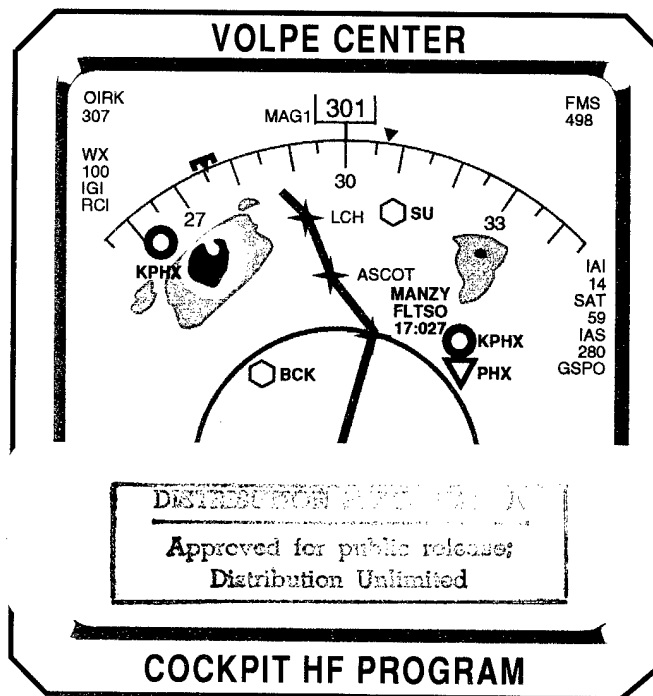




DOT/FAA/AAR-100-98-1
DOT-VNTSC-FAA-98-2

Office of Aviation Research
Washington, DC 20591

Terrain Display Alternatives: Assessment of Information Density and Alerting Strategies



U.S. Department of Transportation
Research and Special Programs Administration
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142

Final Report
April 1998

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
April 1998

3. REPORT TYPE AND DATES COVERED
Final Report
June 1996 - September 1997

4. TITLE AND SUBTITLE
Terrain Display Alternatives: Assessment of Information Density and Alerting Strategies

5. FUNDING NUMBERS
A8123/FA8E2

6. AUTHOR(S)
Melissa Bud,* Mary Stearns, Peter Mengert*

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
Research and Special Programs Administration
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142-1093

8. PERFORMING ORGANIZATION
REPORT NUMBER
DOT-VNTSC-FAA-98-2

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
Federal Aviation Administration
Research and Development Service
800 Independence Ave. S.W.
Washington DC 20591

10. SPONSORING/MONITORING
AGENCY REPORT NUMBER
DOT/FAA/AAR-100-98-1

11. SUPPLEMENTARY NOTES
*EG&G Services

12a. DISTRIBUTION/AVAILABILITY STATEMENT
This document is available to the public through the National Technical Information Service, Springfield, VA 22161

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
Current technology makes it possible to display navigation and terrain information on electronic screens in the cockpit. The conventions used for position and terrain information must be clearly presented so pilots can maintain their positional awareness and avoid collision with terrain. There are very few recommendations or guidelines available for the design and evaluation of electronic displays.

The Volpe National Transportation Systems Center (Volpe Center), in support of the Federal Aviation Administration's (FAA's) Office of the Chief Scientific and Technical Advisor for Human Factors, AAR-100, conducted a series of experiments to explore human factors issues in depicting terrain on electronic displays. Experiments examined instrument-rated General Aviation (GA) pilots' ability to interpret terrain shown on electronic plan view displays in a flight simulator. The four experiments examined the following electronic display alternatives: the utility of presenting nonthreatening terrain during approaches; effectiveness of showing only terrain features for terrain avoidance; preferences for information density; and the utility of terrain displays paired with visual terrain alerts. Results suggest display designs should incorporate alerts that identify danger and reorient pilots. Electronic displays with terrain that incorporate these recommendations should diminish the number of accidents resulting from a loss of positional awareness, such as controlled-flight-into-terrain (CFIT) accidents.

14. SUBJECT TERMS
avionics, controlled-flight-into terrain (CFIT) accidents, cross track error (XTE), electronic displays, terrain display

15. NUMBER OF PAGES
54

16. PRICE CODE

17. SECURITY
CLASSIFICATION
OF REPORT
Unclassified

18. SECURITY
CLASSIFICATION
OF THIS PAGE
Unclassified

19. SECURITY
CLASSIFICATION
OF ABSTRACT
Unclassified

20. LIMITATION OF
ABSTRACT

PREFACE

Electronic display technology is a recent development offering many possibilities for visual representations of terrain information. Electronic displays of terrain information have the potential to increase pilot positional awareness and to aid in terrain avoidance. This report describes a series of four experiments conducted to identify human factors issues associated with presenting terrain information on electronic displays. The experimental results provide information to pilots, aviation regulators, and display designers to help them ensure that this new technology is used effectively to improve aviation safety.

The experimental research was performed in the Cockpit Human Factors laboratory located at the Volpe National Transportation Systems Center (Volpe Center). In the experiments, researchers examined electronic display presentations, positional awareness, terrain alerts, and terrain avoidance.

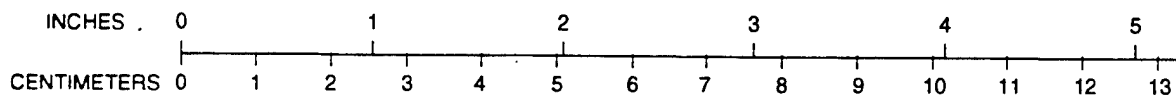
The authors would like to thank the many people who were integral to the completion and success of this sequence of experiments: Dr. Daniel J. Hannon designed the experiments and provided guidance during experimentation and analyses; Stephen Ransom, EG&G Services, and Jonathan Baxter contributed to the design, testing, and analyses; and Frank Sheelen, W.T. Chen, designed the software used in these experiments and provided technical and computer support throughout the experimental process.

The authors would also like to acknowledge their FAA sponsors: Dr. Maureen Pettitt, Chief Scientific and Technical Advisor for Human Factors and Dr. Eleana Edens, manager of the Cockpit Human Factors Program, AAR-100, for their guidance and support of this work.

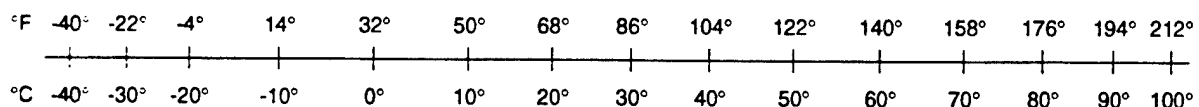
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EXECUTIVE SUMMARY

Current technology makes navigation and terrain information available on electronic display screens in the cockpit. This information must be presented clearly for pilots to maintain positional awareness and to avoid collision with terrain. However, there are few recommendations or guidelines as to how electronic displays of information should be designed or evaluated.

Electronic displays present enhanced information to the pilot which may help to reduce the accident rate in General Aviation (GA) flight. For example, in the United States from 1983 to 1994, Controlled-Flight-Into-Terrain (CFIT) incidents accounted for 32% of the GA accidents in instrument weather conditions.¹ Enhanced real-time positional information on electronic displays might help to prevent collisions with terrain.

The Volpe National Transportation Systems Center (Volpe Center), under the sponsorship of the Federal Aviation Administration's (FAA's) Office of the Chief Scientific and Technical Advisor for Human Factors, AAR-100, conducted a series of interrelated experiments to explore the human factors issues in depicting terrain on electronic displays. The series of experiments examined instrument-rated GA pilots' ability to interpret terrain depicted on electronic plan view displays using a flight simulator.

Because the resolution of electronic display screens causes a disproportionate relationship between the airplane symbol and the terrain features, the initial experiment examined the utility of displaying nonthreatening terrain to pilots during approaches. Participants flew the approaches accurately and did not veer off course despite the disproportionate size of the airplane symbol relative to terrain features.

Terrain elevation information, presented on a supplemental plan view display, might prove useful to detect and avoid dangerous terrain. In the second experiment, pilots failed to make use of the terrain information presented on an electronic display. When they were presented with a display showing only terrain features, pilots showed heightened awareness to terrain but not enough to take corrective action. When the display presented showed navigation and terrain information, pilots failed to detect the dangerous terrain.

The third experiment measured pilots' preferences for information density on plan view electronic displays. Despite findings that pilots may better recognize potential obstacles using displays with a lower density of information, participants preferred the displays with higher content levels.

Visual alerts may enhance the interpretability of electronic plan view displays. In the final experiment, pilots used an electronic display paired with a visual terrain alert. Using alternate

¹ Bud, M., Mengert, P., Ransom, S., and Stearns, M.D. General Aviation Accidents, 1983-1994: Identification of Factors Related to Controlled-Flight-Into-Terrain (CFIT) Accidents. Final Report DOT-VNTSC-FAA-97-8. May 1997.

map formats, the pilots were measured to see how well they interpreted these displays to obtain terrain elevation information when there was a potential problem. The map formats varied in terms of density of terrain and navigation information. The pilots were able to interpret the displays with equal facility regardless of the map format.

This series of experiments addressed several human factors issues associated with presenting terrain information on electronic displays. The summation of these points is that terrain information on electronic displays helps pilots to avoid terrain if combined with a terrain alerting system, regardless of the information density of the map. These results suggest that designs for display formats should incorporate alerts to make pilots aware of danger and reorient them quickly. Display formats that incorporate these recommendations should contribute to a reduction in the number of accidents which result from a loss of positional awareness, such as CFIT accidents. Further research into information presentation options and systems and the benefit of training is needed.

1. INTRODUCTION

Current technology consolidates navigation and safety information, such as weather and traffic, on electronic display screens in the cockpit. The information displayed must be clear to allow pilots to maintain positional awareness and avoid collision with terrain. However, there are few recommendations or guidelines available on how to design or evaluate the acceptable display configurations.

Electronic displays also incorporate additional information that, until recently, could not be presented. This increased information available to the pilot may contribute to reducing the General Aviation (GA) accident rate. Because research has shown the unchanged incidence of Controlled-Flight-Into-Terrain (CFIT) accidents in GA operations (32% in instrument conditions from 1983 to 1994²), the Volpe Center and the Federal Aviation Administration's (FAA's) Office of the Chief Scientific and Technical Advisor for Human Factors, AAR-100, conducted experiments to examine the potential value of, and issues in, consolidating and depicting additional information using electronic displays.

2. PURPOSE

Technological development in avionics, specifically in electronic display screens, computer technology, and memory processors, is expanding rapidly and the human factors issues that are inherent in these technologies warrant examination. The Volpe Center, under the sponsorship of the FAA's AAR-100, conducted a series of experiments to examine how quickly and accurately pilots are able to interpret alternative presentations of information on electronic display screens.

3. PROCEDURES

3.1 PARTICIPANTS

Participants in the experiments were general aviation (GA) pilots with multi-engine and instrument ratings. The pilots were recruited from the Subject Database maintained at the Center for Human Factors Research at the Volpe National Transportation Systems Center (Volpe Center) and from fliers posted at local airports.³

² Bud, M., Mengert, P., Ransom, S., and Stearns, M.D. General Aviation Accidents, 1983-1994: Identification of Factors Related to Controlled-Flight-Into-Terrain (CFIT) Accidents. Final Report DOT-VNTSC-FAA-97-1. May 1997.

³ Due to the time (a minimum of four hours per participant) and cost requirements with pilot participants, sample sizes were kept small. Although these sample sizes were not large enough to provide significant statistical power, they were considered adequate for identifying trends in the data.

3.2 APPARATUS

The Center for Human Factors Research at the Volpe Center maintains a Frasca 242 light twin engine instrument flight simulator which was used for these experiments. This simulator is a fixed-base training device reconfigured and instrumented for data collection. It did not have an outside the window (OTW) display at the time of these experiments.

The flight dynamics of the simulator were designed to resemble a Piper Aztec. (Appendix A-1 shows the Frasca 242 simulator.) There is a picture window in the wall behind the simulator which permitted the researchers to observe the pilot during testing. Researchers also observed the pilot on a television monitor located outside the simulator room using a closed-circuit television. During the experiments, researchers communicated with the pilots using a standard aircraft intercom system with headsets.

Flight instruments in the Frasca are arranged in the standard T formation in front of the pilot's seat. The avionics stack is directly in front of the copilot's seat. The electronic display screen is in the position of the center avionics stack in a Piper Aztec. The electronic display screen measures 8.5-in wide by 6.5-in high with multi-functional buttons along the bottom and right-hand side of the screen. A diagram of the flight instrument panel, including the electronic display, is presented in Appendix A-2.

The Volpe Center developed software programs to simulate flight and to produce the maps presented on the electronic display screen. The maps were shown on a plan view display in the upper left hand corner of the screen, measuring approximately 4.5-in wide by 5-in high.

3.3 ELECTRONIC DISPLAY FORMATS

The electronic display formats used in this series of experiments were consistent in size, color attributes, and symbology. Terrain was displayed in one of two ways: as green contour lines of uniform color on a black background with green elevation labels on the lines or as solid, stacked polygons in a range of greens—dark greens for the lowest elevations to light greens or yellow for the highest elevations. Elevation labels were placed within the solid polygon.

Both terrain presentations used similar conventions to describe elevation. For the contour lines, the maximum elevation, above mean sea level (MSL), for the area between two bounding lines, was described by the lower of the two elevation labels. For the solid contour shapes, the maximum elevation, above mean sea level, for an area of a certain color, was described by the elevation label within that polygon.

Navigation information on the electronic display screen employed formats consistent with previous research using the Frasca simulator.⁴ Purple lines indicated airways. Global

⁴ Hannon, D.J., and Huntley, M.S., Jr. Electronic Depiction of Instrument Approach Procedure (IAP) Charts. Phase I: Development and Preliminary Evaluation. Final Report DOT-VNTSC-FAA-95-14. May 1995.

Positioning System (GPS) waypoints, VORs, and intersections were presented in white and labeled with the appropriate identifiers. Runways were indicated with a yellow line that was thicker than the airway lines. Labels were shown in capital letters.

The airplane shape, shown in yellow, was the same size in all experiments. Information on the screen moved relative to the airplane's course changes. For north-up oriented maps, the airplane symbol moved along the map until it reach an edge of the screen. The map would update and the airplane would appear in the middle of the screen with corresponding terrain and navigation information. For track-up (inside-out) oriented maps, the airplane symbol remained heading up and, in a constant position, near the bottom of the screen, and centered horizontally.

3.4 PROTOCOL

Procedural protocols were reviewed and approved by the MIT Committee on the Use of Human Subjects. Accordingly, pilots signed an informed consent form and filled out an information sheet prior to research and were debriefed at completion of the study.

4. TERRAIN DEPICTIONS AND NAVIGATIONAL ACCURACY

Electronic displays with terrain depictions could be useful for navigation when there is potentially dangerous terrain and, consequently, a requirement for a high degree of flight accuracy on approach. The purpose of the first experiment was to determine whether electronic displays of terrain affect the pilot's navigational performance during instrument approaches. Previous research has suggested that providing aircraft position information, relative to the terrain, increases pilot accuracy when compared to a display with no position information.⁵ However, if the pilot does not recognize that, based on space and pixel limitations of the display, the scale of terrain depictions, relative to other symbols, i.e., airplane symbol, is disproportionate, a pilot might tend to overcorrect his or her track to avoid terrain.

The experimental question was, is pilots' cross track error (XTE) more likely to deviate from the flight path when they use maps with terrain features as compared with maps without terrain features? Variation in XTE would indicate that pilots deviated from their intended course due to terrain representations which are not in scale with the aircraft symbol. (XTE is measured as the perpendicular lateral distance of the airplane's actual location to the course line.)

4.1 PROCEDURE

Participants in this experiment flew three fictional GPS approaches, two of which had corresponding electronic displays. Appendix B-1 shows an example of the electronic approach display used in this experiment. The participants were aided by maps on the electronic display screen and corresponding paper instrument approach charts when they flew these approaches. The paper instrument approach charts created for this experiment were similar in format and information to National Oceanic and Atmospheric Administration (NOAA) or Jeppesen approach charts (Appendix B-2 shows a paper approach chart used in this experiment).

The three approaches had similar geometry (turn angles, rate of descent, rate of ascent) but varied in headings and elevations. These approaches showed mountain peaks at four relevant positions: on an initial approach turn, adjacent to the final approach leg, adjacent to the missed approach leg, and on the missed approach turn. The approach used as a baseline, to establish flight technical ability, only differed in that it did not present terrain information or use an electronic display.

The four target terrain features on each of the two experimental approach were positioned close to the course line and in conformance with Terminal Instrument Procedures (TERPS) minimum clearances. The electronic charts were drawn such that terrain contours were close to, but did not cross, the flight path. The terrain features had a lower elevation than the closest anticipated point

⁵ Amar, M.J., Hansman, Jr., R.J., Hannon, D.J., Vaneck, T.W., and Chaudhry, A.I. A Human Subject Evaluation of Airport Surface Situational Awareness Using Prototypical Flight Deck Electronic Taxi Chart Displays. Final Report DOT-VNTSC-FAA-95-36 (DOT/FAA/AR-95/103). November 1995.

on the flight path. Position of the terrain, relative to the course line (left or right), varied between the two approaches.

Participants flew all approaches from the initial approach fix to the end of the published missed approach procedure under IFR conditions and were instructed to maintain certain aircraft performance measures and to perform the normal activities of an approach procedure. (Participants used the Flight Checklist shown in Appendix B-3.) Participants were given unlimited practice flight time to become familiar with the simulator.

When the participants felt comfortable, they flew six trials (i.e., a practice approach, two baseline approaches, and three experimental approaches). Table 4-1 shows the sequence of trials as well as the navigation and terrain information shown on the electronic display. Participants' XTE was measured for all approaches.

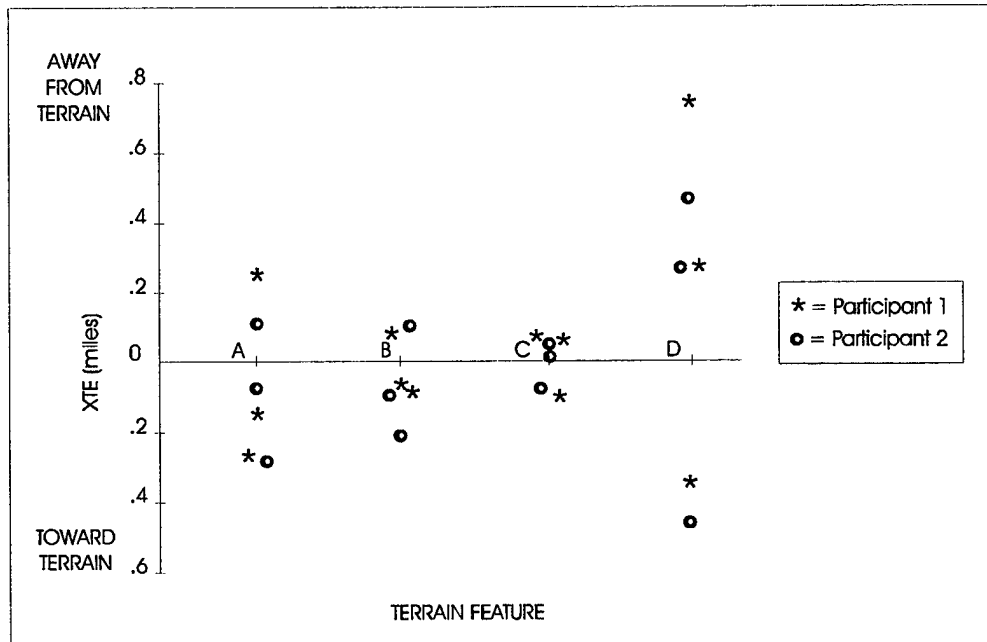
Table 4-1. Sequence of trial presentation for approaches by information on the electronic display.

Trial Number	Approach	Approach	Information Shown on Electronic Display
	Subject 1	Subject 2	
Practice	Experimental Approach 1	Experimental Approach 2	None
1	Baseline Approach	Baseline Approach	None
2	Experimental Approach 2	Experimental Approach 1	Terrain
3	Experimental Approach 1	Experimental Approach 2	Terrain and navigation
4	Experimental Approach 2	Experimental Approach 1	Terrain and navigation
5	Baseline Approach	Baseline Approach	None

The participants were debriefed after completing six trials and were asked for their reactions to the electronic charts. The Post-Flight Questionnaire used in the debriefing is in Appendix B-4.

4.2 RESULTS

The mean XTE for each participant's baseline approach flights was within requirements for flight competency. The maximum baseline XTE occurrence was 0.5 miles, but XTE was most often less than 0.1 miles. For the experimental approaches, the maximum occurrence of XTE was 0.745 miles, which is also within requirements for flight competency. Figure 4-1 shows a scatter plot of the XTE at the obstacle points (labeled A, B, C, and D) for participants flying the experimental approaches. Participants had the opportunity to use an electronic moving map display when flying these approaches.



**Figure 4-1. Flight cross track error (XTE) at each obstacle point across trials.
(Obstacle points located at A, B, C, and D)**

The XTE at the obstacle points reveals that the participants were as likely to err toward the terrain as away from it (24 incidents; 12 toward, 12 away). The XTE is evenly distributed about the flight path with no skew. In debriefing, participants reported that they did not find the terrain information on the display useful for making the approaches. The debriefing results corroborate the XTE results. The participants used the map display as a navigation aid for heading, elevation, and distance information, or as a reference for position relative to course line.

4.3 DISCUSSION

Use of terrain depictions on electronic displays was not associated with flight performance in this experiment. Participants did not alter their flight path systematically when the electronic display showed their airplane symbol flying near nonthreatening terrain depictions. Since the safe terrain did not negatively impact navigation, further research is warranted to examine issues related to avoidance of dangerous terrain.

5. DETECTING AND USING POSITION INFORMATION

Before advocating the use of electronic displays for terrain avoidance, it is necessary to know how readily pilots can interpret terrain information from supplemental electronic displays. In this experiment, participants were routed off their original airway toward terrain that was at a higher elevation than the aircraft. The experimental scenario made it difficult for participants to avoid terrain impact if they used only the standard flight instruments and paper charts. The supplementary electronic display presented relative position information that made it easier to detect the dangerous terrain. If the pilots did not use the terrain and position information on the electronic display, the rerouting in the scenario would cause them to impact terrain.

5.1 PROCEDURE

In addition to holding instrument and multi-engine ratings, more than half of the twelve participants held Commercial and ATP ratings and three were Certified Flight Instructors (CFI). The mean age of the eleven men and one woman participants was 52 years (SD = 17). Table 5-1 shows participants' flight experience.

Table 5-1. Participants' flight experience.

Total Flight Hours (in hours)	Instrument Flight Hours (in hours)	Time Since Last Flight (in days)
Range = 586-17,000 Mean = 3,120 (SD = 5,290)	Range = 70-10,000 Mean = 1,625 (SD = 2,964)	Median = 6

Participants were assigned to one of three Map Conditions and asked to carry out a simulated flight to Albany, NY. Four pilots were randomly assigned to each of the three Map Conditions. The descriptive statistics for the participants in each of the three Map Conditions are show in Table 5-2.

Table 5-2. Participants' age and flight hours by Map Condition.

Map Conditions	Age (in years)	Total Flight Hours (in hours)	Instrument Flight Hours (in hours)
Map Condition 1: No Display, Paper Chart Only	Mean = 56 (SD = 13)	Mean = 7,550 (SD = 5,204)	Mean = 1,713 (SD = 2,209)
Map Condition 2: Display with Terrain and Navigation Information	Mean = 62 (SD = 8.8)	Mean = 5,810 (SD = 7,511)	Mean = 2,719 (SD = 4,856)
Map Condition 3: Display with Terrain Information Only	Mean = 38 (SD = 20)	Mean = 2,559 (SD = 1,413)	Mean = 443 (SD = 526)

The Map Condition assignment determined the type of electronic map display, if any, provided to the participants on the supplemental display screen. Participants in Map Condition 1 used a

paper chart and were not provided an electronic display. Participants in Map Condition 2 were given a paper chart and an electronic display with terrain and navigation information. Participants in Map Condition 3 were provided with a paper chart and an electronic display of terrain information only.

The participants in Map Conditions 2 and 3 used a Volpe-designed electronic moving map of the area between Poughkeepsie and Albany (approximately 40 miles) which had 1000 foot terrain contour lines, navigation information, and a north-up orientation. The navigation information, only available to participants in Map Condition 2, included airways labeled with Victor airways numbers, VORs, and intersections. Appendices C-1 and C-2 show the displays used in Map Conditions 2 and 3.

Prior to flight, the researcher reviewed the Frasca instruments, radio stack, and the electronic map symbols with the participant, where appropriate, without revealing the study's goal of examining terrain avoidance displays. The Frasca simulator generated moderate turbulence during the entire experiment to increase workload.

First, the participant flew a practice flight and was instructed to perform normal activities of en route flight while becoming familiar with the simulator. The participant used a NOAA sectional chart of the area around Allentown for navigation and dialed up the Allentown VOR for familiarization. The researcher answered the participants' questions over the headset. Participants were given unlimited practice time, but most spent approximately 20 minutes.

After the practice flight, but prior to the experimental trial, the participant completed an en route paper chart familiarization task, which required him or her to identify ten items circled in red on a photocopy of a NOAA sectional chart for another area. All participants completed this task accurately.

On the experimental flight, the participants were instructed to fly to Albany. They used a sectional chart of the area around Albany and approach plates for both Albany and Poughkeepsie. The airplane started in level flight at 3000 ft above sea level, which was the Minimum En Route Altitude (MEA) on the originating airway (V123). The researcher, as Air Traffic Control (ATC), communicated with the pilot using the headset and vectored the participant around weather off the original airway with no altitude change. Shortly before the pilot reached a new airway, V213, the researcher reported loss of radar contact and cleared the pilot direct to Albany. The participant was still flying at an altitude of 3000 ft, although the new airway had a Minimum Obstacle Clearance Altitude (MOCA) of 5500 ft. The chart of this flight path is presented in Appendix C-5 and the ATC script is presented in Appendix C-4.

If the participant noticed the terrain and questioned the current altitude, ATC issued a higher clearance and the trial ended. If the participant did not question ATC immediately after radar contact was lost, the participant flew for approximately ten more minutes to allow time to notice the terrain conflict, albeit too late to take corrective action. If the participant still did not notice the higher terrain, the trial was terminated.

During debriefing, the researchers explained that the experimental goal was to see how effective the electronic display was in improving pilot ability to avoid terrain. The researchers emphasized that the study was not a test of piloting skills, but was intended to demonstrate the potential usefulness of the display.

5.2 RESULTS

As shown in table 5-3, 83% of the participants failed to detect the terrain conflict. Half of the participants (two out of four) in Map Condition 3, electronic display with terrain information only, detected the higher terrain. Neither participant, however, caught the error in time to avoid impact with the terrain. One of the participants in Map Condition 3 that did not detect the terrain reported, in debriefing, that he had noticed the terrain elevation but did not, and would not, question ATC. The remaining eight participants in the other two Map Conditions did not recognize the terrain conflict. One participant avoided the terrain due to tuning the wrong VOR.

Table 5-3. Distribution of participants by whether or not terrain conflict was detected.

Map Conditions	Detected Terrain Conflict	Did Not Detect Terrain Conflict	% of Total
Map Condition 1: No Display, Paper Chart	0	4	33%
Map Condition 2: Display with Terrain and Navigation Information	0	4	33%
Map Condition 3: Display with Only Terrain Information	2	2	33%
% of Total	17%	83%	100%

5.3 DISCUSSION

These results suggest that the participants focused on terrain elevation when it was highlighted as in Map Condition 3, where, for example, the participants used a display that presented only terrain information. This interpretation was supported by the comments during debriefing from the participants who detected the terrain conflict. These participants reported that they detected the higher elevation terrain because they had been thinking about the reasons for presenting a terrain-only electronic display. If they did not have this terrain-only display, these participants reported that they would not have thought about terrain during the scenario.

Participants' comments supported the interpretation that pilots do not tend to think of terrain as an issue when flying en route. A few participants mentioned that they might have been more alert to potentially dangerous terrain if they had been flying in the mountainous western United States. One third of the participants reported that they depend on ATC for altitude guidance and were trained not to question ATC.

Kuchar and Hansman also demonstrated this high level of trust in ATC. In their experiment, pilots were vectored into terrain by ATC and had a very low initial terrain conflict recognition rate, regardless of the electronic display presentation, contours or spot elevations. However, once the pilots recognized that ATC might not give accurate vectors, terrain conflict recognition increased dramatically when the pilot was provided with a display with terrain contour information.⁶

In the debriefing, participants mentioned that they were not comfortable trusting the electronic display, which was unfamiliar, when it contradicted ATC and their training. Three participants cited the high workload (i.e., the turbulence and resulting difficulty in maintaining straight and level flight) as too distracting to permit them to include the display into their scan. One-third of the participants said that if they had bought the map for their own airplane, understood it was for terrain alert, and had practice using it, they would have noticed the terrain conflict.

Participants presented with a terrain only-display noticed the terrain but participants with the terrain and navigation display did not. This suggests that the additional clutter of airways may have reduced their ability to focus on terrain. However, since the participants in Map Condition 1, without an electronic display, failed to give attention to terrain issues, the underlying issue may be *attention*. These results proved to be a turning point in the conceptualization of this series of experiments. The crucial issue emerging that drawing the pilot's attention to the display was, possibly, more important than the information presentation. The responses from the participants suggest that pilots will use an electronic display for terrain avoidance if their attention is drawn to the display for a terrain-related reason, and are presented with clear, informative terrain information.

⁶ Kuchar, J.K. and R.J. Hansman Jr. (1991). Advanced terrain displays for transport category aircraft (Report ASL-91-3). Cambridge, MA: MIT Aeronautical Systems Laboratory.

Kuchar, J.K. and R.J. Hansman Jr. (1993). An exploratory study of plan-view terrain displays for air carrier operations. *International Journal of Aviation Psychology*, 3(1), 39-54.

6. PREFERENCES FOR INFORMATION DENSITY ON ELECTRONIC DISPLAYS USED FOR TERRAIN AVOIDANCE

This experiment examined pilots' preferences for density of information on electronic displays. Although the previous experiment suggested that minimal information on an electronic display creates the clearest presentation, other studies have indicated that pilots prefer maps with higher information density.⁷ In this experiment, participants were asked what map features would have been useful to detect and avoid terrain in the earlier experiment. The participants were presented alternative electronic displays, with different terrain and navigation features. Their preferences were recorded to see if they agreed with the previous results.

6.1 PROCEDURE

The eight participants had participated in the previous experiment. They held instrument and multi-engine ratings; half held ATP ratings, and two were also CFIs. The average participant age (seven men and one woman) was 55 years (SD = 17 years). Table 6-1 shows participants' flight experience.

Table 6-1. Participants' flight experience.

Total Flight Hours (in hours)	Instrument Flight Hours (in hours)	Time Since Last Flight (in days)
Range = 586-17,000 Mean = 5,372 (SD = 5,412)	Range = 102-10,000 Mean = 1,747 (SD = 3,354)	Median = 7.5

Participants viewed twelve alternative electronic display presentations on a desktop computer and on the electronic display screen in the Frasca 242 simulator. They evaluated twenty-four static electronic maps each of which had a standard yellow aircraft symbol in the center for reference. The airways were labeled with MOCAs rather than Victor airway numbers. Participants rated the displays using paired comparisons and individual evaluations.

Each electronic display showed three types of information; contour type, contour increment level, and navigation information available. Appendices D-1 through D-3 show three representative display alternatives. There were two terrain layouts for each terrain increment level.

Each participant was shown twelve maps, one from each cell in the design. Table 6-2 has twelve cells, each of which has a unique combination of alternatives. The participants viewed all the display formats on a desktop computer prior to evaluating them. Participants were instructed to look at the displays and develop their own evaluation criteria, with terrain avoidance as the main focus. Participants received an instruction sheet which included suggestions for rating criteria (see Appendix D-4 for a copy of this form). Each participant was asked to evaluate how useful

⁷ Kuchar, J.K. and R.J. Hansman Jr. (1993). Results of the terrain database resolution requirements study (Report ASL-93-4). Cambridge, MA: MIT Aeronautical Systems Laboratory.

each display format was for alerting a pilot to a terrain conflict in a situation, similar to the previous experiment, where a pilot is vectored off course and not given a new clearance.

Table 6-2. Electronic display map formats.

(Note: two terrain layouts were created for each terrain increment level.)

CONTOUR INCREMENT LEVEL	CONTOUR TYPE				
	SOLID COLOR CONTOURS		CONTOUR RINGS		
		Navigation Information	No Navigation Information	Navigation Information	No Navigation Information
500'	Layouts 1 & 2	Layouts 1 & 2	Layouts 1 & 2	Layouts 1 & 2	Layouts 1 & 2
1000'	Layouts 3 & 4	Layouts 3 & 4	Layouts 3 & 4	Layouts 3 & 4	Layouts 3 & 4
2000'	Layouts 5 & 6	Layouts 5 & 6	Layouts 5 & 6	Layouts 5 & 6	Layouts 5 & 6

The participants rated the displays using the paired comparison technique.⁸ Participants compared each of the twelve alternative formats to each of the eleven others, for a total of 66 trials. The participants were asked to think carefully about each comparison and were given unlimited time to complete the task. In each trial, two static charts were presented on a screen side by side with a 17-point radio button rating system located underneath the charts at the bottom of the screen. The rating system ranged from “absolutely better” for one chart to “same” in the center (between the two) to “absolutely better” for the other chart (see Appendix D-5 for an image of the paired comparison program). Participants were instructed to select the radio button on the rating scale that corresponded with their rating for that pair of charts. They could change their responses at any time, including responses to previous trials.

For the paired comparisons, the twelve design alternatives received scores based on the participant's selection. The scores ranged from 1 to 17, where 1 indicated a rating of most preferred, 9 indicated a rating of equal preference and 17 indicated a rating of least preferred. When a participant indicated a preference for one chart, that chart was given a low rating, between 1 and 9, that corresponded with the gradation of preference. The nonpreferred chart was assigned a rating of 18, minus the preferred chart's rating.

The participants then viewed, and evaluated, each display format using the electronic display in the Frasca simulator. The Frasca simulator display gave the participants a more realistic context for evaluating the charts' function. The participants evaluated each format using a display rating questionnaire (shown in Appendix D-6). Following this, participants were debriefed on their opinions and suggestions.

6.2 RESULTS

6.2.1 Paired Comparison Task

The mean rating scores for the two terrain layouts within every cell of the design were analyzed using Wilcoxon Rank Sums. Since there were no significant differences between the ratings for

⁸ This technique was based on the one used in Amar, M.J., et al. A Human Subject Evaluation of Airport Surface Situational Awareness Using Prototypical Flight Deck Electronic Taxi Chart Displays. Final Report DOT-VNTSC-FAA-95-36 (DOT/FAA/AR-95/103). November 1995.

terrain layout, the rating scores for terrain layouts in each cell were pooled and descriptive statistics calculated. These results are presented in table 6-3.

Table 6-3. Paired comparison ratings for each display format.
(1 = most preferred format, 17 = least preferred format).

	<i>Solid color contours and Navigation information</i>	<i>Solid color contours and no Navigation information</i>	<i>Contour rings and Navigation information</i>	<i>Contour rings and no Navigation information</i>
<i>500' increment level</i>	Mean = 3.65 (SD = 3.00)	Mean = 8.28 (SD = 4.68)	Mean = 7.24 (SD = 4.46)	Mean = 11.05 (SD = 4.13)
<i>1000' increment level</i>	Mean = 5.84 (SD = 4.05)	Mean = 9.88 (SD = 4.59)	Mean = 8.20 (SD = 4.52)	Mean = 12.25 (SD = 3.40)
<i>2000' increment level</i>	Mean = 7.34 (SD = 4.31)	Mean = 11.58 (SD = 4.04)	Mean = 9.35 (SD = 4.63)	Mean = 13.34 (SD = 2.88)

Table 6-3 shows that the most preferred display format (rating = 3.65, SD = 3.00) had solid color contours, navigation information, and 500' contour increments. The least preferred display (rating = 13.34, SD = 2.88) had contour rings, no navigation information, and 2000' contour increments.

The graph in figure 6-1 shows that participants preferred more detail, i.e., navigation information, finer grained contour increments, and solid color contours.

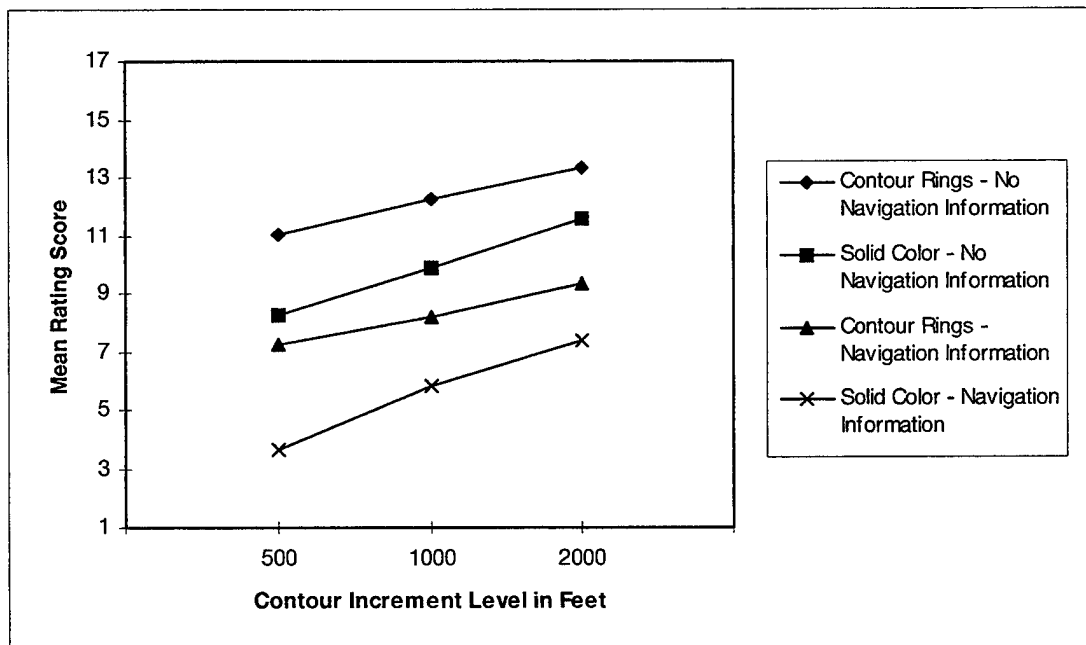


Figure 6-1. Preferences by contour increment level.
(Note: rating score inversely related to preference.)

6.2.2 Individual Evaluation Task

Evaluation of alternative display formats showed that participants preferred a higher density of information, as indicated in the paired comparison results. Generally, they preferred finer grained contour increment levels (500 ft or 1000 ft). Most of the participants preferred the denser information alternative, especially the positional orientation provided by navigation and terrain information, and the solid color contours.

This preference for solid color contours reflected participants' preference for color to change relative to elevation, which allows graphical information to substitute for digital. Participants also reported that the solid color contours gave them a better three dimensional perception of elevation. Only two participants said they disliked the solid color contours because the colors cluttered the display. Three participants suggested that unfilled contours could create visual space for more and different information.

Participants suggested the following ways to improve the displays:

- Reduce clutter by providing fewer elevation labels and allowing color gradation to describe the curves.
- Place an altitude tag on the airplane to provide a clearer sense of the relationship between the airplane and the terrain.
- Restrict navigation information to the current flight path. (It is not necessary to include all the airways.)
- Include more airway information such as VOR frequencies, DMEs, and assigned altitudes.
- Eliminate en route MOCAs when terrain contours and elevation labels are present. MOCAs should be replaced by airway numbers (this was the format in the previous experiment).
- Add range information.
- Add distance and heading to nearest airport.
- Indicate terrain higher than the airplane in red.
- Use track-up display presentations.

6.3 DISCUSSION

Participants preferred to use electronic displays with dense information to improve their terrain awareness. They preferred graphical presentations to reduce redundancy and saw graphical presentations as freeing space for additional information. These results are consistent with previous research.⁹ However, the previous experiment indicated that a high density of information on the displays was not the best way to foster positional and terrain awareness. It appears that *how* the information was presented was secondary to getting the pilots to look at the display. Unless the display captures the pilot's attention, it cannot be useful for terrain avoidance. With these results in mind, the final experiment was designed to explore the usability of display formats paired with visual alerts.

⁹ Kuchar, J.K. and R.J. Hansman Jr. (1993). Results of the terrain database resolution requirements study (Report ASL-93-4). Cambridge, MA: MIT Aeronautical Systems Laboratory.

7. VISUAL ALERTS AND THE INTERPRETABILITY OF ELECTRONIC DISPLAYS OF TERRAIN

Since the display is not in the primary field of view, the three prior experiments explored how pilots incorporate into their instrument scan a supplemental electronic display which did not have warning cues. This final experiment measured the effectiveness of a visual alert presented together with an electronic display for terrain avoidance. If the visual alert presented in this experiment highlights potential problems, this alert could help pilots to better interpret a range of display formats, including those with dense information.

7.1 PROCEDURE

Six instrument- and multi-engine-rated pilots participated in this experiment; four of the six held Commercial and ATP ratings, and four held CFI ratings. All the participants in this test were male with an average age of 42.5 years and a standard deviation (SD) of 14 years. Table 7-1 shows participants' flight experience.

Table 7-1. Participants' flight experience.

Total Flight Hours (in hours)	Instrument Flight Hours (in hours)	Time Since Last Flight (in days)
Range = 593-28,000 Mean = 5,740 (SD = 10,922)	Range = 60-2,800 Mean = 779 (SD = 1,096)	Median = 8.5

The participants flew the Frasca 242 simulator and were required to react to the display screen by pressing one of the six buttons located below the screen. There was a clearly marked label above each button. The labels, from left to right, were, "No Action," "Left," "Climbing Left," "Climb," "Climbing Right," and "Right".

The electronic display formats varied on three dimensions: map density (high, medium, and low), airplane orientation (track-up and north-up), and alert type (true alarm and false alarm). One thousand foot contour increments were present on all the maps. The high density map had navigation information (airways, VORTACs, and intersections) and solid contour shapes. The medium density map had solid contour shapes but no navigation information. The low density map had contour rings and also lacked navigation information. Appendices E-1 through E-3 show examples of the three display formats.

Each participant flew two practice flights and four experimental flights. The practice flight was 25 miles long and included procedures similar to the experimental runs, but only presented six alerts, one for each electronic display in each of the two airplane orientations: north-up and track-up. The experimental flights, 100 miles in length and 40 to 45 minutes long, were identical to one another for navigational purposes. The four experimental flights differed in terrain layout and sequence of alerts (i.e., independent variables manipulated). Alerts were presented twelve times on each experimental flight.

The researcher briefed each participant at a computer terminal prior to the experiment. The researcher showed the participant six electronic displays, each of the six formats presented, and explained how to interpret the electronic displays. The participant was given the paper chart (see Appendix E-4 for a copy of the chart with the routes flown) and told to fly the assigned route at the assigned altitude. The paper chart included information present on standard charts such as headings, VORTACs, and airways, but did not provide terrain elevation information. The participant was told to respond to ATC commands (as issued by the researcher) such as changes in altimeter setting, communication frequencies, and transponder squawk codes, and to react to the alert maps as accurately and quickly as possible. (See Appendix E-5 for a flight script). The participant was informed that the assigned route was within restricted airspace and he or she should not deviate from course unless necessary.

The first practice flight familiarized the participants with the flight dynamics and the moderately high turbulence present throughout the experiment without having to use the electronic display. There was no time limit set for this practice flight but most participants flew for approximately ten to fifteen minutes.

The participant flew a second practice flight using an assigned route that included alert triggers to become familiar with the electronic display and to practice responding to alerts. During this flight and the subsequent experimental flights, the participant was required to maintain 5,000 feet and 170 to 180 knots airspeed. The electronic display was blank and navigation was by VORs. The participant was not permitted to use the autopilot.

During the flights, the researcher would trigger an alert every two to five minutes, presenting the participant with a potential terrain conflict. During an alert, the airplane would continue flying, the screen would flash twice, displaying a red background with the word "alert" in black letters, and then the map display would appear. The participant was expected to assess the situation and determine what action, if any, was necessary to maintain terrain separation. The participant was instructed to keep the airplane straight and level and to respond to the alert by pressing a button located below the screen. Pressing a button blanked the screen. The participant could not change his mind after making a selection. Reaction time (in seconds) was measured from the time an alert appeared on the screen to the time the pilot pressed a button (made a decision). Percentage correct responses at each alert point were recorded for every flight in addition to flight data such as plane orientation, speed and pitch.

After the participant completed four experimental flights, he or she completed a questionnaire (see Appendix E-6) to obtain subjective responses to the experiment. The researcher used the questionnaire as the starting point to discuss the session with the participant.

7.2 RESULTS

The mean overall reaction time to alerts was 5.5 seconds with a standard deviation of 4.18 seconds. The median reaction time was 4.6 seconds. (See table 7-2 for the mean reaction times for each display format combination.) There were no significant differences in reaction time by map density, airplane orientation, or alert type using factorial Analysis of Variance (ANOVA).

Table 7-2. Mean reaction times to alerts for display formats.

ALERT TYPE					
AIRPLANE ORIENTATION >		TRUE ALARM		FALSE ALARM	
		Track-up	North-up	Track-up	North-up
MAP DENSITY	Low	5.0 sec., 3.2 sd	4.8 sec., 1.5 sd	6.2 sec., 7.5 sd	5.2 sec., 2.1 sd
	Medium	4.9 sec., 4.2 sd	5.9 sec., 4.1 sd	7.1 sec., 8.8 sd	5.2 sec., 2.4 sd
	High	5.1 sec., 1.8 sd	6.3 sec., 3.0 sd	5.4 sec., 2.4 sd	5.2 sec., 1.8 sd

The percentage of correct responses was 81%. A correct response was defined as responding with any of the five action types when an action was required or with "No Action" when no action was required. Error was divided into two categories: "False Positive" errors resulted from participants responding with one of the five types of actions if no action was required, and "False Negative" errors which resulted from the participants responding "No Action" when there was an action required. No determination was made in advance as to what type of action was the most appropriate for each "action" trial, and consequently, type of action was not analyzed for accuracy. Table 7-3 shows accuracy of responses to alerts.

Table 7-3. Distribution of responses to alerts by correct and actual (pilot) response.

	Correct Response: Action	Correct Response: No Action	Total Responses
Actual Response: Action	43.1%	11.8%*	54.9%
Actual Response: No Action	6.9%**	38.2%	45.1%
Total Responses	50%	50%	100%

* These errors are referred to as False Positive because they occurred when no action was necessary and the participant responded with an action.

** These errors are referred to as False Negative because they occurred when an action was necessary and the participant responded with no action.

The nearly 19% error rate led to the question: Were there alert points (trials) along the flight path that produced a significantly higher number of errors than other alert points? Error rate was examined at each alert point. Percentages of correct and incorrect responses across trials are shown in table 7-4. Four points along the flight path had a total error rate of 25% or higher (trials 3, 7, 10, and 11).

Table 7-4. Percentages of correct and incorrect responses across alert points.
(Bold type indicates the four points where the error was greater than 25% of the responses.)

ALERT POINTS												
	1	2	3	4	5	6	7	8	9	10	11	12
Correct Responses	95.8%	83.3%	75.0%	91.7%	87.5%	83.3%	62.5%	87.5%	83.3%	70.8%	66.6%	87.5%
Incorrect Responses	4.2%	16.7%	25.0%	8.3%	12.5%	16.7%	37.5%	12.5%	16.7%	29.2%	33.4%	12.5%
False Positive	4.2%	8.3%	20.8%	0.0%	12.5%	16.7%	20.8%	8.3%	4.2%	8.3%	29.2%	8.3%
False Negative	0.0%	8.3%	4.2%	8.3%	0.0%	0.0%	16.7%	4.2%	12.5%	20.8%	4.2%	4.2%

The higher incorrect response rate at some alert points was of concern. Perhaps participants did not respond to the alerts in the manner that was intended at these points or participants may not have been oriented appropriately when the alert was triggered. Using a program to examine map type and airplane position and heading during each alert trigger, incorrect responses (false positives and false negatives) were subcategorized. Each incorrect response, whether it was a false positive or a false negative, was classified as either a "real error," or as one of four types of "invalid response," outlined in table 7-5.

Table 7-5. Invalid response categories used to code incorrect responses.

INVALID RESPONSE CATEGORIES
- Participant responded based on an anticipated navigational maneuver instead of based on current heading. - Participant was provided with more look ahead than was intended and the participant responded to higher terrain ahead that was not supposed to be seen. (This happened primarily on track-up maps because the airplane was often placed at the bottom of the screen with maximum look ahead instead of in the center on north-up maps.) - Participant was not on the expected flight path when the alert was triggered and was therefore oriented incorrectly to the terrain features. - Computer glitches prevented the researcher from triggering the alert at the appropriate time and therefore the participant was oriented incorrectly to the terrain features (this was rare).

Half of the incorrect responses, 19% of the total responses, were coded as invalid responses. A new data set was created for additional analyses excluding the invalid responses, approximately 9% of the data points. An ANOVA for reaction time and two chi-squares were performed on the reduced data set; these results were not significant.

7.3 DISCUSSION

There were no significant differences in interpretability for any of the displays. If terrain elevations were clearly marked, pilots were able to quickly interpret displays with varying information densities. These results open a range of electronic display possibilities. However, if the goal of this type of research is to create a display that produces little to no error, then error rate in this experiment indicated that the format presented was not ideal. Further studies to assess generalizability of these results and explore ways to increase accurate interpretability are needed.

8. OVERVIEW

Terrain depictions on maps can be useful, but the depictions must present information in a clear manner. It is apparent that there needs to be a mechanism to draw the pilot's attention to the display. This could be a minimal display (such as the terrain-only map in chapter 5) or an alerting system used in conjunction with the display (visual alert in chapter 7).

This research also supports previous work that indicates pilots prefer displays with higher densities of information. Electronic displays with terrain depictions, of varying information densities, combined with a terrain alerting system, will allow pilots to quickly and accurately interpret information useful for terrain avoidance.

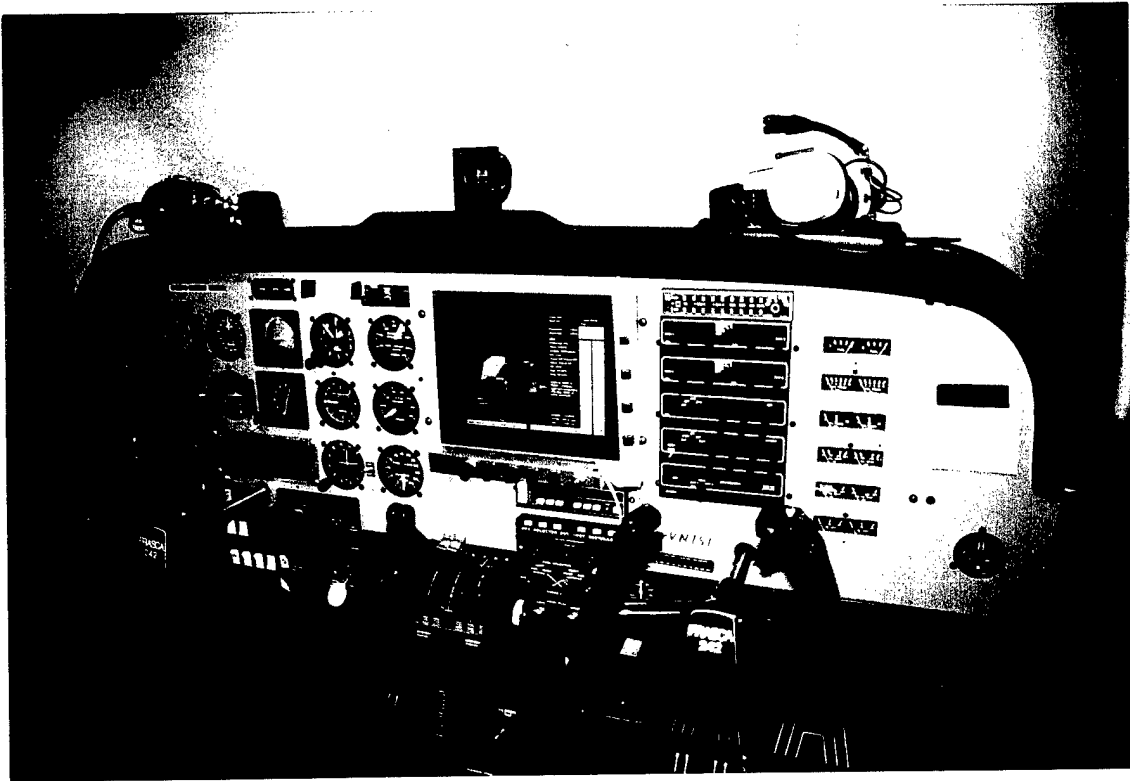
The major issues yet to be addressed which were raised by this series of experiments were: familiarity with electronic displays (amount of training), clarity and interpretability of the display (placement and presentation of elevation information), and airplane relative position on the map. Each of these issues need to be addressed. To further investigate the human factors aspects of electronic displays, it is necessary to modify training practices in experimentation, including training to proficiency. One possibility for modifying elevation information is to label elevations of a safety floor and only present the terrain that is relevant to the pilot (terrain at his altitude or higher). The position of the airplane could be modified to provide maximum look ahead, instead of in the middle of the screen, as it was in the last experiment (chapter 7).

Overall, this series of experiments addressed important issues for designing electronic display terrain avoidance systems and of interest for future research.

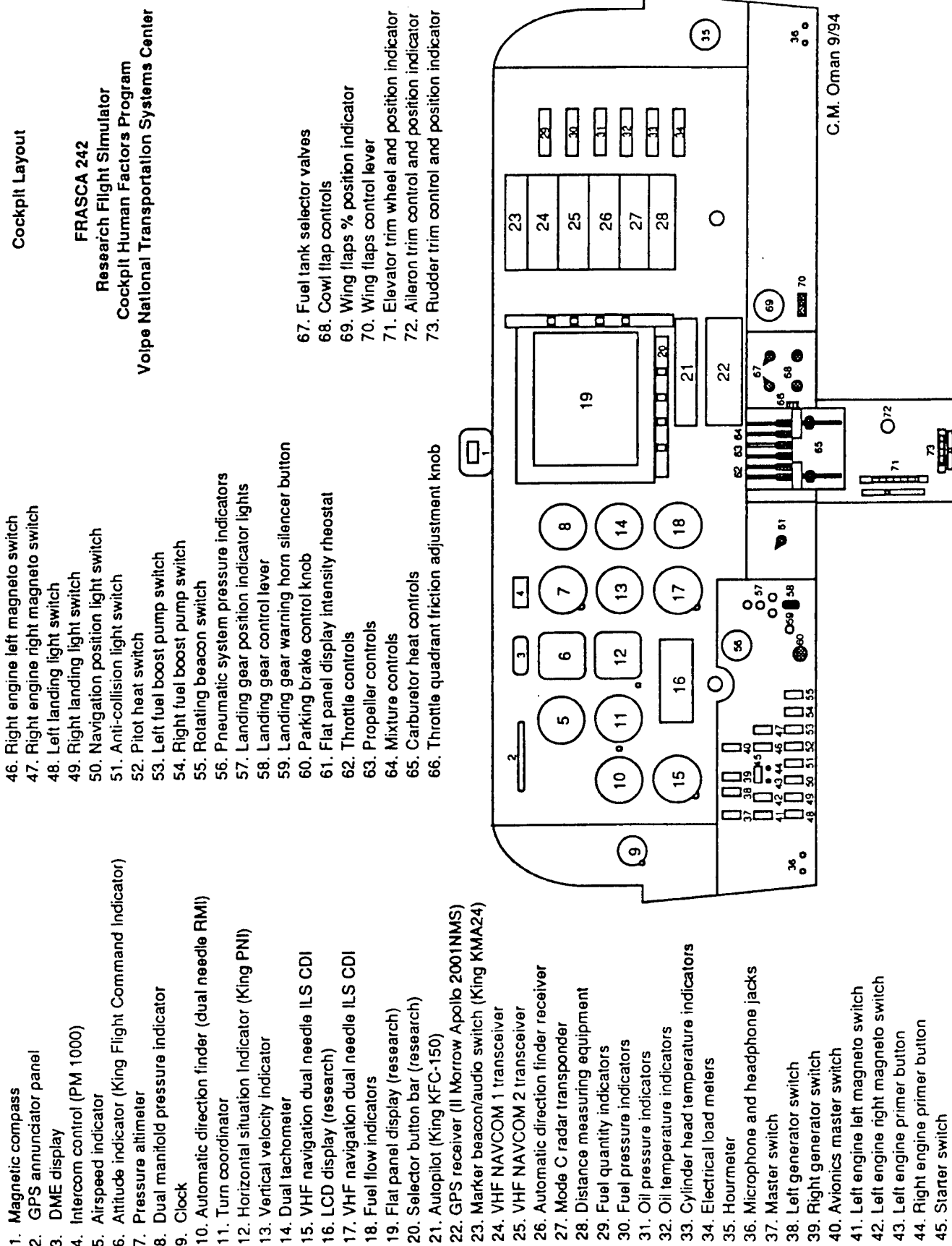
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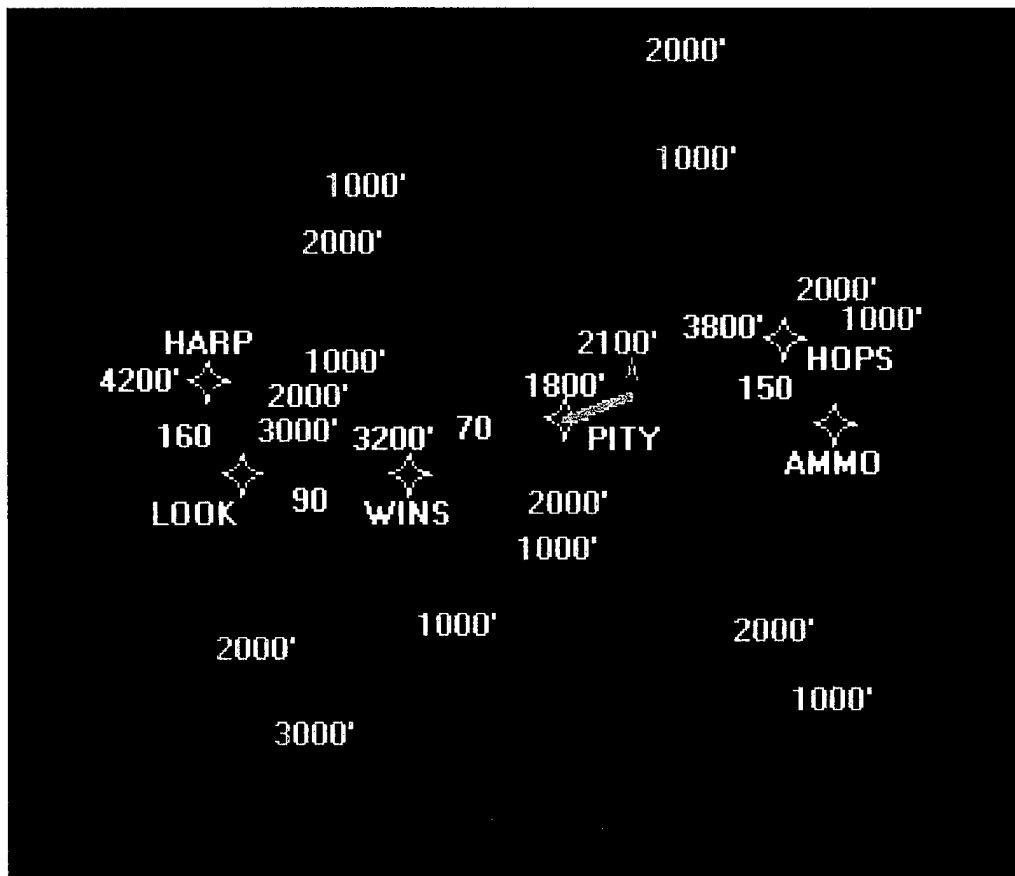
Appendix A-1. Frasca 242 Simulator



Appendix A-2. Simulator Flight Instrument Panel



Appendix B-1. Electronic Approach Display



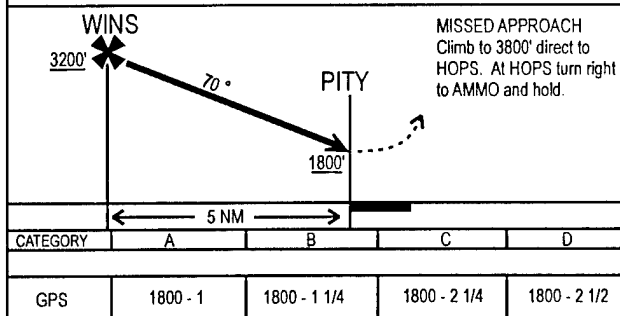
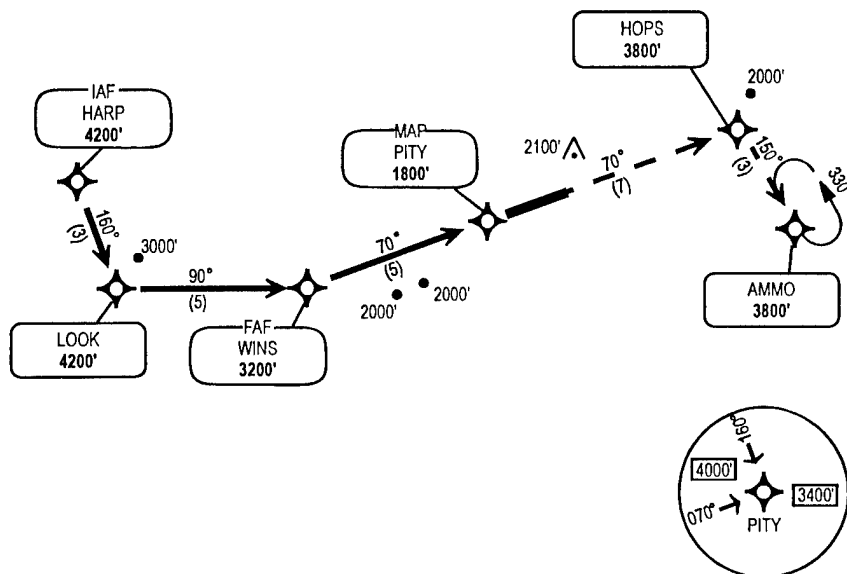
Appendix B-2. Paper Approach Chart

For Research Purposes Only

GPS RWY 7

DEGOBAH

ATIS 118.4
DEGOBAH TOWER
122.3 (CTAF)
UNICOM 120.6



ELEV 1155

10260 X 150

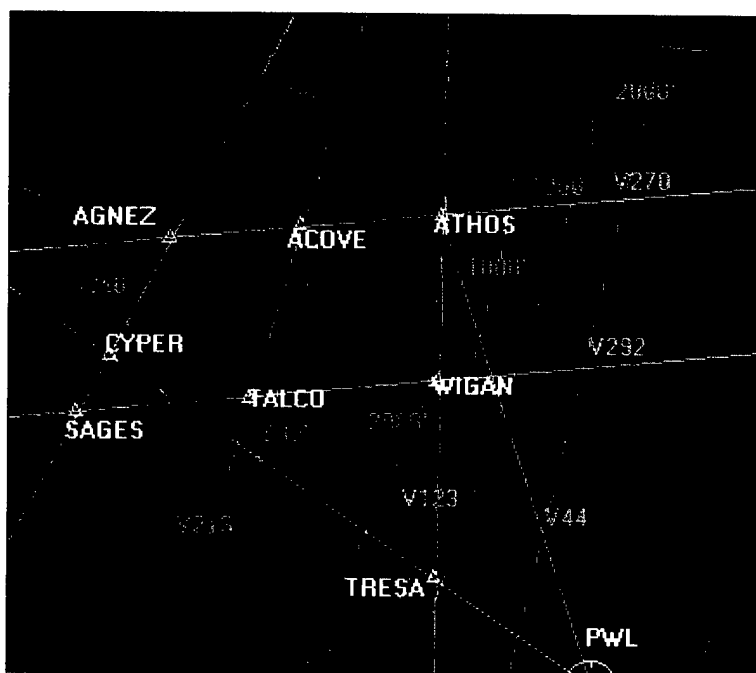
Appendix B-3. Flight Checklist

	Approach number:					
	<u>0</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
Called in Final Approach	-	-	-	-	-	-
Applied carb heat (on)	-	-	-	-	-	-
Boost pumps (on)	-	-	-	-	-	-
Wing Flaps (down)	-	-	-	-	-	-
Landing gear (down)	-	-	-	-	-	-
Called in Missed Approach	-	-	-	-	-	-
Applied carb heat (off)	-	-	-	-	-	-
Boost pumps (off)	-	-	-	-	-	-
Wing Flaps (up)	-	-	-	-	-	-
Cowl Flaps (open)	-	-	-	-	-	-
Landing gear (up)	-	-	-	-	-	-
Maintained speed: +/- 5 kts						
Maintained altitude: +/- 100 ft.						
Responded to ATC when flight corrections requested						

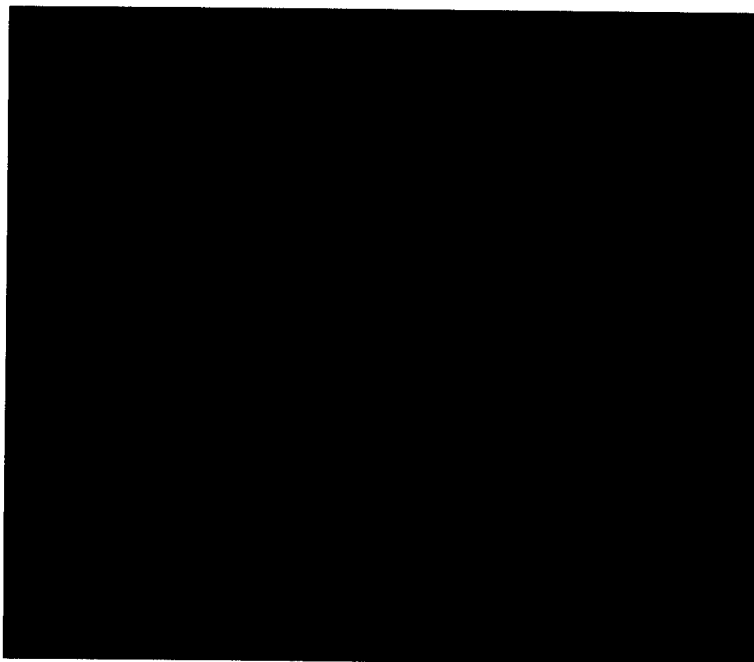
Appendix B-4. Post-Flight Questionnaire

1. What kind of information was most helpful to you on the electronic map?
2. In particular, was the terrain depiction useful information?
3. Were there specific legs of the flight where the electronic map facilitated flying?
4. At Waypoint turns, did you fly through them or anticipate them?
In either case, did you use the moving map or the needle for the turn?
5. Which information on the map did you find unnecessary?
6. Would you find this map useful in VFR conditions as well?
7. Any other suggestions or comments on the map display?
8. Any other suggestions or comments on the flight testing procedure?

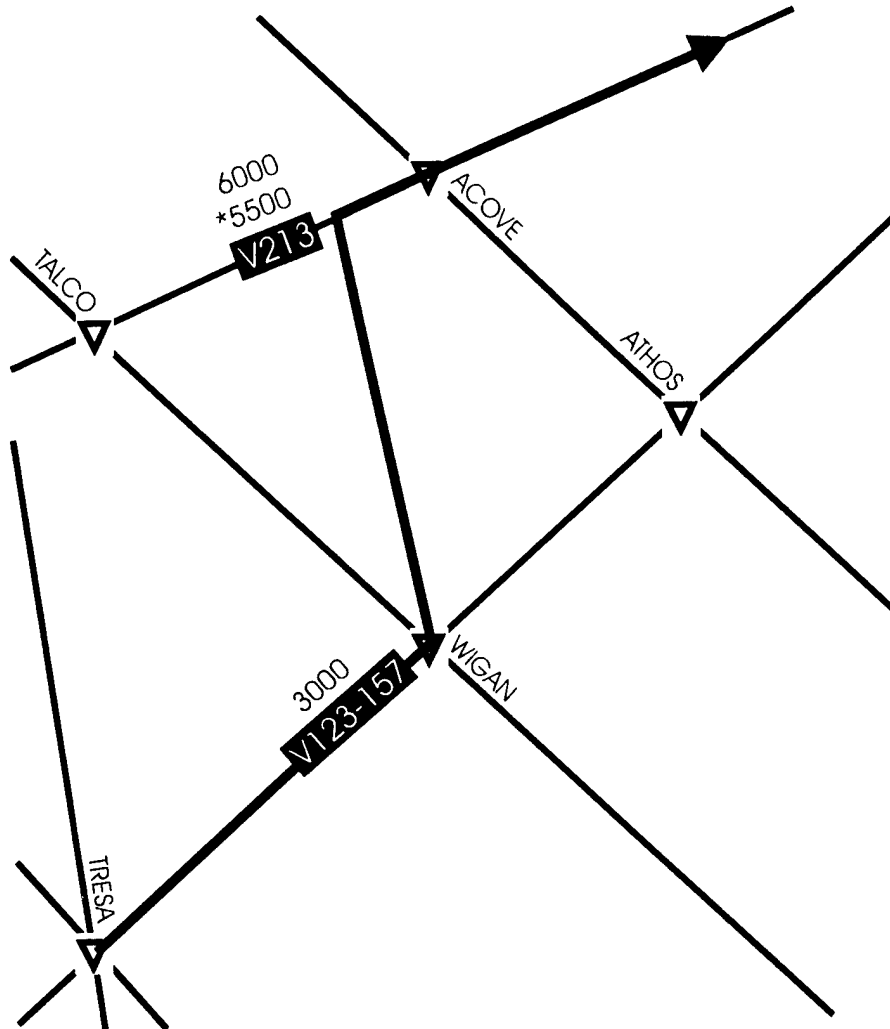
Appendix C-1. Electronic Display for Map Condition 2: Navigation and Terrain Information



Appendix C-2. Electronic Display for Map Condition 3: Terrain Information



Appendix C-3. Chart of Flight Path



Appendix C-4. Script for Experiment 2 (Albany Experiment)

Pilot Briefing: Airplane starts at TRESA at 3000' on V123 direct to Albany.
Pilot is talking to NY approach control.
ATIS at Albany is not functioning.
Autopilot is NOT to be used.

Flight:

ATC: "N123SH This is New York approach. Maintain 3000"
(after a few minutes of flight)

ATC: "N123SH contact Albany approach control on 122.4"

(pilot contacts Albany)

Alb. ATC: "N123SH Albany altimeter setting is two-niner-niner-seven"

(at WIGAN)

ATC: "N123SH this is a vector around weather along Victor 123. Turn Left to heading of two-niner-zero 290. Expect 15 miles."

(after new heading is established)

ATC: "N123SH contact Albany on 125.025"

(pilot notices error)

ATC: "Roger, N123SH, make that 122.6"

ATC: "N123SH your transponder is intermittent, squawk code 2526 and ident"

(before intersection with V213 and terrain)

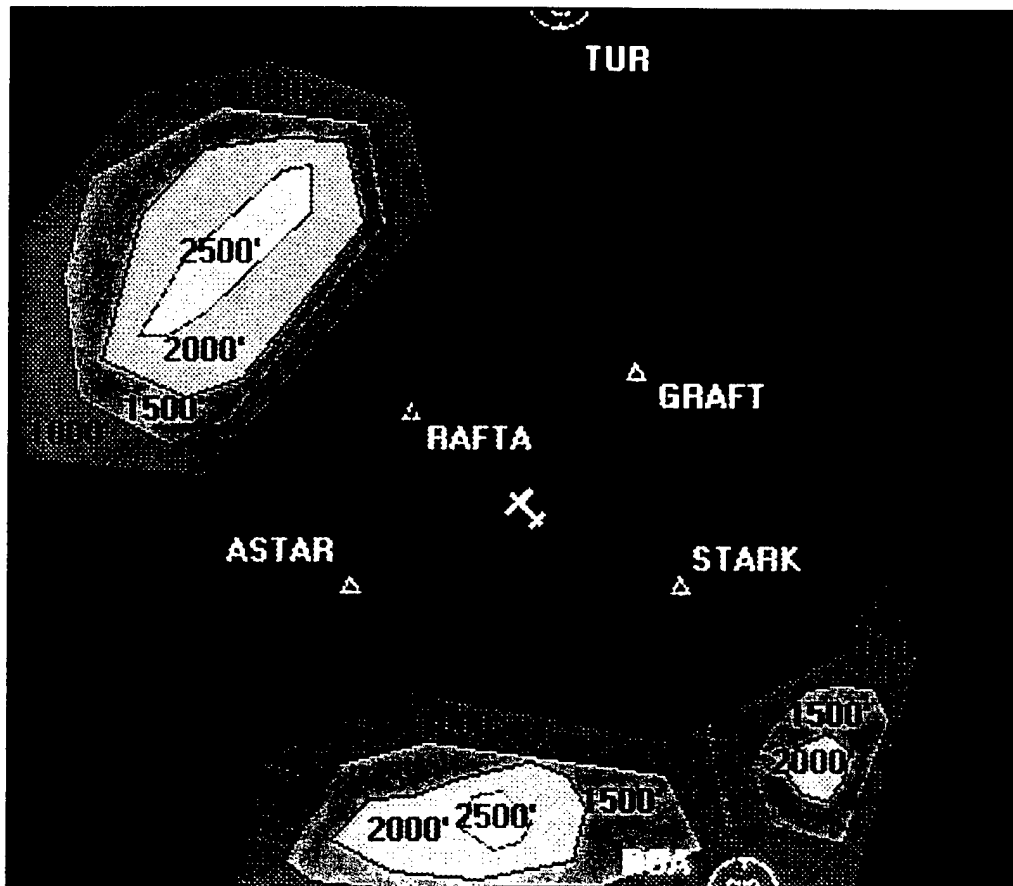
ATC: "N123SH, radar contact has been lost, you are cleared direct to Albany"

(if pilot questions altitude)

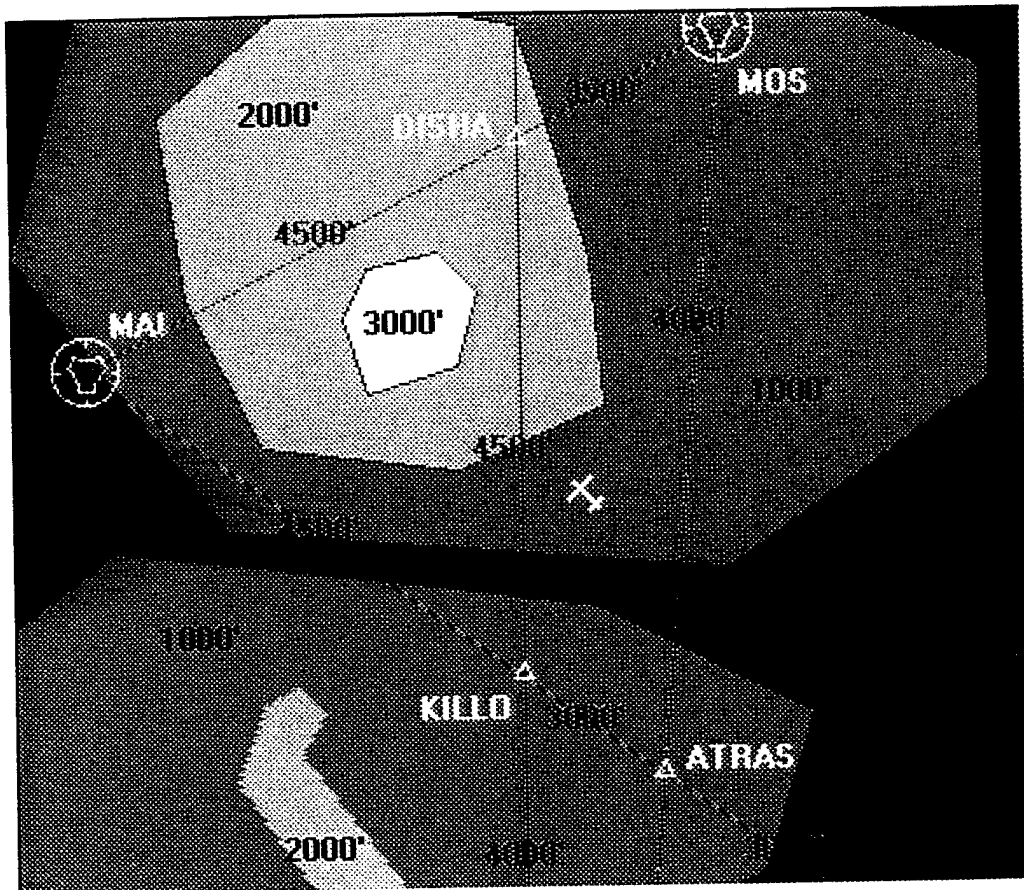
ATC: "Roger, expect higher in 2 miles"

ATC: "N123SH climb and maintain 7000."

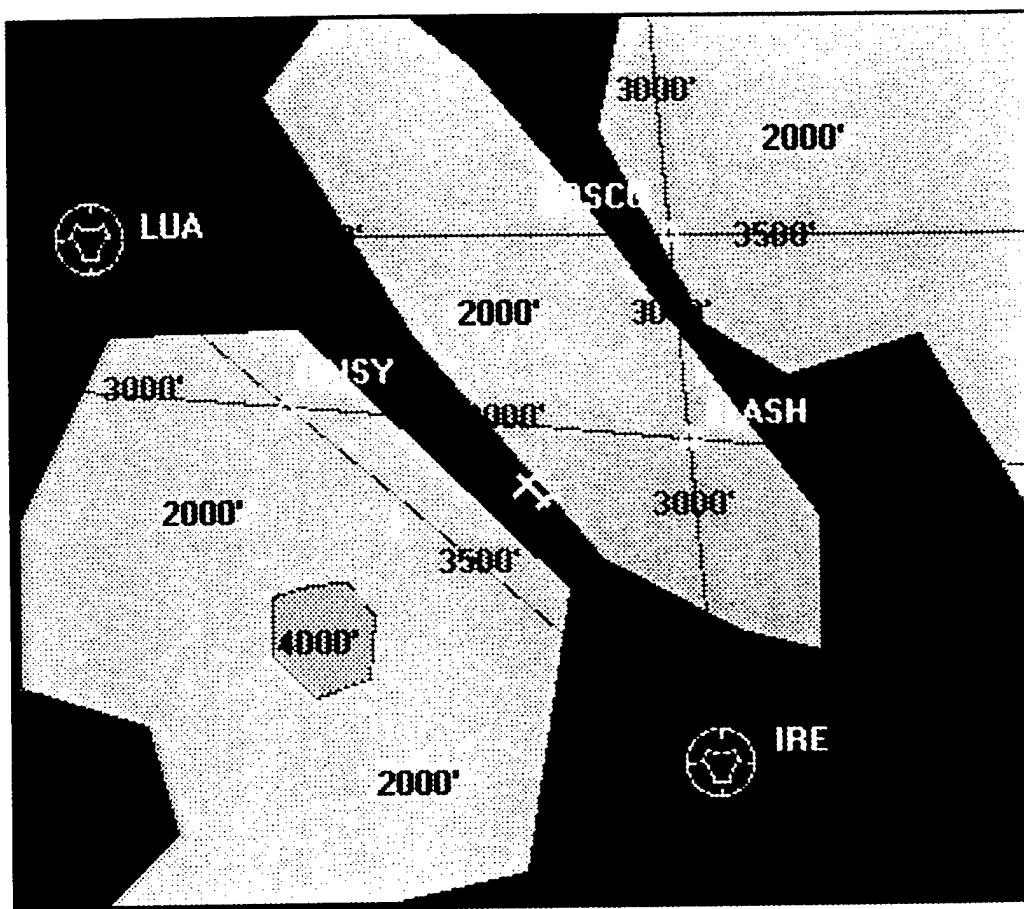
Appendix D-1. Static Electronic Display Format: 500-ft Contours, Filled Contours, and Navigation Information



Appendix D-2. Static Electronic Display Format: 1000-ft Contours, Filled Contours, and Navigation Information



Appendix D-3. Static Electronic Display Format: 2000-ft Contours, Unfilled Contours, and Navigation Information



Appendix D-4. Electronic Display Format Preference Task Rating Criteria

For this part of the study we will ask you to look at a series of two chart comparisons. There will be 66 comparisons in all.

Your task will be to rate the maps based on the scenario you just flew.
Ask yourself the following question:

Which of the two maps would have been more useful to me during the flight to notice and avoid terrain?

Before you begin, you will have a chance to look at each map individually at your own pace. During this time, think about criteria you will use for evaluation. Please try to maintain consistent criteria throughout the rating task.

The following are a few suggestions for setting criteria. Please note they are only suggestions:
You are not limited to these nor are you required to use them.

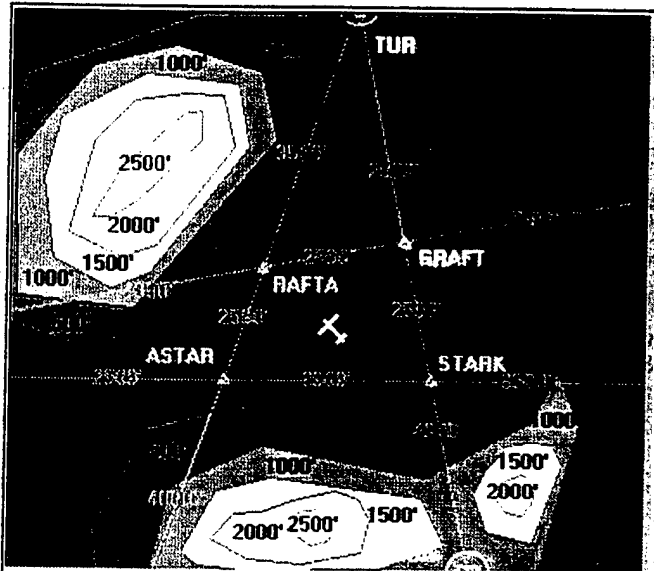
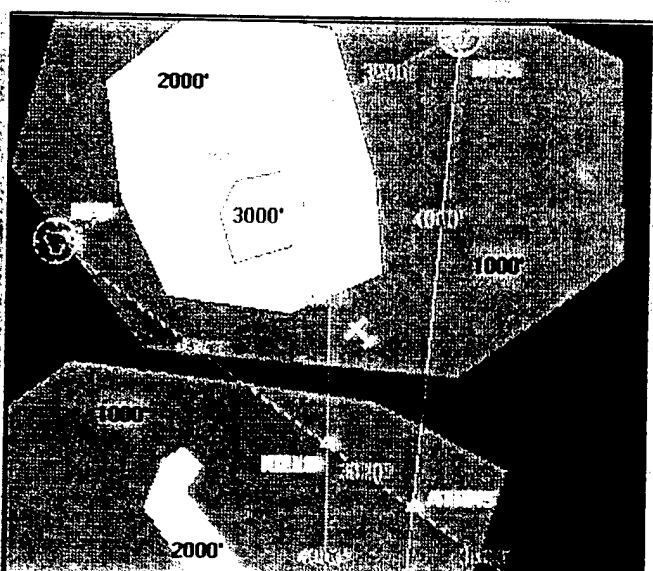
- Is the level of clutter useful?
- Is the level of detail useful?
- Is the text easy to interpret?
- Is the terrain presentation clear?
- Is the navigation information clear and/or necessary?

You will be able to pace yourself through the comparisons. Click on the rating circle that most appropriately matches your evaluation of the maps. Choosing a rating will not advance the computer to the next comparison. Only when you click on "Next" will the computer advance. You may also go back to previous comparisons if you want to change your mind.

Appendix D-5. Static Electronic Display Format Comparisons

CFR 3A

☐ ☐ ☐ ☐

Counter: 1

Rating

☐

absolutely
better

☐

much
better

☐

better

☐

slightly
better

☐

same

☐

slightly
better

☐

better

☐

much
better

☐

absolutely
better

Show Details

Setup

Quit

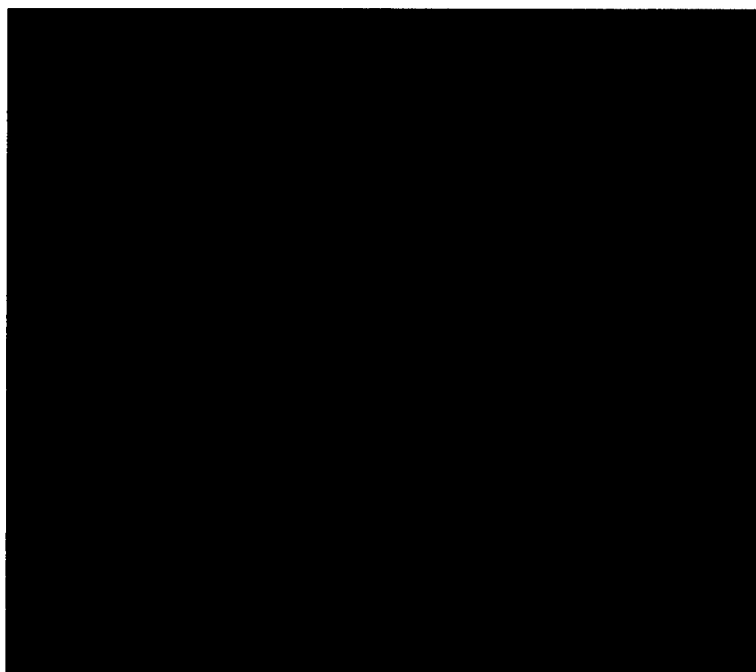
Previous

Next

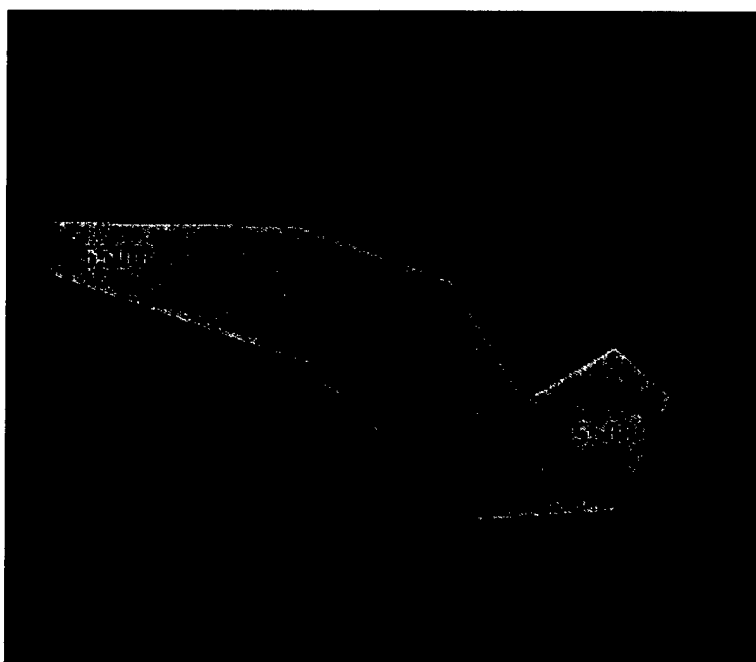
Appendix D-6. Display Rating Questionnaire

- I. Can the map be easily interpreted? Explain.
- II. What suggestions for improvement do you have?
 - A. What information should or shouldn't be included?
 - B. What are the best and worst features of the map?
 - C. In what other ways could information be presented?
- III. Is the terrain depiction clear and easy to understand? Explain.
 - A. Does it have enough detail? If no, what else should be added?
 - B. Does it have unnecessary detail? If yes, what should be removed?
- IV. If the map contains navigation information:
 - A. Is the depiction clear and easy to understand? If no, why?
 - B. Is there enough information? Should anything be added or removed?

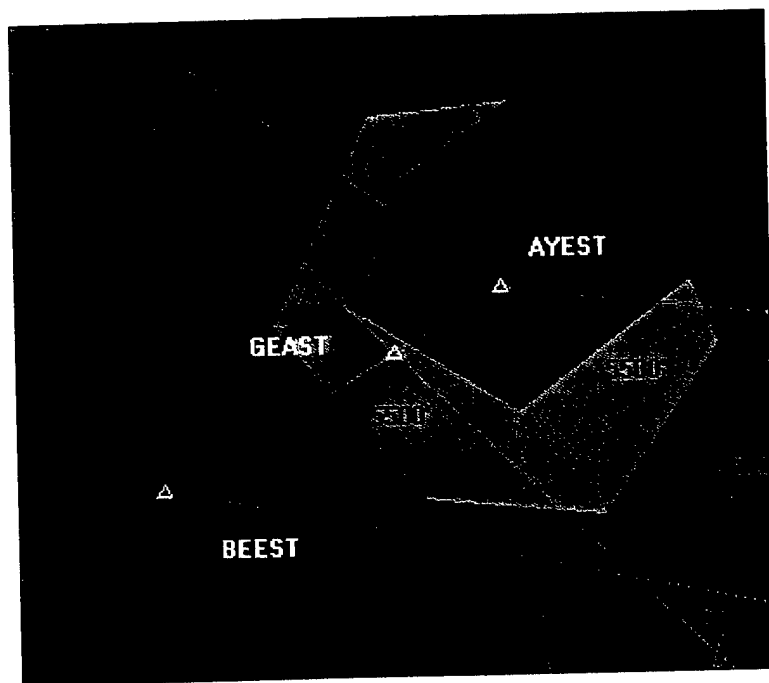
Appendix E-1. Low-Density Display Format



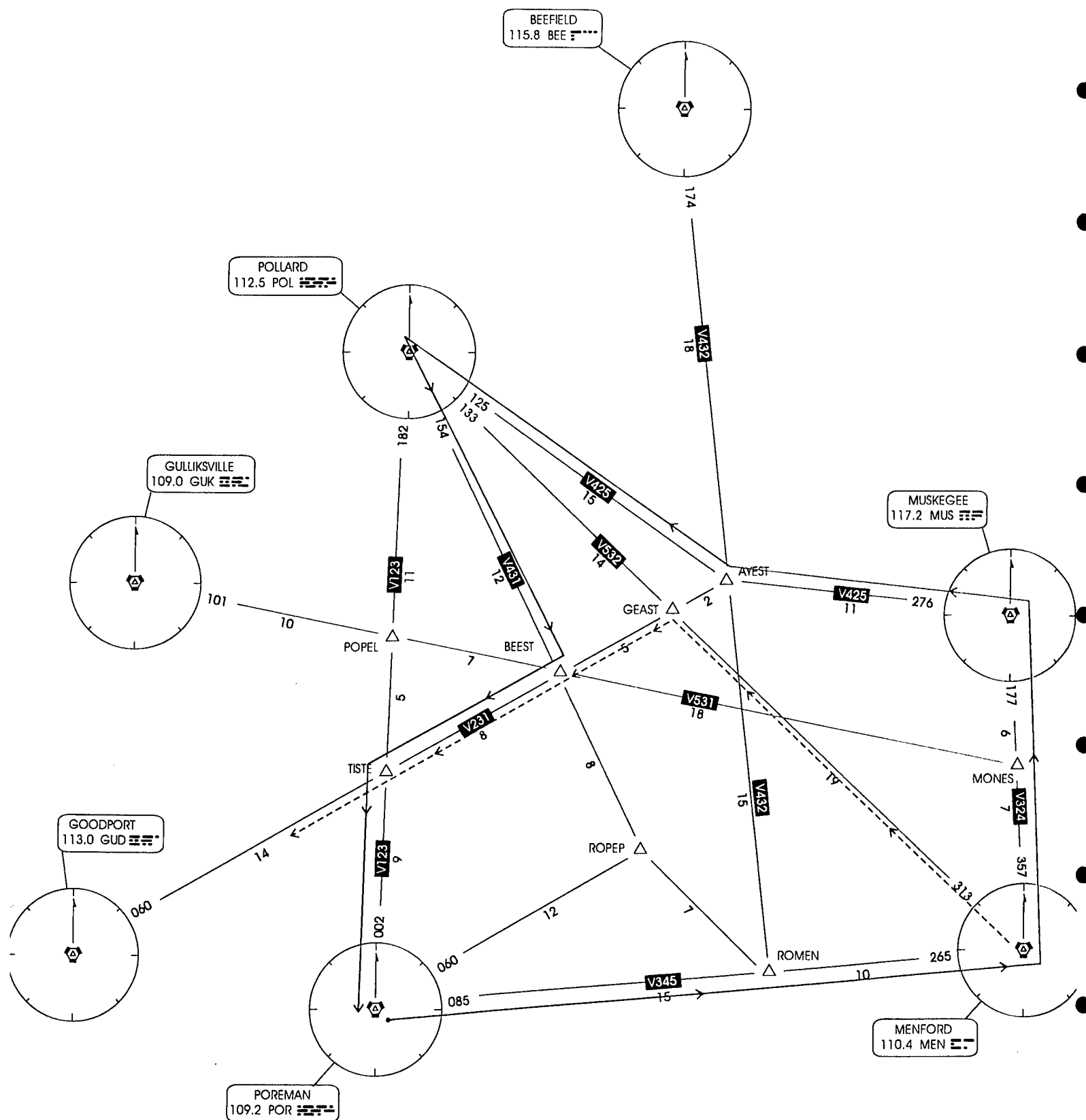
Appendix E-2. Medium-Density Display Format



Appendix E-3. High-Density Display Format



**Appendix E-4. Paper Chart Including Flight Paths for the
Practice and Experimental Runs**
practice flight indicated with dotted line and experimental flight indicated with straight line



Appendix E-5. Example of Flight Script (for Experiment 4)

Talking to ATC at Poreman Airport on 122.4

- ATC: "N123SH this is Poreman Approach. Maintain 5000 feet"
- 1 (phase 1: first alert: alarm)
2 (phase 1: second alert: alarm)
3 (phase 1: third alert: false)
- ATC: "N123SH altimeter is two-niner-niner-four"
- 4 (phase 2: first alert: alarm)
ATC: "N123SH transponder is intermittent, squawk code 4021 and ident"
5 (phase 2: second alert: false)
ATC: "N123SH contact Poreman on 131.25"
6 (phase 2: third alert: alarm)
- ATC: "N123SH Report crossing AVEST"
- 7 (phase 3: first alert: alarm)
ATC: "N123SH contact Poreman on 122.75"
ATC: "N123SH altimeter is 29.99"
8 (phase 3: second alert: false)
ATC: "N123SH transponder is intermittent squawk code 2040 and ident"
9 (phase 3: third alert: false)
ATC: "N123SH contact Poreman on 130.5"
- ATC: "N123SH transponder is intermittent, squawk code 3231 and ident"
- 10 (phase 4: first alert: false)
ATC: "N123SH altimeter is 29.98"
11 (phase 4: second alert: false)
ATC: "N123SH contact Poreman approach on 128.75"
12 (phase 4: third alert: alarm)

Appendix E-6. Post-Experiment Questionnaire

1. Which map(s) did you find the easiest to interpret? Why?
2. Which map(s) did you find the most difficult to interpret? Why?
3. In what other ways could this alert information be presented?
4. Should more detail be added to any of the maps? If yes, what else should be added?
5. Did any of the maps have unnecessary detail? If yes, which maps and what should be removed?
6. Which orientation of the map (north up or track up) did you prefer? Why?
7. Any other suggestions/comments:
8. Have you had any flight experience in mountainous areas? If so, how much?