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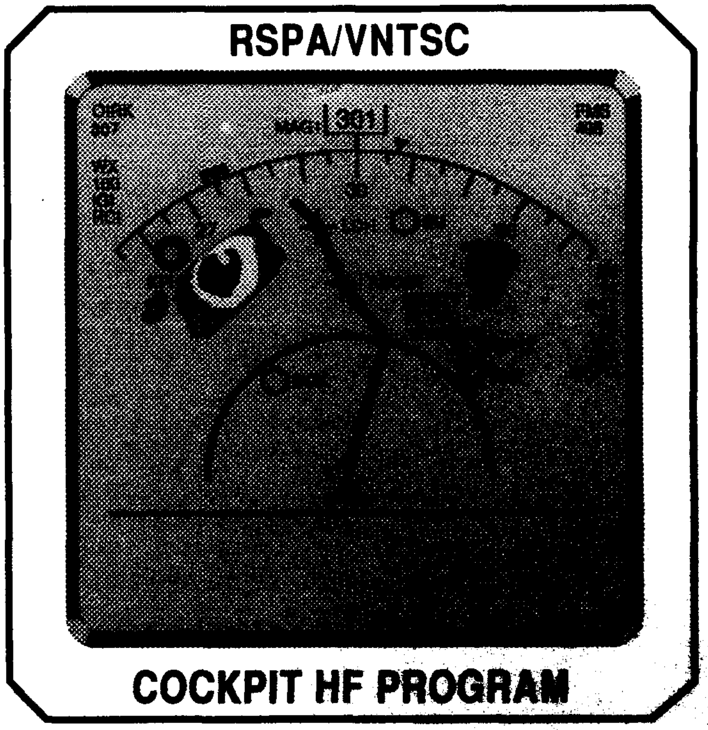
# Cockpit Electronic Display Workshop: A Synopsis







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

Final Report



December 1993



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Thirty-six government, academic, and industry human factors professionals participated in a workshop convened at the Volpe National Transportation Systems Center to identify human factors issues associated with depicting terminal area operations information on electronic cockpit displays. Two working groups, formed from the meeting attendees, identified a variety of research issues associated with the identification, distribution, and electronic presentation of terminal area information to flight crews. This document presents a summary of the proceedings produced by that meeting and an edited list of research issues derived from those proceedings. The summary document also includes two disks containing the original workshop proceedings. These disks have been formatted in Microsoft Word 5.1 for Macintosh. Please refer to the Read Me file for further instructions.

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# PREFACE

This document is a summary of the proceedings of a workshop held at the John A. Volpe National Transportation Systems Center on April 7-9, 1993, in Cambridge, Massachusetts. The general purpose of the meeting was to identify human factors issues associated with the implementation of electronic library systems in aircraft, and more particularly, with the electronic presentation to flight crews of information required for terminal area operations.

This summary includes a description of the general structure of that workshop, abstracts of papers presented, and an edited list of the human factors issues recommended for research. The proceedings from the workshop comprise nearly 500 pages of material and are much too voluminous for distribution as a paper document. Therefore, along with the synopsis we have included two diskettes, formatted in Microsoft Word 5.1 for Macintosh, which contain the complete workshop proceedings. Please refer to the Read Me file located on Disk 1 for further instructions. If you do not have access to a Macintosh, please contact Steve Huntley at (617) 494-2339 to request a paper copy of the proceedings. Because this document is being distributed electronically, we could not include the accompanying viewgraphs. To order a complete set of the draft viewgraphs, please complete and return the card located at the front of this report.

The authors are grateful to the Human Performance Program of the FAA's Research and Development service for providing the funding required for this activity and for their patience in waiting for this report. We also thank Garvin Holman, of Prime Factor, Inc., for providing the logistical support required for the workshop, and Lloyd Popish for laboriously recording and editing the extensive proceedings of this two-day meeting. In addition, we thank Donald Eldredge, of Battelle, for his tireless efforts in coordinating the activities of the many players required to support this activity.

Thanks are also due to Elaine Casey, of EG&G Dynatrend, for the final editing of this document and the collation of its contents with the workshop proceedings.

Finally, and most importantly, this document would not have been possible without the gracious support of the 38 researchers, certification specialists, and industry participants who contributed their valuable time and expertise to this activity.

## METRIC/ENGLISH CONVERSION FACTORS

### ENGLISH TO METRIC

**LENGTH (APPROXIMATE)**

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

**AREA (APPROXIMATE)**

1 square inch (sq in, $in^2$ = 6.5 square centimeters ($cm^2$)
1 square foot (sq ft, $ft^2$ = 0.09 square meter ($m_2$)
1 square yard (sq yd, $yd^2$) = 0.8 square meter ($m^2$)
1 square mile (sq mi, $mi^2$) = 2.6 square kilometers ($km^2$)
1 acre = 0.4 hectares (he) = 4,000 square meters ($m^2$)

**MASS - WEIGHT (APPROXIMATE)**

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

**VOLUME (APPROXIMATE)**

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, $ft^3$) = 0.03 cubic meter ($m^3$)
1 cubic yard (cu yd, $yd^3$) = 0.76 cubic meter ($m^3$)

**TEMPERATURE (EXACT)**

$[(x-32)(5/9)]\ ^oF = y\ ^oC$

### METRIC TO ENGLISH

**LENGTH (APPROXIMATE)**

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

**AREA (APPROXIMATE)**

1 square centimeter ($cm^2$) = 0.16 square inch (sq in, $in^2$)
1 square meter ($m^2$) = 1.2 square yards (sq yd, $yd^2$)
1 square kilometer ($km^2$) = 0.4 square mile (sq mi, $mi^2$)
1 hectare (he) = 10,000 square meters ($m^2$) = 2.5 acres

**MASS - WEIGHT (APPROXIMATE)**

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

**VOLUME (APPROXIMATE)**

1 milliliters (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter ($m^3$) = 36 cubic feet (cu ft, $ft^3$)
1 cubic meter ($m^3$) = 1.3 cubic yards (cu yd, $yd^3$)

**TEMPERATURE (EXACT)**

$[(9/5)\ y + 32]\ ^oC = x\ ^oF$

### QUICK INCH-CENTIMETER LENGTH CONVERSION

| INCHES | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|

CENTIMETERS: 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 25.40

### QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

| $^oF$ | $-40^o$ | $-22^o$ | $-4^o$ | $14^o$ | $32^o$ | $50^o$ | $68^o$ | $86^o$ | $104^o$ | $122^o$ | $140^o$ | $158^o$ | $176^o$ | $194^o$ | $212^o$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $^oC$ | $-40^o$ | $-30^o$ | $-20^o$ | $-10^o$ | $0^o$ | $10^o$ | $20^o$ | $30^o$ | $40^o$ | $50^o$ | $60^o$ | $70^o$ | $80^o$ | $90^o$ | $100^o$ |

For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10286.

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# 1. INTRODUCTION

The Cockpit Electronic Display Workshop, sponsored by Federal Aviation Administration (FAA), was held April 7-9, 1992, at the Volpe National Transportation Systems Center (VNTSC) in Cambridge, Massachusetts. The workshop was conducted to identify questions and issues regarding electronic presentation of information in aircraft cockpits, especially in terminal area operations.

Electronic display of information in the cockpit–often referred to as the Electronic Library System (ELS)–has real and attainable advantages. It is likely to substantially reduce the amount of paper a flight crew has to handle, and can give the crew considerable flexibility in accessing information. However, this same capability provides an opportunity for a new family of design-induced errors, and can also reduce workload predictability.

The Cockpit Electronic Display Workshop was convened in order to identify display issues that should be addressed through human factors research in anticipation of difficulties that may be encountered in the design and identification of new electronic display formats. Professionals closely involved in design and certification of such displays were invited to identify areas of uncertainty that require further research.

Sample issues that were presented for discussion included the following:

- What information do flight crews need?
  - What "core information" must always be present?
  - How might this core information vary from one phase of flight to another?
- Which information can best be displayed electronically?
- Where in the cockpit should the information be displayed?
- In what format should the information be displayed?
- To what degree and under what conditions should the flight crew be allowed to change the appearance and information content of their displays?

The principal output of the workshop was a preliminary list of cockpit display issues that require research. These issues are tabulated in Section 6 of this synopsis.

# 2. ATTENDEE REPRESENTATION

Many of those professionals most closely involved in the design and certification of new electronic display formats were invited to attend the Cockpit Electronic Display Workshop. They included researchers in display design, display designers and manufacturers, airframe manufacturers, air carrier representatives, and FAA certification personnel. Six U.S. government sectors and sixteen private sectors were represented at the workshop. Table 2-1 categorizes the attendee representation for the workshop.

**TABLE 2-1.**
**ATTENDEE REPRESENTATION**

| |
|---|
| **FEDERAL GOVERNMENT SECTOR (6)** |
| Defense Mapping Agency |
| Federal Aviation Administration |
| National Aeronautics and Space Administration |
| National Oceanic & Atmospheric Administration/National Oceanic Survey |
| Air Force |
| Volpe National Transportation Systems Center |
| **PRIVATE SECTOR (16)** |
| ***Airlines (2)*** |
| Delta Air Lines |
| Northwest Airlines |
| ***Associations (1)*** |
| Air Line Pilots Association |
| ***Foreign Governments and Universities (2)*** |
| Transportation Development Center (Canada) |
| Concordia University (Canada) |
| ***Industry (7)*** |
| Boeing Commercial Airplane Company |
| Collins Commercial Avionics |
| Galaxy Scientific Corporation |
| Honeywell, Incorporated |
| Jeppesen-Sanderson |
| Monterey Technologies, Incorporated |
| Smith Industries |
| ***Private Consultants (1)*** |
| Prime Factor, Inc. |
| ***University and Research Organizations (3)*** |
| Battelle Memorial Institute |
| Embry-Riddle Aeronautical University |
| Massachusetts Institute of Technology |

## 3. WORKSHOP OBJECTIVES AND THEMES

The need for human factors research related to terminal-area operations of transport aircraft was recognized in the FAA's National Plan for Aviation Human Factors. However, the plan identified only a few specific research issues. The Cockpit Electronic Display Workshop had two main objectives:

- Identify human factors research issues related to depiction of terminal-area and approach information on air transport electronic cockpit displays.
- Provide a forum for discussing problems that can be expected to accompany design and certification of new-generation Electronic Library System display devices and formats.

Two categories of human factors technical issues formed the workshop program agenda. These were *system-level issues*, and *display-format issues*.

## 4. WORKSHOP FEATURES

The workshop program consisted of an opening plenary session, two special working group sessions, and a final plenary session. Presentations and discussions took place over two and one–half days of workshop activities.

*Plenary Session 1* was devoted to the presentations of 17 speakers representing the major interests in the aviation community concerned with human factors issues. These included government regulators, human factors researchers, and industry representatives. The purpose of these presentations was to establish a common understanding of research and operational environments that would influence the design of electronic displays.

Following Plenary Session I, two special working groups were formed. Each of these groups was charged with compiling a list of issues that required new or further research, in the collective opinion of group members.

*Working Group 1* (the Information Formatting Session) was assigned responsibility for developing specific research issues concerned with the layout of information presented on electronic displays. The moderator was Dr. John Hansman, Associate Professor of Aeronautics and Astronautics at Massachusetts Institute of Technology.

*Working Group 2* (the Systems Integration Session) identified research issues associated with the requirements of the flight crew for information and characteristics, and potential sources of that information in the cockpit. The moderator was Dr. Robert Hennessy, of Monterey Technologies, Inc.

In a concluding *Plenary Session 2,* working group moderators presented summary statements of session discussions, and read into the record lists of the research issues identified by the respective groups.

# 5. ABSTRACTS OF PRESENTATIONS

## System Issues – Overview

During the plenary session, papers concerning broad systems issues, the formatting of information on displays, information management with electronic library systems, display facilities, and certification issues were presented.

1. *System Considerations in the Design of Airborne Electronic Library Systems*, Frank E. Gomer, Honeywell, Incorporated (pp. 21-40).

   A description is given of an ELS evaluation program that Honeywell developed and tested in collaboration with American Airlines and Jeppesen-Sanderson. The purpose of this program was to look at the possibility of reducing, and eventually eliminating, requirements for paper information–manuals, charts, and checklists–on the flight deck (p. 25). In *Phase 1* of the evaluation, a work-station-based, rapid prototyping environment was developed to allow engineers and test pilots to work directly with ELS system components, including flat-panel display devices, control devices, mass storage devices, and printers (pp. 25, 32-34). The only feature of user interface to receive marginal ratings was response time for printing text pages and charts; this was 20 seconds for complicated plates/charts, and was attributed to workstation limitations. *Phase 2* involved a simulator flight deck using 15 three-person, B-727 flight crews (p. 35). ELS controls were co-located with the ELS display by using a touch-screen overlay. Results of simulations and recommended improvements are highlighted (p. 38, Tables 6-7). Following this program, Honeywell started a new ELS program with United Airlines, Jeppesen, and Boeing to improve understanding of data-integration issues (p. 39, Table 8).

   <u>Discussion</u>

   - The active area of the ELS display was inadequate to present a full standard approach plate. Honeywell concluded that the display active area needs to be 9 inches vertically by 7 inches horizontally–a significant problem for narrow-body aircraft retrofit installations (p. 37).

2. *Electronic Depiction of Flight Information*, Don Sellars, Jeppesen-Sanderson (pp. 41-63).

   Discussion focuses on the resolution of various displays and formats, as these might be presented in a cockpit ELS system. Advantages and disadvantages of raster graphics, CGM vector graphics, and object form graphics are reviewed in some detail (pp. 42-47, Tables 1-6). The principal advantages of *raster graphics* are faster and more efficient printing and fewer possibilities of display errors (p. 42). The principal disadvantage is that there is almost no inherent "intelligence" to a raster image–data cannot be coded or manipulated at will. Raster images also cannot be revised incrementally, have large storage requirements, and poor gray-scale capability (p. 42). The current ATA standard for *vector graphics* is computer graphics metafile (CGM) format. CGM advantages include superb hot-linking capability and reduced storage requirements. Disadvantages include greater screen drawing-time requirements than for raster images; inability to retain latitude-longitude information; lack of level differentiation (capability of selecting or de-selecting certain information); and the need for a high-level software integrity check to ensure errorless display. It is suggested that *object form graphics* have many advantages that make them the format of the future. These features include excellent hot-linking capability; superb intelligence embedded in the data; and selection/deselection of non-mandatory data (p. 46, Table 5). Disadvantages are that object form is currently beyond state-of-the-art; requires a high-level integrity check to ensure errorless display; and often generates visual conflicts that are not easily detected (p. 47, Table 6). Write-protection of data files is an issue (p. 50). Airlines will need to develop policies for pilot selection of mandatory and non-mandatory information (p. 54, Table 8). Landscape (horizontal) data files are a further challenge (p. 54). It is sometimes difficult to get the data on one frame (p. 55A, Figure 6). The capability of panning across a large image (creating a window) or zooming into an image (enlarging the image) may help solve problems of landscape data presentation (pp. 56A-57A, Figures 7-8). Several electronic chart revision issues need to be resolved. These issues include determination of granularity of objects; decision to revise or replace; effectivity dating; revision-cycle compatibility with various sources of data; and compatibility of navigation, paper, and electronic charts (p. 62, Table 10).

Discussion

- Resolution of visual conflicts in dynamic displays will have to involve good expert systems and extremely fast computers (p. 59).

3. *Implementation Capability and Constraints Associated with Electronic Terminal Chart Display*, Jim Curran, Collins Commercial Avionics (pp. 64-73).

Issues related to the implementation of electronic terminal chart displays are discussed. Electronic terminal chart display will offer certain benefits. These advantages include highlighting of certain information; de-cluttering of information; support of phase transitions (gate-to-gate); and support of autonomous airplane navigation (p. 65, Table 1). *User interface issues* include user acceptability, format (static north-up versus track-up moving map), interactive mechanisms (menu-tree chart selection, panning and zooming), fonts, clarity of display, and color (p. 66, Table 2). Certain *technology implementation issues* also need to be considered in developing navigation chart display capability. One group of implementation issues includes system integration, processor throughput, memory capacity, and display characteristics (p. 67, Table 3). Another group involves display sizes and orientations, access-display response time, real-time aircraft position display, and graphics encoding (p. 67, Table 4). A third group of implementation issues includes data integrity, data format, and data compression standard (p. 68, Table 5). A phased approach to electronic chart display is suggested (p. 69). A near-term approach to electronic chart display might implement procedural charts (SIDs, STARs, and approach plates); orientation would be north-up only; chart mode would be static and features minimal (p. 69, Table 6). The long-term approach might implement area-en route charts; orientation would be track-up; chart mode would be dynamic and features would be maximum (p. 69, Table 6).

Discussion

- In regard to resolution of flat-panel displays, it is important to relate psychophysical data to display resolution data. Resolutions for flat-panel displays may not need to exceed 210 to 220 pixels/inch (p. 71).
- There is some question as to the minimum LCD resolution requiring no antialiasing (p. 71).
- Resolutions are being pushed higher and higher to accommodate new types of display technology (p. 72).

## Dynamic Aspects of Display Formatting

4. *Design and Evaluation of Advanced Electronic Chart Displays for Instrument Approach Information*, Mark Mykityshyn, Massachusetts Institute of Technology (pp. 74-85).

A review of experimental results involving electronic instrument approach plates (EIAPs) is given. These results were based on a two-phase experiment by the MIT Aeronautical Systems Laboratory using pilots currently qualified on glass-cockpit aircraft (p. 74). *Phase 1* was designed to study the effect of paper, monochrome electronic, and color electronic IAP charts on pilot preference and performance in IAP-related information retrieval tasks (p. 76). *Phase 2* was an effort to explore prototypical IAP formats and an IAP de-cluttering technique (p. 75). A majority of pilots ranked the color format first, when compared with the paper and monochrome formats used (p. 77-78A). Response times while using the color format also were generally faster (p. 77, 79A). Error rates for performance questions were higher than expected (p. 77, 81A). The study showed that there is no degradation in performance with transition from paper IAP format to electronic format (p. 77). In fact, there was a slight performance gain associated with the changeover. A majority of the pilots preferred the north-up chart (p. 82). Most pilots said they wanted to have the IAP separate from the primary navigation display (p. 82). Participating pilots liked the de-cluttering feature of the electronic chart and thought it should be incorporated (p. 85).

Discussion

- Boeing has found that the display orientation issue depends on the pilot's task (p. 83). For planning tasks, north-up orientation works well. For tracking tests (flying a designated path or flying guidance), track-up mode works well.
- Boeing reports that pilots complained about following a southern track on north-up presentations (p. 83).
- Further research is needed in the area of standardizing display colors for various functions (p. 84). Some experts believe that colors should be "intuitive"–green for the ground, red for obstructions, and another color for the flight track. Once chosen, the colors would be common standards used by all manufacturers.
- Some individuals believe that symbols should also be standard (p. 84).

5. *Advanced Terrain-Depiction Research*, John Hansman, Massachusetts Institute of Technology (pp. 86-99).

The main focuses of current MIT research are terrain situational awareness, and terrain alerting (p. 87). Discussion focuses on preliminary MIT studies of terrain situation-awareness displays, and a prototypical graphical ground-proximity warning system (GGPWS) (p. 92A, Figure 4). Current spot elevation symbols were compared with a smoothed contour display (p. 87, 88A-89A). Experiments featured vectors into terrain or microburst alerts. Crews performed better, on average, with the smooth-contour displays (p. 91). However, they would not fly into spot elevation icons (p. 91). One conclusion of these studies is that when crews assume ATC has responsibility for terrain separation, they show a low sensitivity to display format (p. 95, Table 2). Conversely, when pilots assume responsibility for terrain separation based on cockpit displays, the hazard recognition rate is much higher. Also, an aircraft symbol on the terrain display may enhance visual awareness (p. 95, Table 2).

Discussion

- An advanced terrain-depiction system will most likely fuse sensor systems with data base systems (p. 96A, Figure 7).
- The alerting criteria (maneuvering limits) for three-dimensional GPWS systems are an important issue (p. 97).
- A related issue is whether pilots be given cues for escape guidance information once terrain is detected. (p. 97).

## Information Management and Electronic Library Systems

6. *Flight Crew Information Requirements*, Tim Brabec, Northwest Airlines (pp. 100-107).

Discussion presents one airline's vision of the ideal data system for today's electronic airplanes. Certain pilot expectations are central to this vision (p. 101, Table 1):

- Give me only what I need (p. 102, Table 2);
- When I do need it, give it to me fast (p. 103, Table 3);
- If you know it, do it–most of the time (p. 103, Table 4);
- Picture it rather than say it–if practical (p. 104, Table 5);
- Don't forget it–unless I tell you to (p. 104, Table 6);
- What if I do list it? (p. 104, Table 7);
- Don't expect me to know how to operate it (p. 105, Table 8);
- Don't lie to me (p. 105, Table 9).

"Are data dangerous?" is the main question that must be answered if data systems are to be used profitably (p. 106, Table 10).

7. *Why the Pilot-Automation Interface Can Become a Killing Zone: A Plea from the Operational Community*, Jack Maher, Delta Airlines (pp. 108-112).

Discussion focuses on the proposition that the present generation of automated aircraft has reached, and in some cases has exceeded, the cognitive limitations of the human operators (p. 108). Task overload, a form of stress, is suggested as the primary cause. No new research on the effects of stress on human judgment has been undertaken in the last 20 years (p. 109). There also has been no research in an automated cockpit setting to examine the known biasing that individuals and dyads experience when overloaded (p. 109). Today's pilot asks for simplicity in the data portrayed, and in the procedures needed to use them (p. 110). Design and operational recommendations include the following:

- Accomplish hardware and software design in a language that harmonizes with the way pilots *think* when they fly (p. 111);
- Design pilot and crew into the loop during low-load events, and unload crew during high-load events (p. 111);
- Apply error-resistance and error-checking artificial intelligence programs to all programming functions (p. 111);
- Do not build hard electronic cocoons (p. 111);
- Build aircraft that can internally generate precision glide slopes (p. 111).

Discussion

- Pilots' need for innovative display concepts, such as three-dimensional views, is questioned (p. 112). A plea is made for simplicity.

8. *A Review of NASA Langley's Flight Deck Information Management Research Program*, William Rogers, NASA Langley Research Center (pp. 113-125).

The goals of NASA Langley's information management research program are to document current and future information management problems; understand information-management requirements; and explore design concepts and guidelines, as well as automatic information-aiding (p. 114, Table 1). The followinig three NASA Langley information management experiments are discussed:

- The development of an information management taxonomy based on information attributes (such as quantity, salience, and format). The taxonomy will be tested using a group of ASRS incident reports (p. 116).
- A categorization and prioritization experiment that is attempting to learn how pilots think about flight-deck information and the tasks it supports (p. 117).
- An experiment designed to assess the effects of situation factors and some cognitive factors on information demand. This experiment is called MAPLIST, for Management of Approach and Landing Information Study, and is attempting to learn how pilots use the information on approach plates (p. 117; 118, Table 2).

One goal of MAPLIST is to understand how pilots use information as a function of variables such as time, flight conditions, stress, and fatigue so that constraints can be applied to that information by designers for use in a communication management system (p. 119). Another goal is to put this information in expert systems or in intelligent aids so automation can manage some of the information in displays (p. 119). The test design for MAPLIST requires subject pilots to actively select information they need (p. 121, Table 3).

Discussion

- Techniques for data selection/deselection may hide information that the pilot might otherwise refer to in another display format (p. 123).
- Marginally important information will require more selection effort from the pilot because of task manipulation penalties (p. 123).

9. *Flight Deck Information Display: A Human Engineering Analysis Approach,* Elfie Hofer, Boeing Commercial Airplane Company, Flight Deck Research Group (pp. 326-352).

A human engineering analysis process for the development of flight-deck information requirements is outlined. This process is being used by Boeing to identify the "critical" information set required to execute selected approaches under normal operating conditions (p. 331). The process addresses the following phases (p. 326):

- Requirements
- Design
- Evaluation
- Operation

In the requirements phase, the first step is to determine what tasks, functions, or display configurations need to be changed from what is currently available (p. 327). The goal of information requirements analysis is to obtain performance data to validate the critical information set and to assess which display formats are conducive to better task performance (p. 331). A multi-phased approach of increasing fidelity for the assessment and validation of flight-deck information requirements analysis is recommended (p. 339). Steps in this process include analytical assessment; validation through such methods as part-task simulation; and collection of hard-flying performance data and eye-track data (p. 339). The design phase needs to answer two questions: (1) Are all the needed information items represented on the electronic flight-deck displays? (2) Are symbols available to represent those information items not already part of an existing display? (p. 334) Other design issues include the resolution of symbols used on paper media that are to be integrated into existing flight-deck displays; the selection of a suitable display medium; and the legibility of presentation (p. 334). The evaluation phase needs to determine whether the information items, as well as the chosen symbols, support the tasks performed by the subjects (p. 347; 348A-351A, Figures 9-12).

Discussion

- Operational surveys to assess information criticality or priority may be misleading unless there is validation using alternative methods (p. 339).
- Because of differences among users, prioritization of approach information on Boeing displays will be operator-specific, with the most critical items on the top information layer (p. 342).

## Electronic Display Research Facilities

10. *Display Visibility: Avionics Design Implications*, Charles Lloyd, Phoenix Technology Center (pp. 126-136).

    Constraints of current display technology and human visual sensitivity are discussed. Display visibility problems associated with viewing displays in high ambient lighting environments are enumerated (p. 127, Table 2; p. 128). A strong emphasis is placed on the need to study the appropriateness of various display formats under the actual ambient lighting environments in which they will be used (p. 129). It is suggested that fundamental design questions need to be answered before display formatting proceeds too far (p. 129, Table 4; p. 130). Display visibility human factors research issues are identified, including image utility as a function of display brightness; the number of colors/shades of gray that can be distinguished; the amount of detail that can be put on a chart display; the method for processing sensor images so as to increase utility; and transition time between a forward scene and a head-down display (p. 130, Table 5). The research facilities available for studying constraints of human visual sensitivity are also described (p. 131, Table 6; 132A, Figure 1; 133, Table 7).

    Discussion

- Morning fog and pilots' quick transition from bright above-clouds luminance levels to in-the-clouds low luminance levels need to be considered in HUD raster formats (pp. 135-136).

11. *VNTSC Cockpit Display Facility*, Karl Hergenrother, Volpe National Transportation Systems Center (pp. 137-139).

    A new Volpe Center technology suite for testing human factors issues related to glass displays is described. Past testing of human subjects has been on a Silicon Graphics Iris host and VAPS rapid prototyping software, a simulation model that has been more applicable to small jet display issues than those of light aircraft (p. 137). The Volpe Center is purchasing a Frasca 242 twin simulator that will be substituted for the Silicon Graphics model in experiment cycles (p. 137). The simulator will be configured to resemble the Beechcraft Baron on which the Volpe Center validates its experimental results. There will be no motion simulation, but an out-the-window display is planned (p. 137). The Volpe Center currently plans to get active liquid-crystal displays, VGA and SVGS quality 6-by-8 inch and 3-by-4 inch displays (p. 138).

    Discussion

- The applicability of research findings—either in simulation or in flight-test programs—may be constrained if the design of the display used is not appropriate for those environments, i.e., if the display is not flight-worthy and does not have viewing-angle corrections assigned to it (p. 138).

12. *Boeing 777 Liquid Crystal Display Issues*, John Wiedemann, Boeing Commercial Aircraft Company (pp. 140-158).

Discussion focuses on the shift in cockpit information presentation from the B-747-400 CRT (cathode-ray tube) to the B-777 LCD (liquid crystal) displays, and the ramifications of this shift. Boeing encountered two conversion issues during their work on the 777 (p. 140):

- *Information layering*: display of certain pieces of information more prominently than others (p. 140);
- *Graphic primitives*: use of basic display building blocks such as color, line width, and intensity (p. 143, Table 1).

Past CRT display techniques included grouping certain information in a particular place; highlighting or de-emphasizing certain information; and designating priority areas or masking certain information (p. 143). LCD displays required two new display techniques (p. 146): priority levels of symbols, and "haloing"–drawing black lines around parts of symbols to make them stand out. Haloing dramatically affected the legibility of the symbols when there was an overshaded or raster-type background (p. 151). It was a problem to make displays readable with a shaded background on LCDs. The definition of graphic primitives, (i.e., line widths, halo thicknesses, color coordinates) will be ongoing at Boeing until the year 1993 (p. 156).

<u>Discussion</u>

- ◆ Intensity with the LCD has been a problem, but upgrades in technology have achieved more stability in the LCD image (p. 156).
- ◆ LCD contrast at night has been another problem (p. 157). LCDs have good contrast under sunlight, but at night their contrast diminishes.
- ◆ There is an issue of whether the transition from CRTs to LCDs was a good idea, since LCDs do not achieve the contrast needed (p. 157).

13. *Research Issues in Head-Up Display Symbols and in Display-Sensor Integration*, Richard Huntoon, Collins Commercial Avionics (pp. 159-161).

A series of research questions related to symbology in head-up displays (HUDs) are presented:

- What does the user of the information need to do the job? (p. 158)
- What is the form or format in which the user needs the information? (p. 159)
- How do we compensate for the absence of color coding in HUD symbology? (p. 159)
- How do we handle "visual tunneling" in HUD applications - for example, failure to detect unexpected obstacles on the runway? (p. 160)
- Is there a problem with accommodation to HUDs? Is a different scanning technique needed for HUDs? (p. 160)
- How should pilots control the airplane when using HUDs?–with velocity vector or pitch? (p. 160)
- What happens when "conformal" displays (HUD, FLIR, radar, TV) don't conform? (p. 160)

It is noted that results of many studies related to these issues are in conflict, and that these and other issues need to be resolved before HUD systems are installed in commercial aircraft (p. 161).

14. *Three-Dimensional Display Issues for Terminal-Area Operations*, William F. Reinhart, Phoenix Technology Center, Honeywell Incorporated (pp. 162-179).

Discussion focuses on how 3-D displays might be practically applied in the area of terminal-area-operations (TAO) displays. Common misconceptions about 3-D displays are discussed and refuted (pp. 162-163). Potential 3-D display uses are described. These possibilities include stereoscopic displays for highlighting (p. 163, 165); perspective overlay on top of information (p. 165; 166A, Figure 2); highway-in-the-sky formats for curved approaches and segmented glide slopes with an MLS or differential GPS system (p. 165; 167A, Figure 3); controlled-flight-into-terrain (CFIT) avoidance (p. 165; 168A, Figure 4); TCAS plan-view displays (p. 165; 171A-172A, Figures 7-8); approach procedures charts (p. 165; 173A, Figure 9); and air traffic control applications (p. 174; 175A, Figure 10). Three general categories of 3-D research issues are identified as follows:

- *User function issues*: visual and cognitive biases, training issues, and image quality and user acceptance (p. 174, Table 2);
- *3-D technology parameter selection*: examples include spatial, chromatic, and temporal aspects of display devices; and support of real-time 3-D graphics (p. 176, Table 3);
- *3-D display formatting issues*: selection of 3-D techniques and alternative formats (p. 177, Table 4).

It is concluded that 3-D is not only feasible, but perhaps critically important for near-term terminal-area operations (p. 177, Table 5).

Discussion

- Known disadvantages to flying a 3-D display include problems in transitioning to an out-the-window environment, and individual vision differences (p. 178).
- Display augmentation in more than three dimensions needs to be considered, such as depiction of time, fuel state, and other running parameters (p. 179).

15. *Rate-Field and Perspective Problems Related to Two-Dimensional Presentation Devices*, Jim Blanchard, Embry-Riddle Aeronautical University (pp. 180-186).

A description is given of Embry-Riddle's development of a forward-channel-visual flight simulation system tested in an 1989 study (p. 180). The test bed for the simulation study was a Frasca 141 simulator (p. 184). Two main problems were identified in going to three dimensions from two: *rate-field distortion* and *perspective* (p. 180; 181, Table 1). It was concluded that a 60° field-of-view will not be sufficient if anamorphic 3-D displays are used on flight decks (pp. 181-182). Undefined problems using a highway-in-the-sky option were that "low" seemed too steep, "above" felt like a descent, and cues were lost in the washout (p. 183, Table 2). The study results have been duplicated twice by Embry-Riddle using a HUD with 9-inch and 10-inch monitors (p. 184).

Discussion

- The image source for the initial study was a 4-inch Sony TV monitor modified to have a four-channel visual system with 60° of information (p. 184). Although some distortion and perspective problems originated with the small size of the monitor, it is suggested that these problems will also be major factors in any 3-D depictions on the flight deck.

## Certification Issues

16. *Tentative Liquid-Crystal Display Certification Requirements*, Howard Berk Greene, Federal Aviation Administration, (pp. 187-195).

Certification criteria relevant to the transition from cathode-ray-tube (CRT) cockpit displays to liquid-crystal displays (LCDs) are discussed. The SAE A-4 committee has developed some criteria for active-matrix and traditional segmented liquid-crystal (flat panel) displays. These criteria have been modified and supplemented to reflect FAA experience with these types of displays (p. 187; 188, Table 1; 189, Table 2; 190, Table 3). Advisory Circular 25-11 has provided acceptable guidance for installation of CRTs in transport category aircraft. The FAA will probably change AC 25-11 by adding LCDs and other details that seem pertinent (p. 187). The LCD criteria discussed include viewing envelope (pp. 187-188), ambient lighting (p. 190), matrix anomalies (p. 191), line width uniformity (p. 191), symbol quality (p. 191), *symbol motion (p. 192), image retention (p. 192)*, defects (p. 192), contrast ratios (p. 192), and requirements for activated and unactivated segments (p. 193).

Discussion

- Readability (uniformity of contrast) is an issue related to LCDs. Boeing initially encountered this problem with its LCDs until it manipulated line widths and intensity to create an illusion of depth (p. 194).
- Use of eye glasses can produce a concave rather than a convex effect with flat panel displays (p. 194).

17. *Research Issues and Certification Concerns*, George Lyddane, Federal Aviation Administration (pp. 196-208).

General issues and concerns related to Flight Management Systems (FMS's), predictive wind shear systems, integration of the IRS and air-data information, navigation display issues, and synthetic vision display issues are discussed. Interdependency of the INS (inertial navigation system), IRS, and GPS is one concern (p. 196). There are no published requirements for comparison logic to exist in order to alert the pilot when certain sensors are deviating from the norm (p. 196). In many cases, the pilot doesn't really know what is going on in the navigation system (p. 197). For this reason, there is a need for system designers to add how-goes-it information with raw data (p. 197). Predictive wind shear systems are discussed next. Several airlines are looking at systems that are infrared based (p. 198). The FAA has tentatively proposed that short-range predictive wind shear systems provide guidance at least 10 seconds before the wind shear is encountered (p. 199). Nuisance alerts are a problem with wind shear systems being tested (p.

199). Integration of the IRS and air-data information during time-critical phases of flight is another concern. Pilots are not being trained to deal with multiple display failures in critical flight phases (p. 202). In some aircraft, if the symbol generator fails, it disables three displays (p. 202). In terms of navigation display issues, there is need for up-indicated INS data to be provided on pilot selection (p. 205). Research issues associated with HUDs include the following:

- How can gamma be used during a takeoff or during a go-around? (p. 202)
- Should head-up and head-down displays be permitted in the same airplane? (p. 203)
- Should air transport HUDs incorporate low-speed and high-speed protection requirements like those for GA aircraft? (p. 203)
- When using a HUD, is it a supplemental piece of information or a primary piece of information? (p. 203)

Synthetic vision display issues discussed include implementation of predictive braking systems and high-speed taxiway depiction (p. 206), and display scenery issues such as texture, peripheral cues, and flare capability (p. 207).

Discussion

◆ If HUDs are considered primary category equipment, are they also considered critical? (pp. 204-205)

18. *Chart Content as It Relates to Electronic Library Systems*, Leroy Addis, Smith Industries (pp. 225-246).

Five areas of concern in relation to chart content Electronic Library Systems are identified (p. 225):

- Format of the navigation chart or the electronic version of it (pp. 226A-229A, Figures 1-4);
- Size and shape of the chart as it relates to display area available;
- Use of color;
- Symbols, as these relate to the EHSI (electronic horizontal situation indicator) and other cockpit displays;
- Data interchange standards.

A major challenge is to identify essential chart information and the time at which it is needed (p. 225). Electronic displays allow selection of mode-dependent information (p. 231, Table 1). Suggestions are made as to the type of information that may not be usable or that may be deselected (p. 232, Table 2). Flight-mode information requirements are discussed (p, 232, Table 3). Studies need to address the issue of whether mode selection should be automatic or manual (p. 231). Integration of information from other avionics, such as ACARS, raises the possibility of conflicts in presentation of information (p. 233, Table 4). It is concluded that electronic displays need some standardization, and also need to be tailored to available display size and shape (p. 233; 234, Table 5; 236, Table 6). Matters of color, gray-scale capabilities, and resolution must also be considered (p. 236, Table 7; 237A-242A, Figures 7-12).

## 6. RESEARCH ISSUES

This section presents 79 research issues associated with the electronic display of information in the cockpit. These subjects are grouped into nine categories ranging from formatting to research methodology issues (Tables 6-1 through 6-9). The issues were identified through a review of the proceedings developed from the discussions in the working group activities and the summary statements presented during the closing activities and closing plenary session. The original list, as it was developed from the proceedings, was shortened to reduce duplication. The remaining items were paraphrased to produce questions that were researchable and could be understood by those who did not attend the discussions.

**TABLE 6-1. DISPLAY FORMATTING (1)**

| | |
|---|---|
| 1 | What are the advantages and disadvantages of electronic presentation of taxiing charts in the cockpit? |
| 2 | What are the advantages and disadvantages of presenting orientation and guidance information for taxiing either on the same or on different display presentations? |
| 3 | How can SID and STAR information be adapted to dynamic displays, since paper depictions of these procedures are not to scale? |
| 4 | What are the advantages and disadvantages of using dot density rather than gray scale to depict terrain contours when they are shown on the navigation display? |
| 5 | What are minimum horizontal and vertical resolutions required by the pilot to effectively use electronic terrain displays for obstacle avoidance? |
| 6 | How should information elements on electronic displays be designed to alert pilots of the need to take specific corrective action? |
| 7 | What design guidelines should be used to determine when manual or automation-assisted management should be used to determine the information content of electronic displays? |
| 8 | How can the negative influences on pilot situational awareness of automating pilot aviation, navigation, and communication functions in the terminal area be reduced through the design of electronic displays? |
| 9 | What information and design characteristics must be present in electronic charts to ensure pilot situational awareness regarding location and performance during the execution of terminal procedures? |
| 10 | What is the proper sequence for the display of instrument approach procedure information, how much control should the pilot have over this sequence, and under what conditions should the sequence be variable or changed? |
| 11 | What are the influences upon crew coordination of variations between crew displays in the electronic formatting of instrument approach information? |
| 12 | What individual differences among pilots should be accommodated by visual displays in the cockpit? |
| 13 | What are the advantages and disadvantages of perspective and pictorial navigation displays as compared to formats currently used with electronic cockpit displays? In particular, with regard to supporting pilot manual control, situational awareness, and speed and accuracy of information transfer? |
| 14 | What are the implications of GPS navigation for the formatting of terminal area information on cockpit displays ? |

**TABLE 6-2. DISPLAY FORMATTING (2)**

| | |
|---|---|
| 15 | How can electronic instrument approach procedure charts be designed to minimize pilot workload from the top of descent through the final approach and missed approach phases of terminal operations? |
| 16 | What is the most easily assimilated graphical format for presenting terrain information? |
| 17 | How should terrain map information be displayed electronically? How should it be formatted for integration into enroute and terminal area navigation displays? What are the influences on pilot performance of various formatting options? |
| 18 | What are the advantages and disadvantages of electronically depicting terrain in plan, perspective, and profile views? |
| 19 | When pilots are executing and visualizing instrument approach procedures, do they think in terms of multiple two-dimensional or in three-dimensional images? |
| 20 | What characteristics of electronic airport maps increase their utility for ground maneuvering, or reduce their utility for ground maneuvering? |

**TABLE 6-3. RULES AND GUIDELINES (1)**

| | |
|---|---|
| 21 | What are the sensor and display resolution requirements necessary to support dynamic taxiing charts? |
| 22 | What are the functional requirements of ELS displays designed for use with and without a paper backup, and how do they differ? |
| 23 | Should the guidelines that are used to determine the rate, order, density, and formatting of information presented for use during normal flight conditions be the same as those used under non-normal flight conditions? If not, how should they differ? |
| 24 | To what degree does paper printout material have to match the same material presented electronically? |
| 25 | What guidelines should be applied to the use of color, font design, line width, and symbol characteristics in the electronic depiction of aeronautical charts and instrument approach procedures? |
| 26 | What guidelines and analytic procedures should be used for allocating information required for terminal area navigation among cockpit displays? |
| 27 | What data are required to support the development of design criteria, based on flight crew performance, for evaluating new display formats? |
| 28 | What are the electronic display image quality criteria that must be met in order to ensure display usability under cockpit conditions? How do these criteria differ for color, achromatic, LCD, CRT, and HUD-type displays? |
| 29 | What rules and guidelines currently exist for the formatting of information on electronic displays? What changes and qualifications are necessary for their application to cockpit displays? |
| 30 | What design guidelines are available to determine whether cockpit displays should be in a vertical or horizontal orientation? |

**TABLE 6-4. RULES AND GUIDELINES (2)**

| | |
|---|---|
| 31 | What display or operational markers are needed for indicating when displays are too saturated with data to be used effectively? |
| 32 | What documented, rule-of-thumb, and judgmental guidelines are currently used by display designers for formatting graphics and alphanumeric data for electronic depiction on cockpit displays? |
| 33 | What are the documented, rule-of-thumb, and judgmental guidelines used by FAA flight test and certification personnel for evaluating information formatting on electronic cockpit displays? |
| 34 | What guidelines should be observed in the application of tools and procedures for accessing and manipulating information available to the pilot, on electronic charts used to depict terminal and instrument approach procedures? |
| 35 | What standard set of cockpit conditions should be used to evaluate the readability of electronic map and text displays? |
| 36 | What are the minimum conditions that have to be met in order to achieve valid tests of controls and information formats used in the cockpit with electronic displays? |
| 37 | What methods of measurement, figures of merit, and performance thresholds should be used in simulation testing of cockpit displays? Measures should address both flight safety and operating efficiency. |
| 38 | What guidelines should be used for determining the application of multifunction display menus to electronic displays, particularly with regard to menu sequences and information criticality? |
| 39 | What are the operational requirements and formatting characteristics necessary to ensure the appropriate degree of correspondence between electronic displays, cockpit controls, and out-of-the-window views? |

**TABLE 6-5. DATA BASE CONSIDERATIONS**

| | |
|---|---|
| 40 | The use of data bases to drive dynamic map displays may result in slow and jerky movements. How does this influence the design and utility of the map displays? |
| 41 | What tools are available for the application of stochastic data to moving map displays? What operational conditions must be considered in their application? |
| 42 | How can uncertainty in the accuracy of data base information used to support the electronic depiction of terrain be accommodated? |
| 43 | What will the influence of data base standardization, or the lack of it, be on terrain depiction? |
| 44 | What kinds of errors are likely to appear in electronic depiction of data base information, and how can the detectability of such errors be increased? |
| 45 | What are the advantages and disadvantages of the various means of merging synthetic vision with other terrain data bases? |
| 46 | What are the technical and human factors issues associated with merging synthetic vision with other terrain data bases? |
| 47 | What are the pilots' requirements for terrain information during enroute and terminal operations, and how do they differ? |
| 48 | What are the pilots' requirements for information during each phase of terminal operations for normal, non-normal, and emergency operations? |

**TABLE 6-6. DISPLAY TECHNOLOGY**

| | |
|---|---|
| 49 | Under what conditions is information on head-up displays (HUDs) effectively used? When is it not useful or detrimental? |
| 50 | What display features, such as trackup, zooming ,or windowing, are available for use with dynamic electronic maps? What options are available to the display designer in the implementation of these tools? Under what conditions are the various options advantageous or disadvantageous to the pilot? |
| 51 | What are the advantages and disadvantages of display control devices, such as trackballs and keyboards, for controlling cockpit map displays? |
| 52 | What are the differences in the evolution of cockpit displays between large air carriers and general aviation cockpits, and how should these differences be addressed in the design and evaluation of electronic displays? |
| 53 | How must information formatting be designed to accommodate different display technologies such as CRTs and LCDs, and chromatic and achromatic displays? |
| 54 | What differences in display technology should be considered in the development, standardization, and evaluation of information formats, and how should these differences be accommodated? |
| 55 | What characteristics of electronic displays are required to represent the spatial frequencies existing in paper charts, and how will these be influenced by color? |
| 56 | What determines, and what are the processing requirements (e.g., triangles per second) for displaying terrain electronically? |
| 57 | What are the advantages and disadvantages, under the full range of cockpit brightness conditions, of raster video images for depicting terminal procedure information on head-up displays? |
| 58 | How does pilot control of the HUD influence pilot performance on other tasks? |
| 59 | What are the influences of the HUD raster image on pilot operations that depend on out-the-window viewing, such as visual landings, taxiing, and the detection of obstacles and obstructions? |

**TABLE 6-7. COLOR**

| | |
|---|---|
| 60 | To what degree can the use of colors and symbology on electronic approach plates be standardized, and what are the advantages and disadvantages of partial standardization? |
| 61 | What colors and symbols and what application of these should be used on electronic IAP charts? |
| 62 | How does performance on color vision tests used in pilot flight physicals relate to performance on cockpit tasks involving color displays? |
| 63 | What influences do color vision anomalies existing in the current pilot population have on the use of color displays and annunciators in advanced technology cockpits? |

## TABLE 6-8. SYSTEMS INTEGRATION

| | |
|---|---|
| 64 | What similarities must there be between information presented on paper and on electronic media to ensure compatibility? |
| 65 | What are the advantages and disadvantages of displaying terrain and weather information on the navigation display? |
| 66 | How can electronic depiction of STARs, terminal procedures, and SIDs be used to facilitate FMS operations? |
| 67 | What are the functional requirements and technical and human factors issues associated with integrating the FMS and electronic depiction of terminal procedures? |
| 68 | What are the influences of nonconformance between synthetic vision and the real world on pilot performance? |
| 69 | What are the human factors control and display issues associated with having datalink interact with terminal area procedure displays? |
| 70 | Under what conditions should the information normally presented on a single instrument approach plate be integrated into electronic navigation displays or be distributed among a number of displays? |
| 71 | Which of the cockpit displays should be used to show terrain information? |
| 72 | What limits the usefulness of mode-status and mode-change annunciations currently used with automated cockpit systems? How should the design of these annunciators be changed to improve their usefulness? |
| 73 | What are the advantages and disadvantages of envelope protection features in flight management systems for crew alerting during long-range extended missions? Under what conditions should they be used or not used? |
| 74 | How should notes and other text information presently presented on conventional instrument approach plates be handled with dynamic, electronic approach plates? |

## TABLE 6-9. METHODS

| | |
|---|---|
| 75 | Models of electronic displays that can be used to assess the influences of display technology on information formatting need to be developed and evaluated. |
| 76 | What analytic procedures should be used for determining pilot information requirements during abnormal operations? |
| 77 | What are the advantages and disadvantages of cooperative research activities among researchers, designers, producers, and users; and how can such cooperation be promoted? |
| 78 | Identify and evaluate analytical methods that are effective in developing operational scenarios that will be useful for evaluating cockpit map displays. |
| 79 | How can methods based on a functional analysis of line-oriented flight tasks be used to determine flight crew requirements necessary to navigate in the terminal area in the year 2010? |