pt	'Intersect'
	Pick proj view	Pick line to project onto	
	Pick line to project		'Rear view'

```
          'Zoom'         Pick ULH crnr  Pick LRH crnr
          Scale out      Exit intersect
 00:43:40 Execute fillet
          'Fillet'       Pick 1st tan   Pick 2nd tan
          Scale out      Ref line on    Adjust fullness
          Discuss        'Ok'           Select  thin tol
          Exit
 00:44:05 Check coordinates of pt
          ~Scale in      'Coordinate'   Pick pt
          Exit
 00:45:00 Insert balanced arc
          'Insert arc'   'Balance'      Enter station
          ~Scale back    Y trans
          "Supposedly that is a balanced arc across the
               car"
          Scale in       Discuss        Exit
 00:45:55 Execute fillet
          'Zoom'         Pick LRH crnr  Pick ULH crnr
          'Fillet'       Pick 1st tan   Scale out
          Pick 2nd tan   Ref line on    'Ok'
          Pick thin tol  Ref line off   Hit reset
          'Mult'         Exit           Exit edit

***Smooth top and bottom of drawing (mirror results) - use Edit
menu
 00:47:04 Pick edit and reference lines and position drawing
          Rotate Z       Rotate Y       Rotate X
          Discuss        'Edit'         Hit f-key
          Hit f-key      Hit f-key      Hit f-key
          Pick ptset to edit            Discuss
          'Process'      'Plan view'
 00:48:15 Execute fillet (aborted)
          'Fillet'
          "Do a fillet just to show how you can screw
              yourself up (by working across end pts)"
          Pick 1st tan   Pick 2nd tan   'Whoops'
          "Can't work across that opening"
          Exit
 00:48:55 Insert arc (aborted)
          'Insert arc'   'Non-balance'
          Pick 1st pt (didn't take)     Re-pick 1st pt
          Pick 2nd pt    Pick 3rd pt    Ref line on
          'Whoops'
 00:49:06 Insert arc
          'Non-balance'  Pick 1st pt    Pick 2nd pt
          Pick 3rd pt
 00:49:32 Insert arc
          'Non-balance'  Pick 1st pt    Pick 2nd pt
          Pick 3rd pt
 00:50:18 Insert arc
          >Pick pt       'Non-balance'  Pick 1st pt
          Pick 2nd pt    Pick 3rd pt    Ref line off
          Ref line on    Ref line off
 00:51:15 Insert arc (aborted)
```

```
         'Non-balance'  Pick 1st pt    Pick 2nd pt
         Pick 3rd pt    Ref line on    Ref line off
         "Looks like it needs to be pulled out"
         Ref line on    Ref line off   'Whoops'
00:51:34 Insert arc
         'Non-balance'  Pick 1st pt    Pick 2nd pt
         Pick 3rd pt    Ref line on
00:52:29 Insert arc
         'Non-balance'  Pick 1st pt    Pick 2nd pt
         Pick 3rd pt    Ref line off   Exit insert arc
00:53:02 Execute fillet
         'Fillet'       Pick 1st tan   Pick 2nd tan
         Adj fullness   Ref line on    Adjust fullness
         'Ok'           Pick thin tol
00:53:49 Execute fillet (aborted)
         Pick 1st tan   Pick 2nd tan   Adj fullness
         'Not ok'
00:54:44 Execute fillet
         "Can we mirror this against itself?"  "Not here"
         Pick 1st tan   Pick 2nd tan   Adj fullness
         'Ok'           Pick thin tol  Exit fillet
00:55:38 Select pt menu - Error, nothing done
         >'Point'       Discuss
         "Insert pt or use fillet to straighten a curve"?
         Exit
00:56:42 Execute fillet (aborted)
         Discuss        'Fillet'       Pick 1st tan
         Pick 2nd tan   Ref line off
         "Too big, not like down here"
         'Not ok'       Exit
00:57:27 Exchange 2 pts
         'Point'        'Exchange'     Pick exchange pt
         Pick exchange pt              Pick exchange pt
         Exit           Exit point
00:57:43 Select insert arc - Error, meant to choose fillet
         >'Insert arc'  Exit insert arc
00:58:05 Execute fillet
         'Fillet'       Pick 1st tan   Pick 2nd tan
         'Ok'           Pick thin tol
00:59:45 Execute fillet
         Discuss
         "This one looks tighter than this one here"
         Pick 1st tan   Pick 2nd tan   Ref line on
         Adj fullness   Ref line off   Adj fullness
         Ref line on    Ref line off   'Ok'
         Pick thin tol  Exit fillet
01:00:44 Execute fillet
         Discuss        'Fillet'       Pick 1st tan
         Pick 2nd tan   Ref line on    Adj fullness
         'Ok'           Pick thin tol
01:01:37 Execute fillet (aborted)
         Pick 1st tan   Discuss        Pick 2nd tan
         Adj fullness   'Not ok'       Exit fillet
01:02:49 Move pt
```

		'Zoom'	Pick URH crnr	Pick LLH crnr
		Discuss	'Point'	'Move to'
		Pick pt to move		Pick new loc
		Exit		
01:03:30	Insert pt			
		'Insert'	Pick loc	Hit reset
		'Zoom'	Pick URH crnr	Pick LLH crnr
		Scale out	Exit insert	Exit pt
01:05:20	Execute fillet			
		'Fillet'	Pick 1st tan	Ref line off
		Pick 2nd tan	Scale back	Ref line on
		Adj fullness	Ref line off	Ref line on
		Adj fullness	Ref line off	Ref line on
		Adj fullness	'Ok'	Pick thin tol
		Ref line off	Hit reset	Exit fillet
01:06:14	Pull pt to new location			
		'Pull'	Pick 1st tan	Pick 2nd tan
		Pick pt to be pulled		Pick final loc
		Exit		
01:06:38	Execute fillet			
		'Fillet'	Pick 1st tan	Pick 2nd tan
		'Ok'	Pick thin tol	
01:08:12	Execute fillet			
		'Zoom'	Pick URH crnr	Pick LLH crnr
		Scale out	Pick 1st tan	Pick 2nd tan
		Scale out	Adj fullness	Discuss
		"Want pt more toward center more symmetrical"		
		'OK'	Pick thin tol	
01:11:23	Pull pt to new location			
		Scale in	Y trans	X trans
		Scale in	X trans	Y trans
		Discuss	>'Pull'(in fillet)	
		>Pick pt(1st tan)		
		"What are you doing?" "Pulling it down"		
		"Are you in pull?" "Yeah"		
		>Pick pt(2nd tan)		
		"Oh, you're in pull Uh huh" (didn't realize in fillet)		
		"Whoops"	Exit fillet	'Pull'
		Pick 1st tan	Pick 2nd tan	
		Pick pt to be pulled		Ref line on
		Ref line off	Pick final loc	~Scale out
		Exit		
01:12:08	Execute fillet			
		'Fillet'	Pick 1st tan	~Scale in
		Pick 2nd tan	~Scale out	Ref line on
		Adj fullness	Ref line off	'Ok'
		Pick thin tol		
01:12:56	Execute fillet			
		Pick 1st tan	Pick 2nd tan	Ref line on
		Adj fullness	'Ok'	Pick thin tol
01:13:35	Execute fillet			
		Ref line off	Pick 1st tan	Pick 2nd tan

Ref line on   Ref line off   'Ok'
Pick thin tol

***Terminate system
01:14:00 Subjects asked to end session
01:14:35 End session
Exit fillet   Exit edit   Exit smoothing
'Exit'   'Yes'("Save data?")
'Vax'("Store data on")
Type filename & return
"And there you're done"

- APPENDIX C - DATA FROM FIRST TAPING SESSION -

APPENDIX D - DATA FROM SECOND TAPING SESSION

```
Key: Menu and view choices are enclosed in single quotes (' ')
     Things users said are enclosed in double quotes (" ")
     Menu actions which are errors are preceded with a right
          arrow (>)
     Knob actions done in wrong direction first are preceded
with
          a squiggle (~)


TIME      TASK SUBTASKS/COMMENTS
---------------------------------------------------------------
-00:00:12 Start taping session
 00:00:57 Finish task started before session
               ~Scale in      'Utility'      'Erase'
               Pick pt        Rotate X       ~Rotate Y
               Rotate Z       Pick pt        Rotate Z
               Rotate Y       Rotate X       Scale back
               Rotate Z       Rotate X       Rotate Z
               Rotate Y       Exit           Exit utility

***Create data section
 00:02:11 Hang data sections (aborted - didn't know station)
               'Sectioning'   ~Scale in      Rotate X
               'Hang section' 'Single'       Pick sect to hang
               Scale in       X-trans        Rotate Y
               Rotate X       Pick ptset 1   Pick ptset 2
               'Whoops'       'Whoops'       Exit
               Exit sectioning
 00:02:28 Pick edit and reference lines
               'Smoothing'    'Edit'         Pick ptset to edit
               Pick ref line  'Process
 00:03:22 Get station
               'Point'        'Coordinate'   'Rear view'
               'Mult'         Pick pt        Exit
               Exit point     Exit edit      Exit smoothing
 00:05:34 Hang data sections
               'Sectioning'   'Hang section' 'Double axis'
               Pick sect to hang             Pick ptset 1
               Pick ptset 2   Enter sta 1    'Mult'
               Enter sta 2    'Whoops'       'Double axis'
               Pick sect to hang             Pick ptset 1
               Pick ptset 2   Enter sta 1    'Mult'
               Enter sta 2    Enter incr     Exit
               Exit sectioning
 00:05:55 Erase bad data section
               'Smoothing'    'Utility'      'Erase'
```

	Pick line	Exit	Exit utility
	Exit smoothing		
00:08:30	Hang data sections		
	'Sectioning'	'Hang section'	'Double axis'
	Pick sect to hang		Pick ptset 1
	Rotate Z	Rotate X	Pick ptset 2
	Rotate X	Rotate Z	Rotate X
	Enter sta 1	'Mult'	Enter sta 2
	Enter incr	X-trans	Exit
	Exit sectioning		
00:08:47	Pick edit and reference lines		
	'Smoothing'	'Edit'	Pick ptset to edit
	'Process'		
00:09:34	Look at point coordinates		
	'Point'	'Coordinate'	Pick pt
	Exit	Exit point	Exit edit
	Exit smoothing		
00:11:23	Hang data sections		
	'Sectioning'	'Hang section'	'Double axis'
	Pick sect to hang		Rotate X
	Pick ptset 1	Rotate X	Pick ptset 2
	Enter sta 1	'Mult'	Enter sta 2
	Enter incr	Exit	Exit sectioning
00:11:42	Erase bad section		
	'Smoothing'	'Utility'	'Erase'
	Pick line	Exit	
00:12:03	Look at point coordinates		
	'Coordinate'	Pick pt	Exit
00:14:02	Look at drawing		
	Rotate X	X-trans	X-trans
	Rotate X	Rotate Z	Rotate X
	Exit utility	'Edit'	Pick ptset to edit
	Pick ref line	Pick ref line	Pick ref line
	Pick ref line	'Process'	'True view'
	Rotate X	Rotate Z	Z-trans
	Rotate Z	Rotate X	Exit edit
	Rotate X	Rotate Z	Exit smoothing
00:15:45	Hang data sections		
	'Sectioning'	'Hang section'	'Double axis'
	Pick sect to hang		Pick ptset 1
	Pick ptset 2	Enter sta 1	'Mult'
	Enter sta 2	Enter incr	Exit
	Exit	>Exit	Exit sectioning

***Check locations of sections

00:16:48	Check distance between 2 points		
	'Smoothing'	'Utility'	'Distance'
	Pick 1st pt	Pick 2nd pt	Exit
	Exit utility		
00:17:21	Pick edit and reference lines		
	'Edit'	'Pick ptset to edit	
	Pick ref line	Pick ref line	Pick ref line
	Pick ref line	'Process'	

```
00:18:00 Look at point coordinates
              'Point'          'Coordinate'    Pick pt
              Exit             Exit point      Exit edit
00:18:36 Pick edit and reference lines
              'Edit'           Pick ptset to edit
              'Process'
00:19:18 Look at point coordinates
              'Point'          'Coordinate'    Pick pt
              Exit             Exit point      Exit edit
              Exit smoothing
00:20:35 Pick edit and reference lines
              'Smoothing'      'Edit'          Pick ptset to edit
              'Process'
00:20:59 Look at point coordinates
              'Point'          'Coordinate'    Pick pt
              Exit             Exit point      Exit edit

***Erase all but one section created above
00:21:40 Erase bad sections
              'Utility'        'Erase'         Pick line
              Pick line        Pick line       Pick line
              Pick line        Pick line       Pick line
              Pick line        Pick line (didn't take)
              Pick line        Pick line       Exit
              Exit utility     Exit smoothing

***Copy remaining data section
00:24:07 Hang data sections
              'Sectioning'     'Hang section'  'Double axis'
              Pick sect to hang                Pick ptset 1
              Rotate X         Pick ptset 2    Rotate X
              Enter sta 1      'Mult'          Enter sta 2
              Enter incr       Exit            Exit sectioning

***Check locations of sections
00:24:23 Pick edit and reference lines
              'Smoothing'      'Edit'          Pick ref line
              'Process'
00:24:46 Look at point coordinates
              'Point'          'Coordinate'    Pick pt
              Exit             Exit point      Exit edit
00:25:00 Pick edit and reference lines
              'Edit'           Pick ptset to edit
              'Process'
00:25:30 Look at point coordinates
              'Point'          'Coordinate'    Pick pt
              Exit (missed)    Exit            Exit point
              Exit edit
00:25:43 Pick edit and reference lines
              'Edit'           Pick ptset to edit
              'Process'
00:26:07 Look at point coordinates
              'Point'          'Coordinate'    Pick pt
              Exit             Exit point      Exit edit
```

```
 00:26:24 Pick edit and reference lines
               'Edit'          Pick ptset to edit
               'Process'
 00:26:47 Look at point coordinates
               'Point'         'Coordinate'   Pick pt
               Exit            Exit (too soon)
               Exit point      Exit edit
 00:26:58 Pick edit and reference lines
               'Edit'          Pick ptset to edit
               'Process'
 00:27:55 Look at point coordinates
               'Point'         'Coordinate'   Pick pt
               Exit            Exit point     Exit edit
 00:28:07 Pick edit and reference lines
               'Edit'          Pick ptset to edit
               'Process'
 00:28:38 Look at point coordinates
               'Point'         'Coordinate'   Pick pt
               Exit            Exit (too soon)
               Exit point      Exit edit

***Erase lines not on a multiple of 50
 00:29:49 Erase bad lines
               'Utility'       'Erase'        Pick line
               Scale in        X trans        Rotate Z
               Pick line       Rotate X       ~Rotate Z
               X trans         Rotate X       ~Rotate Z
               Pick line       Exit           Exit utility

***Try to connect 3 sections to glove box opening
 00:30:13 Pick edit and reference
               'Edit'          Pick ptset to edit
               Pick ref line   Pick ref line  Pick ref line
               Pick ref line   'Process'
 00:30:29 Intersect 2 lines (left side)
               Rotate Z        Scale in       'True view'
               Rotate X        Rotate Y       Rotate Z
               'Mult'          Scale out      'Intersect'
               Pick proj view Pick line to proj onto
               Pick line to proj
 00:32:53 Intersect 2 lines (center - aborted)
               'True view'     Rotate Z       Z trans
               Rotate Z        Rotate X       Rotate Z
               Scale in        Rotate X       Rotate X
               'Mult'          Pick proj view
               Pick line to proj onto         Pick line to proj
               'True view'     Scale in       >Rotate Y
               Rotate X        'Mult'         Reset
               'Whoops'
 00:34:02 Intersect 2 lines (center - aborted)
               'True view'     Rotate X       Rotate Z
               'Mult'          >'Whoops'      Pick proj view
               Pick line to proj onto         Pick line to proj
               'True view'     Rotate Z
```

```
                "Doesn't seem to want to do it"
                'Mult'          'Whoops'
 00:34:51 Intersect 2 lines (right side)
                Pick proj view Pick line to proj onto
                Pick line to proj               Rotate Z
                Cue data        Scale in        Scale out
                "The center one doesn't want to work"
 00:35:34 Intersect 2 lines (center)
                Pick proj view Pick line to proj onto
                Pick line to proj               Rotate Z
                Exit

***Demonstrate use of reference lines
 00:37:18 Show observer use of reference lines
                'Plan view'     'Mult'          Ref lines on
                Ref lines off   Ref lines on    Ref lines off
                'Point'         'Insert'        Pick loc
                'Whoops'        Exit            Exit point

***Try to connect center section to glove box opening
 00:38:18 Pull point to line
                'Pull'          'Rear view'     Pick 1st tan
                Pick 2nd tan    'Mult'          'Plan view'
                Pick pt to be pulled            Pick final loc
                'Mult'          'Rear view'     'Zoom'
                Pick URH crnr   Pick LLH crnr   >'Point'
                Exit
 00:39:27 Kill point (aborted)
                'Point'         'Kill point'    Pick pt
                'Whoops'        Scale out       'Mult'
                Scale in/out    >'Whoops'       Exit
                Exit point
 00:39:48 Pull point to line
                'Pull'          Pick 1st tan    Pick 2nd tan
                Pick pt to be pulled            Pick final loc
 00:40:45 Pull point to line (aborted)
                Scale in        Z trans         Pick 1st tan
                Z trans         Pick 2nd tan    Z trans
                Scale in/out    Ref lines off
                Pick pt to be pulled            Scale out
                Pick final loc 'Whoops'
 00:41:20 Pull point to line (aborted)
                Pick 1st tan    Pick 2nd tan    Scale in
                Pick pt to be pulled            Scale out
                Pick final loc 'Whoops' (too soon)
                'Whoops'
 00:41:54 Pull point to line (incomplete - aborted later)
                Pick 1st tan    Pick 2nd tan
                Pick pt to be pulled
                "Trying to pull out to get a good line there"
                "  I'm not sure how i'm going to get there yet"
                Pick final loc
 00:42:57 Demonstrate Term and Graph keys, finish pull
                Turn term on    Turn term off   Turn graph off
```

Turn term on   Turn term off   Turn graph on
'Whoops'   Turn term on   Turn graph off
Turn graph on   Turn term off   Exit pull

00:43:29 Execute fillet
'Fillet' (didn't take)
"Let's try something else, I guess"
'Fillet'   Pick 1st tan   Pick 2nd tan
"Looks like that did it" (didn't)
'Ok'   Pick thin tol

***Smooth upper right corner of glove box opening
00:45:12 Execute fillet
Explain thinning tolerance to observer
X trans   Y trans   Z trans
Z trans   Scale out   'Plan view'
Scale out   'Mult'   'Rear view'
>'Point'   >'Whoops'   'Mult'
'Rear view'   Pick 1st tan   Pick 2nd tan
'Ok'   Pick thin tol   Exit

***Remove points to flatten top line of glove box opening
00:47:03 Kill data section
'Mult'   'Point'   'Kill special'
Pick 1st pt   Pick 2nd pt   'Rear view'
'Whoops'   Pick 1st pt   Pick 2nd pt
Ref lines off   'Mult'   Rotate Z
>Rotate X   Rotate Y   Exit
Exit point

***Try to connect center section to glove box opening
00:47:47 Intersect 2 lines
'Intersect'   Pick proj view
Pick line to proj onto   Pick line to proj
Rotate Y   Rotate Z   Rotate Y
"Looks like we've got it now"
Rotate Y
"Don't know why it wouldn't do it before"
Exit

00:49:08 Check to see if it intersected
'True view'   Rotate Z   Rotate X
Rotate Z   >Rotate Y   Rotate X
>Rotate Y   Rotate Z   'Mult'
'Plan view'   'Zoom'   Pick URH crnr
Pick LLH crnr   'Mult'   Scale out
Scale out   'Rear view'   'Zoom'
Pick URH crnr   Pick LLH crnr

***Smooth upper left corner of glove box opening
00:50:28 Execute fillet
'Fillet'   Pick 1st tan   Pick 2nd tan
Dots on   'Whoops'   Pick 1st tan
Pick 2nd tan   'Zoom'   Pick URH crnr
Pick LLH crnr   Scale out   Y trans
Adj fullness   'Ok'   Pick thin tol

***Smooth lower right corner of glove box opening
00:52:45 Execute fillet
'Mult'   Ref lines off   Reset
'Rear view'   Pick 1st pt   Pick 2nd pt
Adj fullness   'Ok' (didn't take)
'Ok'   Pick thin tol   'Mult'
'Side view'   'Zoom'   Pick URH crnr
Pick LLH crnr   Scale out   Exit
Exit edit   Exit smoothing

***Try to hang depth of opening off other two sections
00:53:51 Hang data sections
'Sectioning'   'Hang'   'Double axis'
Pick sect to hang   Pick ptset 1
Pick ptset 2   Enter sta 1   'Mult'
Enter sta 2   Enter incr
"Sections are the same (reading message)
Exit
00:54:42 Xhang data sections
'Xhang'
"Let's see what this does"
Pick sect to hang   Pick pt
Pick pt   Enter sta 1   'Double'
Enter sta 2   Enter incr   Exit
00:55:31 Hang data sections
'Hang'   'Single'
"Maybe this is a single, I don't know"
Pick sect to hang   Pick ptset 1
Pick ptset 2   Enter sta 1   'Mult'
Enter sta 2   Enter incr   Exit
Exit sectioning

***Copy of depth of opening to other sections using 2 pt move
00:56:32 Execute 2-point move
'Smoothing'   'Utility'   '2-pt move'
Pick ptset to move   ~Scale in
X trans   >Scale in/out   X trans
~Rotate Z   Y trans   X trans
Pick from pt   Pick to pt   Exit
00:57:43 Erase line (aborted)
'Erase'   Pick line   Scale out
X trans   Rotate Z   Scale in
Z trans   Rotate X   Rotate Z
'Whoops'   Scale out   Exit
Exit utility
00:58:26 Pick edit and reference lines (aborted)
'Edit'   Pick ptset to edit
Pick ref line   Pick ref line   Pick ref line
'Process'   'True view'   Rotate Z
Exit
00:58:49 Erase line
'Utility'   'Erase'   ~Scale in

X trans   Scale in   X trans
Pick line   Exit   Exit utility
00:59:14 Execute 2-point move (successful on left section)
'2-pt move'   Pick ptset to move
Pick from pt   Scale in   X trans
~Rotate Z   Pick to pt
00:59:51 Execute 2-point move (successful on right section)
Pick ptset to move   Pick from pt
Pick to pt   Exit   Exit utility

***Check it
01:00:08 Pick edit and reference lines
'Edit'   Pick ptset to edit
Pick ref line   Pick ref line   'Process'
01:01:00 Intersect 2 lines (aborted)
'True view'   'Mult'   'Intersect'
Exit   'Intersect'   Exit

***Try to connect new sections to opening (small gap)
01:01:24 Insert 2 pts
'Point' (too soon)   'Point' (too soon)
'Point'   'Insert'   Pick pt
Pick pt   Exit   Exit point
01:02:12 Intersect 2 lines
'Intersect'   Pick proj view
Pick line to proj onto   Pick line to proj
'True view'   Rotate Z   Exit
01:02:36 Kill 2 points
'Mult'   'Point'   'Kill'
Pick pt   Pick pt   Exit
01:02:56 Insert point
'Insert'   Pick pt   Exit
Exit point
01:04:01 Intersect 2 lines (aborted)
'Intersect'   Pick proj view Exit
>'Whoops'   >'Whoops'   Exit
Exit edit
01:04:07 Pick edit and reference lines
'Edit'   Pick ptset to edit
Pick ref line   'Process'
01:04:38 Kill point
'Point'   'Kill'   'Rear view'
Pick pt   Exit   Exit point
Exit edit
01:04:52 Pick edit and reference lines
'Edit'   Pick ptset to edit
Pick ref line   'Process'
01:05:19 Intersect 2 lines
Scale out   'Intersect'
Pick proj view (didn't take)   Pick proj view
Pick line to proj onto   Pick line to proj
01:05:39 Intersect 2 lines
Pick proj view Pick line to proj onto
Pick line to proj

```
01:06:19 Intersect 2 lines
               Pick projection view
               "My wrist is getting tired"
               Pick line to proj onto        Pick line to proj
01:06:47 Intersect 2 lines
               Pick proj view Pick line to proj onto
               Pick line to proj             'True view'
               Rotate Z       Exit
01:07:26 Kill 4 points
               'Point'        'Mult'         'Kill'
               Pick pt        Pick pt        'Side view'
               Pick pt        Pick pt        Exit
               Exit point     Exit edit

***Finish up
01:07:39 Terminate session
               Reset          Rotate Z       Rotate X
               Quit
```

- APPENDIX D - DATA FROM SECOND TAPING SESSION -

APPENDIX E - RESULTS FROM VIDEO TAPE ANALYSIS

Below are the accumulated counts, times, and errors associated with each type of event studied.

Key:

- f — Frequency - number of times event occurred.
- t — Time - total time for event.
- e — Error - number of times errors occurred for this event.
- ave — Average time to do event (in seconds)

	TAPE1				TAPE2				BOTH			
Event	f (#)	t (s)	e (#)	ave (s/ev)	f (#)	t (s)	e (#)	ave (s/ev)	f (#)	t (s)	e (#)	ave (s/ev)
PICKS:												
Pick corner	38	104	0	2.7	10	22	0	2.2	48	126	0	2.6
Pick line	23	93	1	4.0	65	253	1	3.9	88	346	2	3.9
Pick location	12	83	0	6.9	6	31	0	5.2	18	114	0	6.3
Pick mult	4	39	0	9.8	1	4	0	4.0	5	43	0	8.6
Pick point	72	354	5	4.9	44	183	0	4.2	116	537	5	4.6
Pick pointset	17	105	0	6.2	35	127	0	3.6	52	232	0	4.5
Pick section	0	0	0	0.0	10	46	0	4.6	10	46	0	4.6
Pick tangent	52	314	0	6.0	18	79	0	4.4	70	393	0	5.6
Pick view	12	58	0	4.8	40	247	1	6.2	52	305	1	5.9
Pick zoom	19	148	0	7.8	5	19	0	3.8	24	167	0	7.0
ALL PICKS:	249	1298	6	5.2	234	1011	2	4.3	483	2309	8	4.8
SELECTS:												
Select 2 pt move	2	23	0	11.5	2	8	0	4.0	4	31	0	7.8
Select 3 pt conic	1	6	0	6.0	0	0	0	0.0	1	6	0	6.0
Select balance	1	7	0	7.0	0	0	0	0.0	1	7	0	7.0
Select coordinate	2	8	0	4.0	12	40	0	3.3	14	48	0	3.4
Select distance	0	0	0	0.0	1	5	0	5.0	1	5	0	5.0
Select double	0	0	0	0.0	1	4	0	4.0	1	4	0	4.0
Select double axis	0	0	0	0.0	7	27	0	3.9	7	27	0	3.9
Select edit	10	43	0	4.3	17	119	0	7.0	27	162	0	6.0
Select erase	4	20	0	5.0	6	24	0	4.0	10	44	0	4.4
Select exchange	1	11	0	11.0	0	0	0	0.0	1	11	0	11.0
Select fillet	15	75	0	5.0	3	9	1	3.0	18	84	1	4.7
Select hang	0	0	0	0.0	8	32	0	4.0	8	32	0	4.0
Select insert	4	14	0	3.5	3	8	0	2.7	7	22	0	3.1
Select insert arc	8	48	1	6.0	0	0	0	0.0	8	48	1	6.0
Select intersect	2	22	0	11.0	7	24	0	3.4	9	46	0	5.1
Select join lines	2	9	0	4.5	0	0	0	0.0	2	9	0	4.5
Select kill	3	7	0	2.3	4	14	0	3.5	7	21	0	3.0
Select kill special	2	7	0	3.5	1	3	0	3.0	3	10	0	3.3
Select move to	4	17	0	4.3	0	0	0	0.0	4	17	0	4.3
Select multiple	0	0	0	0.0	28	159	0	5.7	28	159	0	5.7
Select non-balance	13	75	0	5.8	0	0	0	0.0	13	75	0	5.8
Select not ok	3	32	0	10.7	0	0	0	0.0	3	32	0	10.7
Select ok	18	119	0	6.6	5	15	1	3.0	23	134	1	5.8
Select on line	1	4	0	4.0	0	0	0	0.0	1	4	0	4.0
Select point	11	49	0	4.5	22	142	4	6.5	33	191	4	5.8
Select process	8	38	0	4.8	17	58	0	3.4	25	96	0	3.8
Select pull	4	70	1	17.5	2	5	0	2.5	6	75	1	12.5
Select sectioning	0	0	0	0.0	7	25	0	3.6	7	25	0	3.6
Select single	0	0	0	0.0	2	9	0	4.5	2	9	0	4.5
Select smoothing	0	0	0	0.0	8	34	0	4.3	8	34	0	4.3
Select thin. tol.	18	49	0	2.7	4	12	0	3.0	22	61	0	2.8
Select utility	5	17	0	3.4	7	43	0	6.1	12	60	0	5.0
Select whoops	12	151	0	12.6	20	132	1	6.6	32	283	1	8.8
Select xhang	0	0	0	0.0	1	5	0	5.0	1	5	0	5.0
ALL SELECTS:	154	921	2	6.0	195	956	7	4.9	349	1877	9	5.4

- APPENDIX E - RESULTS FROM VIDEO TAPE ANALYSIS -

DIALS:*												
Adjust fullness	17	207	0	12.2	2	27	0	13.5	19	234	0	12.3
Cue data	1	5	0	5.0	1	5	0	5.0	2	10	0	5.0
Rotate X	8	24	0	3.0	31	157	1	5.1	39	181	1	4.6
Rotate Y	7	21	1	3.0	12	39	4	3.3	19	60	5	3.2
Rotate Z	12	86	1	7.2	35	221	5	6.3	47	307	6	6.5
Scale in	17	107	7	6.3	15	83	3	5.5	32	190	10	5.9
Scale out	22	165	6	7.5	15	120	0	8.0	37	285	6	7.7
Scale in/out	0	0	0	0.0	3	17	2	5.7	3	17	2	5.7
X trans	9	22	0	2.4	14	110	0	7.9	23	132	0	5.7
Y trans	15	51	0	3.4	3	5	0	1.7	18	56	0	3.1
Z trans	8	30	0	3.8	8	30	0	3.8	16	60	0	3.8
ALL DIALS:	116	718	15	6.2	139	814	15	5.9	255	1532	30	6.0
FUNCTION KEYS:**												
Dots off	2	16	0	8.0	0	0	0	0.0	2	16	0	8.0
Dots on	2	20	0	10.0	1	3	0	3.0	3	23	0	7.7
Exterior off	2	3	0	1.5	0	0	0	0.0	2	3	0	1.5
Exterior on	3	14	0	4.7	0	0	0	0.0	3	14	0	4.7
Graph off	0	0	0	0.0	2	2	0	1.0	2	2	0	1.0
Graph on	0	0	0	0.0	2	3	0	1.5	2	3	0	1.5
Hit reset	9	48	0	5.3	3	12	0	4.0	12	60	0	5.0
Reference off	24	145	0	6.0	5	33	0	6.6	29	178	0	6.1
Reference on	26	149	0	5.7	2	40	0	20.0	28	189	0	6.8
Terminology off	0	0	0	0.0	3	18	0	6.0	3	18	0	6.0
Terminology on	0	0	0	0.0	3	21	0	7.0	3	21	0	7.0
ALL FUNCTION KEYS:	68	395	0	5.8	21	132	0	6.3	89	527	0	5.9
OTHER EVENTS:												
Begin***	1	0	0	0.0	1	0	0	0.0	2	0	0	0.0
Exit	79	620	0	7.8	116	803	5	6.9	195	1423	5	7.3
Decide/discuss	24	443	0	18.5	1	58	0	58.0	25	501	0	20.0
Enter station	1	5	0	5.0	0	0	0	0.0	1	5	0	5.0
Select yes	1	3	0	3.0	0	0	0	0.0	1	3	0	3.0
Select VAX	1	2	0	2.0	0	0	0	0.0	1	2	0	2.0
Enter file name	1	14	0	14.0	0	0	0	0.0	1	14	0	14.0
Enter station 1	0	0	0	0.0	9	113	0	12.6	9	113	0	12.6
Enter station 2	0	0	0	0.0	9	69	0	7.7	9	69	0	7.7
Enter increment	0	0	0	0.0	8	28	0	3.5	8	28	0	3.5
Explain thin. tol.	0	0	0	0.0	1	16	0	16.0	1	16	0	16.0
ALL OTHERS:	108	1087	0	10.1	145	1087	5	7.5	253	2174	5	8.6
Total	695	4419	23	6.4	734	4000	29	5.4	1429	8419	52	5.9

* Thinning tolerance determines the number of points to be placed along the arc created by a fillet. During the 2 taping sessions, the third choice (of three) was chosen to get the maximum number of points along the arc.

** Description of knob actions:

Adjust fullness adjust the arc created during a fillet.

Cue data (also called hidden line removal) adjusts the distance at which the data fades from view.

Rotate x (rotate y, rotate z) is short for rotate around x (y,z) axis. The x axis is horizontal on the screen, the y axis is vertical and the z axis is in and out of the screen.

Scale in (scale out) brings the point of view closer to (farther from) the drawing. This is not the same as zooming, which makes the data larger but does not move it closer.

Scale in/out is a sequence of scale ins and scale outs done quickly in which the end position of the data is the same as the starting position.

X trans (y trans, z trans) is short for translate x (y,z), i.e., move along the x (y,z) axis.

*** Description of function keys:

Dots off (dots on) hide (show) the individual data points on the lines.

Exterior off (exterior on) removes (shows) the data mirrored around the center line of the drawing.

Graph off (graph on) removes from (shows on) the display the graph of the data.

Hit reset resets the point of view by undoing all scaling, rotating, translating, zooming, and view choices.

Reference off (reference on) turns the reference lines off (on). The reference lines are point sets chosen when the smoothing-edit menu option is selected.

Terminology off (terminology on) removes (displays) the names of the programs and routines being executed by the CAD system to display the graph and perform the current functions.

**** Although begin is not a specific event and has no elapsed time associated with it, it is included in this appendix because it represents a significant occurrence during the session.