Design and Evaluation of Advanced Electronic Cockpit Displays For Instrument Approach Information

by

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Systems and human engineering design issues associated with the electronic presentation of Instrument Approach Plates (IAPs) are investigated. Specifically, the effects on information retrieval performance and pilot preference that are induced by the capabilities and limitations of electronic systems are addressed. The information content of current IAP paradigms, and the relative importance of this information at certain points during the execution of a published instrument approach were investigated through a user centered survey of IAP information requirements. The survey produced an information database from which several Electronic Instrument Approach Plate (EIAP) chart modes were constructed. These charts were evaluated using a Boeing 757/767 part-task flight simulation that sought to identify specific areas where improved human engineering in IAP design could create a more efficient information transfer to improve pilot performance and further enhance flight safety. Selectable Instrument Approach Plate information presented to the pilot in a color, electronic display separate from the primary navigation display was observed to be the most effective means of information transfer. Potential problems associated with the implementation of these electronic IAP systems are identified.

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# Table of Contents

Abstract ......................................................................................................................... 2  
Acknowledgements ........................................................................................................ 3  
Table of Contents ......................................................................................................... 4  
List of Figures .................................................................................................................. 6  
1. Introduction .............................................................................................................. 7  
2. Background ............................................................................................................... 9  
   2.1 Documentation of IAP Design Deficiencies ..................................................... 9  
   2.2 Approach Procedures and Information Transfer ............................................ 9  
   2.3 Current IAP Structure and Design ................................................................. 10  
   2.4 Discussion ......................................................................................................... 14  
   2.5 Electronically Based Instrument Approach Plates ....................................... 14  
      2.5.1 Information Update ................................................................................ 15  
      2.5.2 Format Flexibility and Enhanced Display Capability ............................ 15  
      2.5.3 Potential Problems ................................................................................. 16  
3. Survey of IAP Information Requirements ............................................................ 17  
   3.1 Objectives ......................................................................................................... 17  
   3.2 Survey Approach and Design ....................................................................... 17  
   3.3 Survey Results ................................................................................................ 18  
      3.3.1 General IAP Usage .............................................................................. 20  
      3.3.2 IAP Information Analysis .................................................................... 22  
         3.3.2.1 "Information Element" Defined .............................................. 22  
         3.3.2.2 Identification of "Critical" and "Extraneous" IAP Information Elements 22  
4. Electronically Based Instrument Approach Plates ............................................... 27  
   4.1 Information Selection and Decluttering .......................................................... 27  
   4.2 Design Overview ............................................................................................. 29  
      4.2.1 Experimental Charts ............................................................................ 29  
      4.2.2 EIAP Prototype Charts ....................................................................... 31  
5. Part-Task Flight Simulation Experimental Study .................................................. 36  
   5.1 Experimental Goals ......................................................................................... 36  
   5.2 Experimental Design Overview .................................................................... 36  
   5.3 Simulation Facility ......................................................................................... 37  
   5.4 Subject Selection ............................................................................................. 39  

4
List of Figures

Figure 2.1 Representative Jeppesen Instrument Approach Plate .................. 12
Figure 2.2 Representative NOAA Instrument Approach Plate ..................... 13
Figure 3.1 Representative Information Element Selection Process, Approach Phase
(Yellow+"Critical", Pink="Extraneous") ......................................... 19
Figure 3.2 Information Contributing to IAP Clutter .................................... 20
Figure 3.3 Example of the Information Element Ranking Procedure .............. 24
Figure 3.4 IAP Information Element Flow Diagram .................................... 26
Figure 4.1 Prototype Information Layering Scheme .................................... 28
Figure 4.2 Example of Experimental Paper Chart ..................................... 30
Figure 4.3 Color Scheme For Electronically Based IAPs .............................. 31
Figure 4.4 Example of Experimental Color Chart ..................................... 33
Figure 4.5 Example of Track-Up (Moving Map) EIAP Prototype Chart .......... 34
Figure 4.6 Representative EFIS Integrated Prototype Chart ....................... 35
Figure 5.1 MIT Part-Task Simulation Facility ......................................... 38
Figure 5.2 Explicit Information Retrieval Performance Questions ................ 40
Figure 5.3 Relative Ranking Scale ....................................................... 41
Figure 5.4 Representative Experimental Matrix ....................................... 42
Figure 5.5 Representative Approach Scenario ....................................... 43
Figure 5.6 Representative Terrain “Fly-Through” Scenario ....................... 45
Figure 6.1 Experimental Chart Ranking ................................................ 49
Figure 6.2 Experimental Chart Task Ranking .......................................... 51
Figure 6.3 Average Response Time Per Chart ......................................... 53
Figure 6.4 Phase I Error Rate ............................................................ 55
Figure 6.5 Phase I Terrain Penetration Data .......................................... 56
Figure 6.6 EIAP Prototype Chart Ranking ............................................. 58
Figure 6.7 EIAP Prototype Chart Task Ranking ....................................... 59
Figure 6.8 Preference Ranking For All Chart Modes ................................ 62
Figure 6.9 Phase II Terrain Penetration Data .......................................... 62
Figure 6.10 Preferences For Electronic IAPs .......................................... 64
1. Introduction

One of the most complex and crucial tasks required of today's commercial transport aviator is the approach and landing of the aircraft during Instrument Meteorological Conditions (IMC). An Instrument Approach Plate (IAP) similar to those depicted in Figures 2.1 and 2.2 provides the pilot with the requisite navigation, communication, and obstruction information to effect a smooth transition from enroute flight to a safe and expedient approach to landing, or the execution of a missed approach at an airport under these weather conditions.

Currently, IAP information is presented in paper format only. There are two widely used IAP formats in the United States that have evolved in the absence of any formal human factors review. However, these designs have been developed through a mature design process evoked by user feedback and a concern for flight safety. The detailed formats of these charts represents a cartographic balance of innate design tradeoffs including cost considerations, chart size versus legibility, and liability of the charting agency.

On the paper charts, the information required for all user groups and all situations is contained on a single chart because it is too expensive to produce separate charts for different user groups. The small size of the chart (8.5 x 5 in.) forces the textural print to be quite small in order to accommodate all the information that it must contain. Fear of litigation and the ultimate liability of the charting agency often preclude the cartographer from removing marginally useful information from the chart. Therefore, the resulting IAPs tend to contain a high information content and may have clutter problems. The high information content and complexity of the IAP may adversely affect the users' ability to easily and accurately extract the information that is required to safely execute the approach procedure.

Electronically based Instrument Approach Plates (EIAPs) offer a more flexible medium to present approach information to the pilot. However, because of electronic display limitations, larger type fonts and symbol sizes are required to avoid aliasing problems. As a result, it may be desirable to use the flexibility of the electronic format to adjust the information displayed during certain phases of the approach to minimize clutter problems.
This thesis results from an endeavor to investigate IAP information requirements and to resolve IAP presentation and clutter issues. IAP information requirements have been addressed through a user centered survey which explored IAP information content, usage patterns, and crew preferences in order to more accurately assess the information requirements of advanced EIAP charts. IAP presentation and clutter issues were addressed through a part-task flight simulation experiment in which pilots evaluated several EIAP prototype charts, and a prototype IAP information selection and decluttering technique.

The investigations and findings are presented as follows. Chapter 2 briefly summarizes the motivation for this work, describes a typical instrument approach procedure, and discusses the structural design of current IAP formats. Chapter 3 reviews the Survey of Information Requirements for Instrument Approach Charts, including pilot opinion concerning the replication of paper IAP information in electronic format. Chapter 4 discusses electronically based IAPs, while Chapter 5 outlines the objectives of the part-task flight simulation experiment and describes the experimental procedure. Chapter 6 contains a discussion of experimental results and findings. A summary of this effort is contained in Chapter 7.
2. Background

2.1 Documentation of IAP Design Deficiencies

Instrument Approach Plates depict terminal arrival and missed approach procedures that are performed at low altitudes with minimal terrain clearance and a subsequently low threshold for procedural error. Even though the IAP often contains a high level of cartographic and procedural complexity, it has evolved to its current format in the absence of any formal human engineering review [Hansman and Mykityshyn, 1990]. However, IAP design deficiencies have been previously documented on several occasions.

The Special Air Safety Advisory group (SASAG) was contracted by the Flight Standards Service of the Federal Aviation Administration (FAA) in 1976 in order to study approach and landing procedures, vertical guidance and navigation information, and air traffic control systems. Part of their findings indicated that current IAP designs were "superb as a legal document, but a disaster as a work tool" [Ashworth et al., 1976]. They concluded that IAPs were too cluttered with unnecessary information that was presented in textural print too small to read at night or in turbulent conditions.

The Presidents Task Force on Aircrew Compliment was commissioned in 1980 to evaluate the DC-9-80 for certification with a two versus three man crew compliment. During its certification review process, the Task Force further identified IAP design deficiencies, citing that "instrument approach charts are frequently designed in a way that makes them difficult to use" [McLucas et al., 1976].

Finally, the 1985 FAA Human Factors Plan identified chart design as a cockpit human performance problem area which could be addressed through formal human factors research. The review process has been subsequently designed in order to identify areas where improved human engineering in IAP design could create a more efficient information transfer.

2.2 Approach Procedures and Information Transfer

Instrument approach procedures have been designed in order to meet the criteria as outlined in the United States Standard for Terminal Instrument Procedures (TERPS) manual. As such, they are designed to unambiguously define the approach procedure. An
important criteria of these procedures is that they help to ensure that both the pilot and air
traffic controller are aware of the state of the aircraft at all times relative to airport
orientation (correct runway alignment), and to potential aviation hazards that exist within
the terminal area.

The increased demand for air travel has generated the development of new and more
complex instrument approach procedures that were designed to make use of the available
airspace, especially in high density hub areas. Since communications with air traffic
control (ATC) are limited within the terminal area and tend to include only the minimum
information needed to define the approach procedure to be followed, pilots use the IAP as
the primary source of approach information. As such, with a general trend over the past
ten years toward crew compliment reduction in commercial aviation, IAP information needs
to be presented in a "clean" format that allows the pilot to easily and accurately extract the
vital information.

In a recent survey of current air carrier pilots [Mykityshyn and Hansman, 1990],
93.1% stated that it was possible to make operational errors in the cockpit that can be
directly attributed to charting considerations. Chart interpretational errors such as the use
of outdated information, misinterpretation, or the inability to accurately extract vital IAP
information from among "clutter" can often be corrected by either the flight crew or ATC.
However, if these errors remain uncorrected, the aircraft may be placed in a hazardous
situation.

2.3 Current IAP Structure and Design

In the United States, the two most widely used IAP formats are manufactured by
Jeppesen Sanderson, Inc., and the United States Government (NOAA and the Department
of Defense in conjunction with the FAA). In the following, Jeppesen Sanderson, Inc.
charts are referred to as Jeppesen, while U.S. Government charts are referred to as NOAA.
Specifications for NOAA low altitude instrument approach procedures are developed by the
Interagency Air Cartographic Committee (IACC) which is composed of representatives of
the Department of Commerce, Department of Defense, and the Federal Aviation
Administration. Jeppesen charts are manufactured "in house" and comply with internally
generated specifications.
Both of these formats are typically printed on 8.5 x 5 in. paper and include plan and profile depictions of the approach, as well as information concerning communications, minimums, and terrain. While there are variations in detail, both Jeppesen and NOAA IAPs are constructed using the same basic structural format that is depicted in Figures 2.1 and 2.2, respectively. The format is discussed below.

- **Area A: Communication and Airport Identification Information**

The top section of the IAP is used to identify the approach procedure. Communication information is depicted in the upper left corner of Area A on the Jeppesen IAP, while this same information is presented in Area B (plan view depiction) on the NOAA chart. Communication information is depicted in such a manner so as not to interfere with significant items of the approach procedure. Terminal area communication information is depicted by name; i.e., "New York Approach". The Minimum Safe Altitude (MSA) circle is depicted on the Jeppesen IAP, while this same information is presented in Area B (plan view depiction) on the NOAA chart.

- **Area B: Plan view Depiction of the Terminal Area**

The plan view depiction is a north-up overhead view of the terminal area that depicts the instrument approach procedure. Supplemental information such as enroute facilities, feeder facilities, approach facilities, missed approach, terminal routings, and communications are also depicted. Enroute and feeder facilities are used for depicting terminal routes from Radio Aides to Navigation (NAVAIDS), fixes and intersections to the initial approach facility or fix. Ground information such as terrain hazards to aviation also appear in the plan view.

- **Area C: Profile Depiction of the Terminal Area**

The profile view is a "side" view of the aircraft flight path that portrays vertical guidance and navigation information. The facilities and intersections identified in the procedure to be used in the final approach segment with minimum altitudes as required by the procedure are depicted. Both mean sea level (MSL) and above ground level (AGL) altitudes are depicted above and below the course line, respectively. Missed approach instructions are depicted in both graphic and narrative form.
Figure 2.1 Representative Jeppesen Instrument Approach Plate.

Reproduced with permission of Jeppesen Sanderson, Inc.
Figure 2.2 Representative NOAA Instrument Approach Plate.
Area D: Minima Data

The bottom of the IAP depicts landing minima data for the airport. This data consists of the Minimum Descent Altitude (MDA) or Decision Height (DH), Runway Visual Range (RVR) or visibility, and Height Above Airport (HAA) or Height Above Touchdown (HAT). Ceiling-visibility minimums are depicted in statute miles for various approach types and aircraft approach speed categories. Aircraft "performance" information such as ground speed, approach procedure timing, and aircraft descent rates are also depicted. An airport diagram is included on the NOAA IAP, while Jeppesen presents an enlarged version of this same information on a separate page.

2.4 Discussion

The variability in IAP formats reflect the different design balances chosen by each cartographic agency. These differences result from individual philosophies regarding several design tradeoffs such as chart size versus legibility, information content versus chart clutter, cost considerations, and liability.

Regardless of design philosophy, both charting agencies encourage and solicit user feedback in order to identify specific chart errors, and to recommend changes for chart improvement. Data from accident and incident investigations used in conjunction with user comments constitute the primary source of feedback. Substantial format changes are generally implemented based on the best cartographic judgement of the senior management at Jeppesen, or the Inter-Agency Cartographic Committee of the U.S. Government.

2.5 Electronically Based Instrument Approach Plates

Electronic Library Systems (ELS) are currently being developed for use in commercial transport aircraft to initially supplement, and ultimately to help replace paper manuals, including IAPs. Although there is some concern about the impact of major format changes for paper IAPs, the flexibility and capabilities of electronically based information systems provide an opportunity to reevaluate and, if necessary, change conventional IAP design parameters. Currently, some approach information; i.e., aircraft trajectory and flight path, is available electronically on Electronic Flight Information Systems.
However, full depiction of all IAP information on these display systems is unavailable. In the near future, electronically stored data could be used to generate EIAPs [Mincer, 1988] that will interact with aircraft flight control, navigation and communications systems. Potential advantages offered by EIAPs include information update, format flexibility, and enhanced display capability. Potential problems include display clutter, and short term cost, and workload considerations.

2.5.1 Information Update

The currency of information contained on conventional paper IAPs is limited by the preparation and update cycle of the charting agency. NOAA charts are completely updated and redistributed on a 58-day cycle, with a Change Notice (CN) issued midway through the cycle. Jeppesen APs are revised on a 14-day cycle which allows changes to be implemented much more rapidly. However, these changes are individually reissued. Therefore, a substantial amount of manual labor is required in order to update the IAP set. This revision process provides a large opportunity for collation error, and is extremely expensive to implement.

EIAPs that are generated by electronically stored data could be easily uploaded to the aircraft as a unit. This uploading process would provide for enhanced control and ensure that current chart data is maintained. Also, manual labor costs associated with the revision process would be alleviated, and the opportunity for input error would be minimized. In the long term, costs will be reduced as paper IAPs are eventually replaced.

2.5.2 Format Flexibility and Enhanced Display Capability

One of the advantages of electronically based IAPs is the potential format flexibility. Electronically generated IAPs could be used to selectively display or suppress information at the discretion of the pilot to provide for a "clean", less cluttered presentation. Such EIAPs would require some mechanism to provide for an information selection and decluttering capability.

Another advantage of electronically based IAPs is an enhanced display capability that could include the depiction of IAP information in color. Type fonts and symbol sizes could be varied while providing for a chart scaling capability. More descriptive terrain alerting methods such as smoothed color contour lines that provide pilots with an intuitive
representation of potentially hazardous terrain could be added. Graphical Ground Proximity Warning Systems (GGPWS) [Kuchar, 1991] that use colors or patterns in order to indicate various terrain hazard levels could also be added. These features could provide a direct interface between the chart and the Flight Management Computer (FMC) which would reduce operator error.

2.5.3 Potential Problems

Due to resolution limitations that exist in current cockpit rated display systems, type fonts and symbol sizes must be increased in order to maintain legibility and readability of the display. Consequently, clutter problems that exist on current paper IAP formats will be exacerbated when IAP information is presented in electronic format.

One solution is to selectively declutter the chart. However, in order to accomplish this, the information presented on the display needs to be separated into individual elements or, layered. This layering process requires an object oriented database in which symbols and text are treated as individual items. The implementation of a detailed, object oriented database for EIAPs requires a substantial short term financial commitment on the part of the cartographic agency. Another factor which needs to be addressed for information selection is the impact on flight crew workload.
3. Survey of IAP Information Requirements

3.1 Objectives

Electronic Library Systems and the possibility of electronically based IAPs provide an opportunity to reconsider conventional IAP design parameters. Since increased text and font sizes are required to attain requisite display legibility, the EIAP format could be used to adjust the information displayed during certain phases of an instrument approach to minimize clutter problems.

The primary goal of the survey was to evaluate IAP information requirements during the execution of an instrument approach. The importance of specific information elements was recorded as a function of phase of flight. In addition, the information content of current IAP formats was reviewed, and pilot opinion data concerning EIAPs, as well as information selection and decluttering were collected.

3.2 Survey Approach and Design

Initially, a user centered survey of IAP information requirements (Appendix A) was distributed to a group of pilots who were selected to represent the full spectrum of IAP users from major domestic air carriers to general aviation. However, 88% of those who responded were current air carrier pilots. Survey respondents were all male and averaged 39 years in age with approximately 5000 total flight hours. Approximately 20% of the pilots were experienced in "glass-cockpit" aircraft.

The survey contained four parts. Section I ("Background") collected personal information and flight experience data. Pilots were also asked to indicate any familiarity they had with computer systems, and/or any experience with Flight Management Computer (FMC) equipped aircraft.

Section II ("General IAP Usage") was designed to evaluate the information content of current IAP formats. Data concerning IAP experience, and preferences for chart formats were accumulated. Pilots were also asked to indicate on a scale from 1 (No contribution to clutter) to 5 (Significant contribution to clutter) how much specific IAP information contributed to chart clutter. Pilot opinion data concerning the amount of time spent locating
Section III ("Approach Plate Information Analysis") was the primary focus of the survey. Here, pilots indicated their preferences for IAP information as a function of phase of flight in order to analyze the dynamics involved with information selection. For example, at a specific point, pilots might consider certain information to be "critical" to have access to, while at another point this same information might be considered to be "marginally useful".

"Pre-approach", "approach", and "missed approach" phases of flight were subjectively constructed in accordance with the guidelines as outlined in the United States Standard for Terminal Instrument Procedures (TERPS) manual. The Jeppesen IAP format was selected for this procedure because it is used by more than 90% of U.S. commercial airlines [Hansman and Mykityshyn, 1990]. Since the critical information elements are essentially the same for both NOAA and Jeppesen IAPs, the same results should be applicable to both.

Pilots were presented with the sample IAP depicted in Figure 2.1 for each phase of flight and asked to separately identify the approach information they felt was "critical" (and "extraneous") for that phase. Pilots indicated their preferences for IAP information by highlighting in yellow the information they felt was "critical" to have access to. Information that was considered to be "extraneous" and that would be suppressed, if possible, was highlighted in pink. Information which pilots felt was neither "critical" nor "extraneous" was not highlighted. A typical IAP resulting from this procedure for the approach phase is depicted in Figure 3.1.

The final section of the survey, "Electronic Approach Charts", was incorporated in order to collected pilot opinion data concerning electronically based IAPs and the concept of information selection and decluttering. Pilots also commented on issues concerning IAP "customization". Results from the analysis are presented and discussed in Chapter 6.

3.3 Survey Results

The survey attained a response rate of 9.7% (29 respondents). This low rate was thought to be attributed to the extensive nature of the survey, which took approximately 1.5
Figure 3.1 Representative Information Element Selection Process, Approach Phase. ("Yellow"="Critical"; Pink="Extraneous")
hours to complete. The respondents were self-selected, and may have had opinions regarding instrument approach information that differed from the general user group. Therefore, the data analyzed below may not be fully representative of the pilot community.

### 3.3.1 General IAP Usage

Pilots indicated how certain IAP information contributed to chart clutter and the amount of time spent locating and interpreting information while in the terminal area. In addition, pilots were asked to cite operational errors (if any) that could be directly attributed to current IAP formats. Results are depicted below in Figure 3.2.

![Figure 3.2 IAP Information Contributing to Chart Clutter.](image)

As can be seen in Figure 3.2, pilots indicated that terrain information contributed the most to chart clutter.

"...For my purposes, remove terrain information from the IAP entirely. Give me a single, close-in area chart showing terrain and significant geographic features within 20 nautical miles of the airport. Use color, and make it look like a sectional chart ... I can look that over while in cruise. I don't need or want that information on the IAP..."
Some pilots offered differing opinions that included increasing the amount of terrain information that is depicted on the IAP. However, 84.3% of the responding pilots indicated that they would like to see the amount of terrain information contained on an IAP reduced.

"...Too much undesirable information is contained on the plate in the form of transition altitudes, spot-elevations, and other terrain information that should be excluded...Just give me the MSA and I have all the obstacle clearance information I need..."

Of those pilots that responded, 93.1% felt that it is possible to make operational errors in the cockpit that are due to charting considerations. The most frequently cited critical operational error related to IAP design was confusion between the primary and secondary NAVAID frequency; 47% of the responding pilots reported making this error. However, 59% indicated that a new paper IAP format is neither warranted nor desired.

Most of those responding indicated that IAPs were difficult to read in low lighting conditions, and in turbulent weather. Users indicated that the charts could be made more readable by “getting rid” of some information and increasing the size of the print.

"...This question must consider phase of flight. Lots of information and a "busy" chart may be O.K. in the pre-approach phase (after receiving the ATIS but still in cruise or early descent), but the chart clutter becomes a major handicap as the approach progresses. You must also consider ambient lighting and flight conditions. When you are sitting at a desk in good light with all the time you need, the chart looks fine to you. If I’m looking at a chart at night in poor lighting conditions and flying in light turbulence and I’m in a hurry, I can’t find the information I need..."

Some of the information contained on the IAP appears to be situation dependent. A large portion of those surveyed felt that it is possible to make errors in the cockpit that are due to charting considerations. Therefore, it may be necessary to provide pilots with some mechanism to control the amount of information contained on EIAps.

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1 ATIS (Automatic Terminal Information Service) information provides approach and landing information that is generally acquired prior to terminal area entry.
3.3.2 IAP Information Analysis

3.3.2.1 "Information Element" Defined

In order to tabulate pilot preferences concerning instrument approach information, it was first necessary to define an "information element". This was the primary unit of measure used by pilots throughout this procedure to indicate their preferences for information during the execution of an instrument approach.

As it pertains to an IAP, an information element can be defined as a quantity of information that cannot be subdivided and still have utility in the completion of the task at hand. Taken in this context, an example of an information element is a localizer frequency for an instrument landing system (ILS) approach. Procedurally, for the pilot to correctly execute the ILS approach, both the numerical frequency itself and its identity as the localizer frequency as well must be specified for the element to be useful.

Though the frequency itself consists of several digits and a decimal point which would require a certain number of bits to code in an engineering system, the whole frequency has no useful meaning to the pilot except as a complete element. Note here that the specific coding method used to present an information element may be mixed within the element. For example, the localizer numerical frequency itself may be presented with alphanumeric text, but its identification as the localizer frequency may be indicated by its location on the approach chart, the type font used for the frequency, or with a symbol. Because an information element is defined by utility, (which depends upon the task being performed) it is difficult to develop strict criterion that can be used to identify information elements across widely different tasks. However, by recognizing each information element as being well-defined for a given task, the analysis was predicated on this information element definition as an initial assumption.

3.3.2.2 Identification of "Critical" and "Extraneous" IAP Information Elements

In order to analyze the dynamics involved with information selection as a function of phase of flight, the most critical information elements were identified [Mykityshyn and Hansman, 1990] from a procedure that scored all information elements contained on the IAP with a "Net Interest Ranking".

22
Pilots indicated their preferences for "critical" and "extraneous" IAP information for each phase of flight using the following procedure. On a typical IAP, each subject indicated which information elements were "critical" by highlighting them in yellow. Information that was considered to be "extraneous" and would be suppressed, if possible, was highlighted in pink. Information elements that were neither "critical" nor "extraneous" were not highlighted.

The total number of "critical" minus "extraneous" scores for each information element were tabulated and normalized by the total number of respondents. This calculation generated a "Net Interest Ranking" that was used as a criteria to rank all information elements for each phase of flight. An example of this procedure for the pre-approach phase is depicted in Figure 3.3.

Pilot preferences for specific information elements increase with rank. A higher rank indicates a higher preference, while a lower ranking indicates a lower preference. The procedure described above was used to identify those information elements for each phase of flight that were the most preferred and the least preferred. Data for all phases has been provided in "An Exploratory Survey of Information Requirements For Instrument Approach Charts" [Mykityshyn and Hansman, 1990].

As can be seen from the example, those information elements that attained a "Net Interest Ranking" greater than 0.4 were clearly identified as the most preferred. Below 0.4, the number of elements above any critical "Net Interest Ranking" threshold is very sensitive to the value of the "Net Interest Ranking" chosen by individual users. Those information elements that attained a "Net Interest Ranking" of zero or below were clearly identified as unnecessary, and would be suppressed if possible.  

The width of the plateau between the most preferred and the unnecessary information elements illustrates the large dispersion of opinion concerning the amount of information required in order to execute an instrument approach. It also indicates the difficulty in reducing chart clutter.

It seemed unlikely that IAP information requirements could be resolved in a such a manner that would satisfy all user group preferences. The width of the plateau also

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2 A "Net Interest Ranking" value of "zero" means that an equal number of respondents indicated yes and no to the information element.
Figure 3.3 Example of the Information Element Ranking Procedure.
suggests that the depiction of specific information elements may depend on user preferences and the situation. Therefore, it seemed logical for pilots to individually control the total amount of specific information elements presented on the chart.

Both the total amount of information, and the flow of specific information elements were tracked throughout each phase in order to investigate the hypothesis that information requirements change as a function of phase of flight. An illustration of this procedure is depicted on the following page in Figure 3.4. Data for all phases has been provided in "An Exploratory Survey of Information Requirements For Instrument Approach Charts" [Mykityshyn and Hansman, 1990].

It can be seen from Figure 3.4 that the amount and content of the preferred information changed with each phase. Respondents preferred to see a total of 20 information elements for the pre-approach phase of flight, 27 for the approach phase of flight, and 25 for the missed approach phase of flight.

Preferences for specific information elements also changed with each phase. For example, only 9 of the 20 preferred information elements from the pre-approach phase were included among the 27 information elements for the approach phase. Differences in information requirements indicate a clear separation between the approach and missed approach phases. Pilots preferred a total of 52 information elements from the approach and missed approach phases of flight; however, only 11 information elements (21.2%) were common to both.

Results from this procedure indicate that information requirements clearly change as a function of phase of flight. However, the dispersion of opinion regarding the amount of information required to execute the approach suggests that depiction of specific information elements may depend on the situation and user preferences. Therefore, it seemed logical to provide pilots with some mechanism to individually control the information contained on EIAPs.
### Phases of Flight

#### Pre-Approach
- Approach
- ILS Course
- ILS DME Box
- Minimums (Category)
- RVR (Category)
- Airport
- City
- Missed Approach Instructions
- Kennedy VOR
- ATIS Arrival Frequency
- MSA Altitude Depiction
- Approach
- Localizer Frequency
- La Guardia VOR Frequency
- Glide Slope Intercept Altitude (MSL)
- ATIS Arrival Frequency (NE)
- ATIS Arrival Frequency (SW)
- Tower Frequency
- Ground Speed (Category)
- Timing (Category)

#### Approach
- ILS Course
- Minimums (Category)
- ILS DME Box
- Missed Approach Instructions
- Glide Intercept Altitude (MSL)
- RVR (Category)
- Tower Frequency
- IAF Name
- Glide Slope Intercept Altitude (MSL)
- Final Approach Course
- FAF Name
- Approach
- Localizer Frequency
- Missed Approach Heading
- Missed Approach Fix
- Glide Slope Intercept Altitude (MSL)
- FAF DME
- EAF Intercept Altitude (MSL)
- TDZE
- Glide Intercept Altitude (AGL)
- TDZE DME
- Glide Slope Intercept Altitude (AGL)
- Airfield Diagram

#### Missed Approach
- Missed Approach Instructions
- Missed Approach Heading
- Approach Frequency
- MSA Altitude Depiction
- Airfield Diagram
- Kennedy VOR
- Tower Frequency
- Airport
- Ground Frequency
- City
- Approach
- Localizer Frequency
- Approach Plate Date
- Approach Plate Page
- ATIS Arrival Frequency
- MSA Identify
- ATIS Arrival Frequency (NE)
- ATIS Arrival Frequency (SW)
- Airport Elevation
- FAF Name
- FAF DME
- ILS DME Box
- DME

---

**Figure 3.4 IAP Information Flow Diagram.**
4. Electronically Based Instrument Approach Plates

Results from the survey described in Chapter 3 indicated that pilots felt that current IAP designs are too cluttered which detracts from their ability to extract the pertinent information. They also felt (Figure 3.2) that terrain information was a major contributor to chart clutter (84.3% thought that it should be reduced). Although 72.4% of pilots surveyed supported electronically generated IAPs, the increased font and symbol sizes that are necessary to prevent aliasing will exacerbate existing clutter problems. In this Chapter, the design of various experimental and prototypical charts is discussed. A prototype IAP information selection and decluttering technique is also presented.

4.1 Information Selection and Decluttering

A prototype information selection and decluttering feature was designed in order to provide a mechanism to control the amount of information contained on the display. Baker [1960] showed that as the amount of "irrelevant" information on a display increases, the time required to "search" for and locate desired information increases proportionately. As such, the amount of clutter present on current IAP formats directly affects the time it takes to locate desired information.

Due to resolution limitations of current cockpit rated electronic displays, it is necessary to provide a display decluttering capability. One approach that is currently in use on many Electronic Flight Information System (EFIS) displays is grouping the information into various layers. This information may either be shown alone, or in combination with other information layers. For example, on the nominal 757/767 EHSI, pilots can either maintain or suppress information from one of four layers: NAVAIDS, airports, intersections, and weather radar information.

Electronically based IAPs will be used to display complex Terminal Arrival and Missed Approach procedures that often require a high density of information in order to be accurately depicted. Therefore, due to the increased detail and complexity of this information and existing display resolution limitations, the development of an expanded multi-layer decluttering technique was required.

In a prototypical EIAP decluttering design, six information categories were constructed based on an analysis of IAP information elements [Mykityshyn and Hansman,
1990], liaison with Jeppesen Sanderson, and in accordance with the TERPS manual. In a manner similar to the current 757/767 EHSI, each of the six categories was linked to an individual switch. The specific information contained on each is depicted in Figure 4.1.

The expanded multi-layer decluttering technique was necessary to accommodate IAP information that is not available on current EFIS displays. The selectable information available on current EFIS displays is primarily concerned with navigation related information; however, it seemed logical to group approach information in an IAP specific manner. Therefore, each of the six switches contain information elements that specifically pertain to executing the approach.

<table>
<thead>
<tr>
<th>1. Primary Approach Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>• ILS Arrow</td>
</tr>
<tr>
<td>• ILS/DME &quot;Box&quot;</td>
</tr>
<tr>
<td>• Altitudes (MSL &amp; AGL)</td>
</tr>
<tr>
<td>• Vertical Distance Lines (Profile)</td>
</tr>
<tr>
<td>• Fix/Marker Beacon Graphical and Textural Identification</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2. Secondary NAVAIDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>• All Other NAVAIDS</td>
</tr>
<tr>
<td>• DME Distances (Planform &amp; Profile)</td>
</tr>
<tr>
<td>• Intersections</td>
</tr>
<tr>
<td>• Procedural Notes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3. Terrain Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Obstacles</td>
</tr>
<tr>
<td>• Airports</td>
</tr>
<tr>
<td>• Spot Elevations</td>
</tr>
<tr>
<td>• MSA Circle</td>
</tr>
<tr>
<td>• Water</td>
</tr>
<tr>
<td>• Notes That Specifically Pertain to Terrain</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4. Minimums</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Category Specific Procedure Information</td>
</tr>
<tr>
<td>• Category Specific &quot;Performance&quot; Data: i.e., Ground Speed, Timing, G.S.</td>
</tr>
<tr>
<td>• Localizer Only Course. Profile View (Dashed Line)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5. Missed Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Graphics</td>
</tr>
<tr>
<td>• Text</td>
</tr>
<tr>
<td>• Missed Approach Fix and Cross-Radials Used for Identification</td>
</tr>
<tr>
<td>• Holding Fix/NAVAIDS and Cross-Radials Used for Identification</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>6. Procedure Turn</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Procedure Turn (Graphics &amp; Text)</td>
</tr>
<tr>
<td>• Holding Pattern Procedure Turn (Graphics &amp; Text)</td>
</tr>
</tbody>
</table>

Figure 4.1 Prototype Information Layering Scheme.
A part-task flight simulation experiment was designed in order to test the prototype decluttering method and the prototype EIAPs. The experimental design and procedure is described in Chapter 5.

4.2 Design Overview

In order to investigate the transition from paper to various electronic IAP formats, three experimental IAP charts were designed. They were Paper, Monochrome, and Color. In order to evaluate potential EIAP designs, and to investigate information selection and decluttering methods, three EIAP prototype charts were designed. They were North-Up (Static), Track-Up (Moving Map), and EFIS Integrated.

The three experimental charts and three EIAP prototype charts were generated using the following design methodology. Starting with the conventional paper IAP and the current conventional EFIS, the designs were constructed in increasing technical levels toward more advanced electronically based IAPs. Each electronically based IAP was derived from the current paper IAP format and current EFIS, and was designed to utilize the format flexibility provided by electronic systems. The prototype information selection and decluttering capability described above was also investigated. A brief description of each experimental chart is provided below.

4.2.1 Experimental Charts

1) Paper: This experimental chart is depicted in Figure 4.2 and was modelled after the Jeppesen IAP format with two modifications so as to have the same dimensions as the experimental electronic charts discussed below. Font sizes were larger, and the physical size of the chart was elongated vertically by approximately 10%. The paper chart was used as a control from which pilots could base their reactions to increasingly non-conventional charts.

2) Monochrome Electronic: This chart was designed to electronically replicate the Paper chart described above with alphanumerics presented in black against a white background. This chart was designed to match the Paper chart in order to investigate the transition to electronic format; however, this was not considered viable for operational use. A more practical operational design would be to present alphanumerics in white against a black background.
Figure 4.2 Example of Experimental Paper Chart.
3) **Color Electronic**: In this mode, (Figure 4.4) IAP information was presented in color against a black background. The color scheme that was selected for this mode was consistent with the primary navigation display contained on current Electronic Flight Information System (EFIS) equipped aircraft. However, two additions were made; obstruction information was depicted in yellow, while missed approach information was depicted in red. The color scheme used for this mode is depicted below in Figure 4.3.

<table>
<thead>
<tr>
<th>Information</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terrain</td>
<td>Yellow</td>
</tr>
<tr>
<td>Missed Approach</td>
<td>Red</td>
</tr>
<tr>
<td>Course</td>
<td>Magenta</td>
</tr>
<tr>
<td>NAVAIDS</td>
<td>Blue</td>
</tr>
<tr>
<td>Text</td>
<td>White</td>
</tr>
<tr>
<td>Track</td>
<td>Green</td>
</tr>
</tbody>
</table>

**Figure 4.3 Color Scheme For Electronically Based IAPs.**

### 4.2.2 EIAP Prototype Charts

The North-Up (Static), Track-Up (Moving Map), and EFIS Integrated charts described below have been referred to as "EIAP Prototype Charts" since they more closely resemble potential EIAP designs. The color scheme incorporated into each was the same as the color mode described in Figure 4.3 above. They also featured a prototype information selection and decluttering capability described in section 4.1. A brief description of each is provided below. They are depicted in Figures 4.4, 4.5, and 4.6, respectively.

4) **North-Up (Static)**: This EIAP prototype chart is depicted in Figure 4.4 and is based on the Color chart described above. However, the information selection and decluttering capability described in section 4.1.2 was added to the display, along with a moving aircraft symbol. This symbol was displayed on both the plan view and profile depictions in order to provide real-time aircraft position and navigation information.

5) **Track-Up (Moving Map)**: This EIAP chart is depicted in Figure 4.5 and is a prototype moving map with the same color convention and decluttering capability as the North-Up prototype chart. The plan view depiction could be configured as either a moving
map or a conventional north-up depiction. When configured as a moving map, the plan view replicated the current EHSI. Pilots could scale it from 2.5 miles (full scale) to 80 miles. When selected as a conventional north-up depiction, the plan view did not contain the moving aircraft symbol that was depicted in North-Up prototype chart described above.

6) **EFIS Integrated**: This EFIS Integrated chart is shown in Figure 4.6. This was the final design iteration and represented the most non-conventional EIAP design. The current paper IAP was directly merged with the EHSI primary navigation display since pilots are familiar with both. Information that is normally presented on the current IAP plan view was integrated with the EHSI, while a profile depiction was presented electronically below the EHSI. A switch contained on the EIAP control box enabled pilots to convert the normal EHSI moving map presentation to a static, north-up mode for approach planning; consequently, while operating in this mode, pilots had no access to real-time aircraft navigation information. Communication frequencies and procedure minima data were presented in a separate window that was dedicated to textural information. The MSA circle was also overlaid on the EHSI. It should be noted that this display was developed by simply adding the information contained on the paper IAP plan view to the EFIS. Therefore, this may not represent an optimized display design.
Figure 4.4 Example of Experimental Color Chart.
Figure 4.5 Example of Track-Up (Moving Map) EIAP Prototype Chart.
Figure 4.6  Example of EFIS Integrated EIAP Prototype Chart.
5. Part-Task Flight Simulation Experimental Study

5.1 Experimental Goals

To date, no studies have been conducted to investigate the effects on pilot performance when instrument approach information is presented to the pilot in various electronic (vs. paper) formats. Therefore, a part-task simulation experiment was developed to investigate the systems and human engineering issues that are induced by the capabilities and limitations of electronic systems. The experiment was constructed with the following objectives.

1) Investigate the impact of experimental IAP charts on information retrieval performance and pilot preference. Specifically, Paper versus Electronic, and Monochrome versus Color were compared.

2) Investigate the feasibility and desirability of a prototypical IAP information selection and decluttering technique.

3) Investigate the feasibility and desirability of potential EIAP prototype charts. Specifically, North-Up (Static) versus Track-Up (Moving-Map), and EFIS Integrated versus Separate EIAP displays were evaluated.

5.2 Experimental Design Overview

The experiment consisted of two distinct Phases. Phase I was designed to study the impact of Paper, Monochrome Electronic, and Color Electronic IAP charts on pilot preference and performance in IAP related information retrieval tasks. As such, this phase was carefully counterbalanced. Pilots who are currently qualified line pilots flying autoflight equipped aircraft (B-757/767, etc) flew several approaches using each chart. Phase II was designed as an exploratory effort in order to evaluate potential EIAP prototype charts and information selectability issues, and as such, was not counterbalanced.
5.3 Simulation Facility

The part-task flight simulation experiment was conducted using the MIT Advanced Cockpit part-task simulator shown schematically in Figure 5.1. The simulator replicates the "autoflight" systems of a typical advanced automated, "glass-cockpit" transport category aircraft including the Flight Management Computer (FMC), Electronic Horizontal Situation Indicator (EHSI), and Mode Control Panel (MCP). Additional displays (including EIAPs) can be added to the simulator through the IRIS 4D computer on which the primary flight displays are presented.

Pilots generally agreed that the simulation environment was accurate and realistic for the tasks that they were asked to perform. Since the experiment was concerned with cognitive issues rather than airmanship skill, the fact that the MIT part-task simulator is not "full motion" had no deleterious effects on the experiment. Major simulator components are discussed below.

- **Flight Management Computer:** In a manner similar to 757/767 series aircraft currently in service, the MIT simulator has a Control Display Unit (CDU) that contains an alphanumerics keyboard and display that provides for pilot input and control of the FMC. Although the simulator CDU provides for flight path programming and updates, all routes flown during the simulation were pre-programmed into the CDU in order to provide the pilot with more time to evaluate the electronic IAP display formats.

The simulator is "flown" through the autoflight system using either the Flight Management Computer or Mode Control Panel. The simulator contains a replication of the 757/767 autothrottle and autoflight systems to include an LNAV/VNAV capability, and a "hold and capture" mode for altitude, vertical speed, airspeed, and heading. Situational awareness cues are provided to pilots by a small visual external display that has been incorporated into the simulator.

- **Electronic Flight Information Systems:** The Electronic Horizontal Situation Indicator (EHSI) contains a moving map display where the pilot may select various presentations, including a track-up MAP mode that contains programmed flight path and navigational information, or an ILS mode that depicts glideslope and localizer information. The EHSI panel allows the pilot to scale the map display range, and to switch between MAP and ILS modes as desired.
• **Communications and Provisions for Air Traffic Control**: The simulation facility contains a separate IRIS based ATC/Experimental Station which can present either an ATC display, or replicate the flight displays for experimental monitoring. During simulation runs, one experimenter can monitor the particular scenario from the ATC/Experimenters station and impersonate an Air Traffic Controller communicating through a radio link with the "flight station".

**Simulator Hardware and Software**

The MIT simulation facility requires the use of two computers in order to implement the experimental process. A Silicon Graphics IRIS 4D computer was used for the primary flight displays and calculation of flight dynamics, and an IBM-XT was used to simulate the flight management system.

The majority of the IRIS software was written in "C" [Wanke, 1990] to simulate the aircraft/autopilot dynamics, and implementation of FMC navigation algorithms. Various chart prototypes that were contained on the IRIS display were produced using data files generated from *Map*, a rapid prototyping software program developed at MIT [Kuchar, 1990]. IBM software simulated user interface to the FMC.

5.4 Subject Selection

With the aid of the Air Line Pilots association (ALPA), thirteen currently qualified line pilots flying autoflight equipped aircraft (Boeing 757/767, etc) volunteered to participate in the experiment. The volunteers were all male and consisted of six Captains and seven First Officers who averaged 44 years in age, over 10,300 total flight hours, and 1,850 hours in FMC equipped aircraft.

5.5 Phase I Experimental Design

5.5.1 Introduction to Measurements

The experimental objectives were investigated using explicit, implicit, and subjective measures. The number of instrument approach scenarios and experimental charts were used as controlled variables throughout the measurement process. As such,
they were carefully counterbalanced. A brief description of each measurement is provided below.

*Explicit Measurements*

Ten “performance questions” were established in order to explicitly measure pilot performance in IAP related information retrieval tasks. The questions were carefully designed so as to force the pilot to use each major area of the IAP in order to extract the requested information. Response time and error rate were used as indicators of the ease and accuracy with which information could be extracted from each experimental chart. The procedure that was used to query the pilot is described in more detail in section 5.5.3. The explicit information retrieval performance questions are depicted below in Figure 5.2.

<table>
<thead>
<tr>
<th>1) Prior to Intercepting the Final Approach Course:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• What is the Glide Slope intercept altitude (AGL) at the OM?</td>
</tr>
<tr>
<td>• What is the ILS Frequency?</td>
</tr>
<tr>
<td>• How do you identify the missed approach holding fix?</td>
</tr>
<tr>
<td>• What is the distance between the OM and the threshold?</td>
</tr>
<tr>
<td>• What is the inbound course?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2) Prior to the Final Approach Fix</th>
</tr>
</thead>
<tbody>
<tr>
<td>• What is the Minimum Safe Altitude over the airport?</td>
</tr>
<tr>
<td>• If the Glide Slope goes out, could we still shoot the approach?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3) Between the OM and the Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>• What is the Timing between the FAF and the MAP?</td>
</tr>
<tr>
<td>• What is the TDZE? (Touchdown Zone Elevation)</td>
</tr>
<tr>
<td>• What is the highest obstacle in the chart?</td>
</tr>
</tbody>
</table>

*Figure 5.2 Explicit Information Retrieval Performance Questions.*

*Implicit Measurements*

Six different scenarios were used in order to implicitly measure pilot performance and the efficacy of each experimental chart in the following manner. Pilots were either vectored into terrain or forced to execute a missed approach. In both cases, pilots needed to extract information from the IAP that would enable them to either avoid the terrain hazard, or execute the missed approach at the appropriate time.
Subjective Measurements

Subjective opinion measures were obtained by asking pilots to complete the Phase I evaluation questionnaires shown in Appendix B. At the conclusion of each approach scenario, pilots completed a "Post-Format" evaluation in which they assigned a rank to each experimental chart using a relative ranking scale referenced to the current paper IAP. This scale that was used is depicted below in Figure 5.3.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Better</td>
<td>Your Chart</td>
<td>Worse</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.3. Relative Ranking Scale.

Pilots evaluated the IAP for overall acceptability, for the task of "shooting" the approach, situational awareness, and for executing the missed approach.

At the conclusion of all six Phase I approach scenarios, pilots completed a "Debrief" evaluation in which they ranked the Paper, Monochrome, and Color charts in order from the most desirable (1) to the least desirable (3). Pilots also described the best and worst feature (if applicable) of each chart and commented on questions that were concerned with the general format and information content of current IAPs.

5.5.2 Approach Scenario Structure

In Phase I, pilots flew two approach scenarios for each of the following experimental charts:

1. Paper
2. Monochrome Electronic
3. Color Electronic

When used, each chart was displayed on the left side of the IRIS separate from the primary navigation (EHSI) display, as depicted in Figure 5.1. The Paper chart was taped to the same location during the Paper simulation runs in order to remove chart position as a variable.
Each approach scenario began with the aircraft positioned below 10,000 feet inside the terminal area under radar control on an initial flight plan that was pre-programmed into the FMC. Pilots then received radar vectors to intercept the Instrument Landing System (ILS) final approach course. A representative approach scenario is depicted on the following page in Figure 5.5. The aircraft flight path is indicated by the dark thick line; communications with ATC, aircraft descents, and points during the approach procedure where performance questions were asked have also been depicted.

In order to negate subject familiarity with specific airports, all IAPs and approach scenarios were created for fictitious airports. In order to maintain accuracy and realism, the information content of these IAPs was based on actual approaches with the names and frequencies changed.

**Approach Scenario Variations**

The six different approach scenarios and the Paper, Monochrome, and Color charts were arranged in a pseudorandomly counterbalanced design matrix in order to control for statistical artifacts. The matrix was run on two groups of six subject pilots. The matrix, depicted below in Figure 5.4, ensured that each scenario was flown an equal number of times per experimental chart.

<table>
<thead>
<tr>
<th>Approach Scenario</th>
<th>Missed Approach</th>
<th>Uneventful Approach</th>
<th>Terrain &quot;Fly-Through&quot;</th>
<th>Experimental Chart</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td>X</td>
<td>Paper</td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td></td>
<td></td>
<td>Monochrome</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td>Color</td>
</tr>
</tbody>
</table>

**Figure 5.4** Representative Experimental Matrix.

As depicted in Figure 5.4, one scenario per chart block contained an intentional ATC generated terrain "fly-through. The other scenario in each chart block was varied in order to prevent pilots from anticipating erroneous ATC clearances for each approach.
MISSED APPROACH: Climb to 500' then climbing LEFT turn to 4000' outbound via JON VOR R-040 to PDK VOR and hold.

**Figure 5.5** Representative Approach Scenario.
scenario. This scenario either forced the pilot to execute a missed approach, or was uneventful. Each respective scenario is briefly described below.

**Terrain "Fly-Through" Scenarios**

In several scenarios, the aircraft was intentionally vectored into terrain in order to implicitly measure the efficacy of terrain information depiction by spot elevations. In each case, the erroneous vector required no course deviation and entailed a premature descent clearance issued shortly after the "flight" had begun. However, prior to commencing the approach scenario, the pilot had ample time to orient himself to the heading assigned by ATC and to study the situation. If the pilot accepted the erroneous descent clearance without noting the hazardous terrain, a "terrain fly-through" event was recorded. If the pilot correctly identified the hazardous terrain, ATC would immediately comply with his request for either a climb to a safe altitude, or a correct vector clear of terrain.

An example of a representative terrain "fly-through" approach scenario is depicted on the following page in Figure 5.6. The initial aircraft position was north-west of the PRITT intersection at 6800'. The route of flight assigned by ATC entailed radar vectors direct PRIIT, direct CHETT, and was programmed into the FMC before the pilot began flying. When the aircraft was approximately six miles from the PRIITT intersection, the pilot received an ATC descent clearance to 6500'. If the pilot accepted the descent, the aircraft would fly very near (or through) the 6723' obstacle near PRITT which constituted a terrain "fly-through" event. If the pilot noticed that he would be flying too close to hazardous terrain, ATC complied with whatever request was made in order to keep the aircraft clear of terrain.

**Missed Approach Scenario**

In these scenarios, the pilot was unable to proceed with the normal ILS approach procedure due to one of the malfunctions described below.

1. Approach lighting system out of service.
2. Middle Marker (MM) out of service.
3. Glide slope out of service.
Figure 5.6 Representative Terrain “Fly-Through” Scenario.
One of these malfunctions was intentionally scripted into the approach scenario in order to implicitly measure the efficacy of each chart in depicting procedure minima data. If the pilot noticed that he would require an alternate approach procedure, ATC complied with whatever request was made in order to enable the aircraft to safely proceed.

No aircraft or equipment malfunctions were scripted into the other non terrain "fly-through" approach scenario. Pilots completed the normal ILS approach procedure, "saw" the runway environment on the external display window and "landed" the aircraft.

5.5.3 General Experimental Procedure

At the start of each session, pilots received a thorough brief concerning the structure and design of the experiment. After the features of the simulator were demonstrated, pilots were afforded the opportunity to ask questions concerning its capabilities and limitations. A practice approach scenario was then flown with the experimental chart that would be used for the two ensuing data collection runs. Prior to flying each scenario, pilots received ATIS information for the destination airfield, and were allocated as much time as they required to situate themselves and to conduct their standard approach brief, if desired. When the pilots felt comfortable with both the simulator and the IAP, the simulator was taken off "freeze" and the first data collection scenario began. This process was repeated for each chart. Each scenario lasted approximately twenty minutes.

During each simulation run, one experimenter monitored the approach scenario from the ATC/Experimenter station and acted as the Air Traffic Controller communicating with the "flight station" through a radio link. An additional experimenter who was an experienced aviator familiar with IFR operations and instrument flight procedures acted as the Pilot Not Flying (PNF). This experimenter performed radio communications, checklists, etc., leaving the subject pilot free to monitor the instruments and the IAP.

In addition, the experimenter acting as PNF queried the subject pilot with the questions that are depicted in Figure 5.2 to explicitly assess the pilots' ability to retrieve information from various areas of the IAP. The questions were asked non-intrusively by the PNF at predetermined points during the approach scenario when it would be most desirable to know that particular piece of information. All simulator parameters and switch settings were automatically recorded by the simulator during each run, and cockpit
communications between the subject, the PNF, and ATC were videotaped for post run analysis. Both quantitative and qualitative data were collected.

5.6 Phase II Experimental Design

5.6.1 Introduction to Measurements

The primary focus of Phase II was to evaluate the MIT prototype decluttering technique, and the viability of the North-Up (Static), Track-Up (Moving Map), and EFIS Integrated prototype charts that were described in Chapter 4. Due to time constraints and the exploratory nature of the study, pilots flew only one scenario per prototype chart. Consequently, Phase II was not carefully counterbalanced; as such, care must be exercised in extrapolating the results. Subjective and implicit measurements were collected.

Subjective Measurements

At the completion of each Phase II approach scenario, pilots completed a "Post-Format" evaluation similar to the one completed in Phase I; however, pilots also described their preferences for information selection and decluttering, as well as the efficacy of the prototype chart.

At the conclusion of Phase II, pilots completed a "Debrief" evaluation in which they ranked each prototype chart in order from the most desirable (1) to the least desirable (3). Pilots described the best and worst feature of prototype chart, and then ranked all six chart modes used in the experiment in order from the most desirable (1) to the least desirable (6). Phase II evaluation questionnaires are contained in Appendix C.

5.6.2 Approach Scenario Variations

Approach scenario variations were designed and constructed in a manner similar to Phase I. However, pilots were given only one terrain “fly-through” scenario. The other two "terrain fly-through" scenarios were constructed in a manner similar to Phase I.
Terrain “Fly-Through” Scenarios

In a manner similar to Phase I, the efficacy of presentation of terrain information by spot elevations was implicitly measured by issuing an erroneous ATC clearance into hazardous terrain in one of three Phase II approach scenarios. If the pilot accepted the erroneous descent clearance without noting the hazardous terrain, a "terrain fly-through" event was recorded. If the pilot correctly identified the hazardous terrain, ATC would immediately comply with his request for either a climb to a safe altitude, or a correct vector clear of terrain. Care was taken to note whether or not the pilot had terrain information selected at the point where he received the erroneous clearance.

5.6.3 Experimental Procedure

The experimental procedure followed in Phase II mirrored the Phase I experimental procedure with the following exceptions.

Pilots flew one scenario for each prototype chart. The North-Up and Track-Up EIAPs were displayed on the left side of the IRIS separate from the EHSI primary navigation display. However, the EFIS Integrated chart contained information that is normally presented on the current IAP plan view integrated with the EHSI. Performance questions were asked in an attempt to force the pilot to utilize the entire IAP in order to extract the requisite information.
6. Discussion of Results

6.1. Phase I Results

Experimental results obtained from Phase I of the part-task flight simulation experiment are presented below.

6.1.1 Experimental Chart Rankings

In the Phase I "Debrief" questionnaire, pilots ranked the Paper, Monochrome, and Color charts in order from the most desirable (1) to the least desirable (3). The results of this procedure are depicted below in Figure 6.1.

Twelve of thirteen pilots ranked the Color chart first. It became evident from the debriefing responses that the subject pilots thought that the separation of information depicted on the Color chart quickly drew attention to the major components of the approach while allowing them to "mentally eliminate" the extraneous information.

The color scheme used for the Color chart was consistent with the EFIS display which was considered to be advantageous. Information depicted on both the EIAP and the EHSI was easily assimilated (i.e., the inbound course), while a heightened awareness was
generated toward certain information (i.e., terrain) that was depicted on the IAP but not on the EHSI.

Pilots indicated that there was no discernable difference between the Monochrome chart and the current paper IAP.

"It looked like a Jeppesen chart on the screen".

Even though the Paper chart was ranked last by 75% of the pilots, they appreciated the reliability and portability of the paper charts. These features were considered to be its' primary attribute.

"I've never seen paper fail"....."I can put it where I can see it the best, and light it the way I want.."

The paper IAP can be relocated to virtually any location within the cockpit in order to accommodate individual user preferences and needs. This is an especially appealing feature to older pilots who have experienced some loss in visual accommodation. In this regard, the portability aspect of the Paper chart was preferred.

On the negative side, IAPs are currently printed on paper that is easily damaged and hard to read at night. Pilots expressed frustration with the chart update process, and the need to carry a full set of IAPs for each flight.

6.1.2 Experimental Chart Task Rankings

At the conclusion of each approach scenario, pilots completed a "Post-Format" evaluation in which they ranked that particular experimental chart on a 7 point scale where the midpoint was equivalent to the IAP they currently use. Pilots evaluated the IAP for overall acceptability, for the task of "shooting" the approach, situational awareness, and for executing the missed approach. Results of this task ranking are presented below in Figure 6.2.
Pilots indicated a strong preference for the Color chart for each task which is consistent with the overall preference for this chart. Task rankings for the Paper and Monochrome charts were virtually identical. This result was consistent with the general sentiment obtained from pilot comments that the Monochrome chart was essentially a paper IAP on a screen.

Contributing to the overall effectiveness of a chart is the degree of situational awareness attained while using it. Pilots were in general agreement that the use of colors provided for a "nice orientation" and segmented the chart well, especially in the profile view. While some pilots were of the opinion that a multi-colored display was somewhat distracting, the vast majority indicated that it provided for an easy interpretation and allowed them to "fixate and compartmentalize" the approach information. Depiction of the missed approach holding pattern in red provided for a “clean”, easily discernable procedure that was appreciated. The general sentiment was that even thought the same missed approach information was presented in each chart, the color presentation enabled pilots to "just follow the lines."

An analysis was performed in order to determine any statistically significant differences that might exist between the task rankings that were assigned and the IAP currently used. Pilots assigned a rank to each chart using the relative ranking scale...
depicted in Figure 5.3. In this scale, the midpoint was equivalent to the IAP currently used.

A paired T-Test (Appendix D) was used to statistically evaluate the data for any differences that exist when the mean task ranking per chart was compared to the same task from the other charts. Also, each mean task rank per chart was compared to the IAP currently used.

Results from the analysis indicated that no statistically significant differences (to a 95% confidence level) exist between the Paper chart ranking and the expected mean response (the midpoint of the relative ranking scale) for the paper IAP currently used. In addition, no statistically significant differences exist between the Paper and Monochrome charts; however, there was a statistically significant difference between the Color and Paper/Monochrome charts for each task. Since the mean rank for each task was highest for the Color chart, it was conclusively preferred over the other experimental charts.

6.1.3 Average Response Time Per Chart

Ten "performance questions" were established in order to quantitatively compare information retrieval performance. Pilots responded to ten performance questions per chart for a total of thirty Phase I questions for each pilot. Response time has been defined as the time taken by pilots to locate and extract the desired information from the IAP. As such, a "faster" response time was used as an indicator of the ease with which information could be extracted from the IAP.

Videotapes of all cockpit communications between the subject pilot, the PNF, and ATC were reviewed during a post run analysis in which an experimenter used a stopwatch to record response times to each performance question asked during Phase I. Even though response times were subjectively recorded, care was taken to maintain a high level of consistency throughout the measurement process. The average response time per question for each experimental chart was tabulated across all pilots and is depicted on the following page in Figure 6.3.
Figure 6.3 Average Response Time Per Chart.
As can be seen from Figure 6.3, response times were generally faster when pilots used the Color chart. Response times generated for the Paper chart versus the Monochrome chart were nearly even. These results were consistent with pilot comments which indicated that there was no discernable difference between the Monochrome chart and the current paper IAP, but the Color chart was superior. Overall, there was no loss in performance and possibly a limited gain in response time performance when pilots used the Color chart.

It should be noted that response times may be influenced by habitual memorization and/or approach brief content. Collectively, the fastest response times were generated for the following explicit performance questions: "The ILS frequency", and "The inbound course". Survey data from Chapter 3 indicated that these two items were among the top four "critical" information elements desired for the both the pre-approach and approach phases of flight. It appears that pilots may commit the most "critical" information to memory.

Response times to the performance question concerning the location of the “highest obstacle on the chart” were considerably faster when pilots used the Color chart. This prompted further investigation of response times for each question per chart. An Analysis of Variance (ANOVA) was conducted (Appendix D) in order to determine statistically significant differences that exist between the average response time for each question per chart.

Results from the analysis indicated that there was no statistically significant difference (to 95% confidence) between the average response time for each question when the Paper and Monochrome charts were used. However, there was a statistically significant difference in response times when the Color chart was used to locate obstruction information. This result was consistent with the general sentiment obtained from pilot comments which indicated that the separation of information depicted on the Color chart drew attention toward certain information (i.e., terrain) that was depicted on the IAP but not on the EHSI.
6.1.4 Error Rate Results

Error rate was used as an indicator of the accuracy with which information could be extracted from each chart. Taken in this context, error was defined to be an incorrect response elicited to an information retrieval performance question. The average error rate for each question per experimental chart was tabulated across all pilots and is depicted below in Figure 6.4.

![Figure 6.4 Phase I Error Rate.](image)

The error rate depicted in Figure 6.4 also indicates that there is no loss and possibly a limited gain in performance when IAP information is presented in electronic format. The error rate generated while using the Color chart was slightly lower for each question than for the other charts, but may not be significant. However, in general, the error rate was higher than expected.

As can be seen from Figure 6.4, pilots made no errors in response to questions concerning "The ILS frequency", and "The inbound course". Survey data from Chapter 3 indicated that these two items were among the top four "critical" information elements desired for the both the pre-approach and approach phases of flight. As depicted in Figure 3.3, both attained a "Net Interest Ranking" greater than 0.6. Therefore, no errors were made concerning the most "critical" information that might be committed to memory.
Conversely, when averaged across all charts, the highest error rate per question was recorded for the following questions: "What is the distance between the Outer Marker (OM) and the threshold", and "What is the glide slope intercept altitude (AGL) at the OM". Survey data from Chapter 3 indicated that the information elements required to answer these questions attained a "Net Interest Ranking" below "zero" for the both the pre-approach and approach phases of flight. As such, they were considered to be unnecessary. This implies that pilots may be more susceptible to error while extracting information that is considered to be "extraneous".

6.1.5 Phase I Terrain "Fly-Through"

For the implicit information retrieval test, terrain penetration rate was defined as the ratio of approach scenarios in which pilots "fly-through" hazardous terrain to the total number of terrain fly-through opportunities. Pilots accepted an erroneous ATC clearance and penetrated hazardous terrain without question 38 of 39 times, generating a terrain penetration rate of 97.4% that is depicted below in Figure 6.5.

The extremely high number of recorded terrain "fly-through" events indicates that the current methods of terrain depiction were not being used to their full potential. While hazardous terrain information was depicted on the chart, pilots did not appear to have been
aware that a hazard existed. The fact that pilots often accepted ATC clearances without checking the IAP to confirm adequate terrain separation indicates a general tendency to rely on ATC for terrain clearance.

It was observed that pilots tended to be considerably more concerned with flying near hazardous weather than they were with flying near hazardous terrain. Pilots frequently accepted an erroneous ATC clearance without confirming that the aircraft would remain clear of terrain; however, whenever weather radar information indicated a hazard, pilots promptly requested a re-routing from ATC.

The perception that weather poses more of a hazard than terrain might be attributed to differences in information accessibility. Weather radar information currently available in transport aircraft far exceeds the area weather presentation available to the air traffic controller. Pilot Reports (PIREPS) and enroute information obtained from Flight Service Stations (FSS) serve to augment weather radar information. Conversely, pilots do not have access to Minimum Vectoring Altitudes (MVA) that are used by ATC. Therefore, pilots may perceive more responsibility for weather avoidance than for terrain avoidance.

It should be noted that two of the nine IAPs used in this experiment did not fully comply with the guidelines as outlined in the TERPS manual. The TERPS manual requires that published airways and MSA sectors must provide the aircraft with 1000' of terrain clearance within 4 nautical miles of the depicted route or sector.

In one of the experimental IAPs, spot elevation symbols higher than 4000' were located within 4 nautical miles of a 3500' MSA sector altitude. Similarly, the second IAP depicted terrain obstacles that were located within 4 nautical miles and 1000' of a published airway.

6.2 Phase II Results

Experimental results from Phase II of the part-task simulation experiment are presented below.
6.2.1 EIAP Prototype Chart Rankings

In the Phase II "Debrief" questionnaire, pilots ranked the North-Up (Static), Track-Up (Moving Map), and EFIS Integrated prototype charts in order from the most desirable (1) to the least desirable (3). The results are depicted below in Figure 6.6.

![Figure 6.6 EIAP Prototype Chart Rankings.](image)

The North-Up (Static) prototype chart was ranked first by ten of thirteen pilots. Each pilot commented that the real-time aircraft position and navigation information depicted by the moving aircraft symbol provided a cue for error reduction.

The general pilot sentiment was that this chart was the closest of any EIAP chart to being the "complete display picture". It was felt that the use of colors on the display drew attention to the major components of the approach. In this Phase of the experiment however, pilots could eliminate the extraneous information by using the information selection and decluttering capability. Most felt that this option should be considered for EIAP implementation.

Pilots liked the Track-Up (Moving Map) chart because of the "hybrid" plan view section. Those who favored the moving map plan view depiction did so because it was a replication of the EHSI. As such, one did not "have to reorient your mind to the approach" when scanning back and forth between displays. On the negative side, some thought that it
was a redundant depiction of the EHSI that did not provide for the transfer of any additional information.

The most salient result obtained from the EFIS Integrated prototype chart was that each pilot specifically stated that it was desirable to have the IAP separate from the primary navigation display for planning purposes. Since this chart was a synthesis of the current paper IAP and the current EHSI, it may not have represented an optimized display presentation. Pilots indicated that there would be large learning curve effects in order to become proficient with this type of non-conventional display configuration.

6.2.2 EIAP Prototype Chart Task Ranking

Pilots completed a "Post-Format" questionnaire in which they ranked that particular EIAP prototype chart on a 7 point scale where the midpoint was equivalent to the IAP they currently use. Pilots evaluated the chart for overall acceptability, and for each of three tasks that are normally performed in the execution of an instrument approach. Results of this task ranking are presented below in Figure 6.7.

![Figure 6.7 EIAP Prototype Chart Task Ranking.](image)
It is important to note that each task ranking depicted in Figure 6.7 for the prototype charts is higher than the same task ranking for the non-selectable experimental charts (Figure 6.2). The greater preference for the prototype charts is thought to be due to information selectability and the depiction of real-time aircraft position information. This result was also found to be consistent with pilot preferences for the North-Up prototype chart.

The strongest preference for the North-Up chart was found to be for the acceptability "task" which provided pilots with a means by which to assign a general rank to each chart. Although both the EFIS Integrated and Track-Up charts depicted real-time navigation information, pilot comments indicated that the aircraft position information depicted on the North-Up format was the most compelling. This was consistent with the high situational awareness score attained by the North-Up format. Pilots indicated that this format provided for the quickest orientation "with respect to the rest of the world".

Recent surveys of operational IAP usage patterns in EFIS displays indicated that the "Map Mode" moving map display was preferred to North-Up oriented charts [Chandra, 1989]. The fact that North-Up charts were preferred for the depiction of IAP information was thought to be attributed to the moving aircraft symbol and past experience with north-up oriented IAPs. Since specific position and attitude reference information was constantly available, orientation may have been better facilitated using a reference frame that was fixed with respect to the runway.

The North-Up chart provided the highest degree of situational awareness as indicated by the high task ranking score it attained. For the task of shooting the approach, some pilots thought that the moving aircraft symbol depicted on the profile view provided an advantage with regard to vertical guidance and navigation. Others however, felt that this symbol was a "nice reference", but was not critical to have. Pilots were especially receptive to having the moving aircraft symbol depicted when executing a missed approach, and for terminal area maneuvering. Pilots indicated that if they were flying at night with minimum ceiling-visibility conditions, they would clearly prefer to have this EIAP.

Preferences for the EFIS Integrated and Track-Up charts were mixed. Pilots liked the Track-Up EIAP because it provided a selectable north-up mode for approach planning that was separate from the primary navigation display. Therefore, north-up and moving-map information could be displayed concurrently. However, on the EFIS Integrated chart,
pilots were able to select only one or the other. Some pilots were reluctant to sacrifice moving-map information in order to have access to the north-up depiction.

"It gave the impression that everything was frozen".

However, pilots who did not favor the display indicated that once learning curve effects with the format were negated, it may have the potential to provide better situational awareness information.

Pilots consistently indicated that a situation dependent IAP decluttering capability would help to reduce clutter problems. Those who used the prototype decluttering technique in the experiment unanimously agreed that it was desirable to customize the IAP. Pilots indicated that this procedure would not constitute a workload increase while maneuvering in the terminal area.

"If I didn't have time to do it, I wouldn't."

6.2.3 Preference Ranking For All Chart Modes

At the conclusion of Phase II, pilots ranked all chart modes in order from the most desirable (1) to the least desirable (6). The results of this procedure are depicted in Figure 6.8.

The overall preference rankings were consistent with pilot preferences for the North-Up prototype chart, and previous experimental and prototype chart rankings. The general preference for the prototype charts may imply the importance of color, information selectability and the depiction of real-time aircraft position information. The fact that the EFIS Integrated chart was ranked in the bottom half of all chart modes 41.66% of the time may be attributed to learning curve effects associated with the "non-conventional" nature of the display.

The overall lack of preference for the Paper and Monochrome experimental charts was clearly indicated. Paper attained the highest overall rank attained by either chart; a rank three was assigned by one pilot. These charts were clearly the least preferred of all the chart modes that were evaluated.
6.2.4 Phase II Terrain "Fly-Through"

The ratio of approach scenarios in which pilots penetrated hazardous terrain to the total number of terrain fly-through approach scenarios has been defined as the \textit{terrain penetration rate}. In Phase II, pilots accepted an erroneous ATC clearance and penetrated hazardous terrain without question 11 of 13 times, generating a terrain penetration rate of 84.6% that is depicted below in Figure 6.9.
As is depicted in Figure 6.9, pilots were using the Track-Up chart in each instance when the hazardous terrain was identified and avoided. However, these results were obtained using a limited data set, and may not be significant. A more complete study of terrain depiction methods has been conducted at MIT [Kuchar and Hansman, 1991].

When using the Phase II prototype charts, pilots successfully identified the hazardous terrain 2 out of 13 times, generating a 84.6% terrain penetration rate. The improvement in terrain avoidance performance between Phase I and Phase II may indicate that charts which do not contain a specific display of aircraft location with respect to terrain are not as effective as those that do.

Pilot comments were recorded by an additional experimenter during the terrain "fly-through" scenarios. When using the North-Up chart, two pilots commented on high terrain as they observed the moving aircraft symbol penetrating the hazard. However, neither pilot requested an altitude change or an ATC vector clear of terrain.

Individual IAP configuration techniques were carefully noted during the terrain fly-through approach scenarios. Pilots flew the approach with terrain information deselected in five of the thirteen terrain fly-through scenarios, generating a 62% terrain penetration rate when the pilot did not have access to terrain information. Several pilots indicated that they rarely (or never) look at the plan view depiction of terrain information when executing an instrument approach procedure. As indicated by the survey data presented in Chapter 3, terrain clearance information was primarily acquired from the MSA circle.

6.2.5 Preferences For Electronic IAPs

A section was included in the Phase II "Debrief" questionnaire in order to determine pilot preferences concerning the replication of paper IAP information in electronic format. These questions were asked of the subject pilots after they experienced the flexibilities and capabilities of these electronic systems. These same questions were asked on the general survey discussed in Chapter 3; however, pilots who responded to that survey did not have the opportunity to "fly" with these electronic systems. It should be noted that all pilots who participated in the experiment were qualified "glass-cockpit" pilots, while only a portion of those who responded to the survey held that same qualification. Results are presented in Figure 6.10.
The results indicate that pilots who have experienced the capabilities provided by electronic IAPs tend to prefer them more than those who had not. Most of the reluctance toward the use of electronic charts was attributed to concern for the reliability of the electronic systems. While over 90% of the subject pilots were in favor of EIAPs, only half stated that they were comfortable using them without a paper backup. Subject pilots generally acknowledged that the advent of EIAPs was inevitable, and that if these systems proved to be reliable, they would eventually trust them without requiring a backup.
7. Conclusions

Systems and human factors engineering issues associated with the electronic presentation of Instrument Approach Plates (IAPs) were investigated. Specifically, the effects on information retrieval performance and pilot preference that are induced by the capabilities and limitations of electronic systems were addressed. These investigations resulted in the following findings.

1. Error rates obtained from the experimental charts indicate that there appears to be no loss in performance and possibly a limited gain in information retrieval performance when IAP information was presented in electronic format. Pilot comments indicated that there was no discernable difference between the Monochrome and Paper charts, but that the Color chart was superior to both.

2. Paper and Monochrome charts were clearly the least preferred of all chart modes. The Paper chart was ranked in the bottom 50% of all modes 91.66% of the time.

3. Information requirements clearly change as a function of phase of flight; however, there was a large dispersion of opinion regarding the amount of information required to execute the approach. The depiction of specific information elements may depend on the situation and user preferences. Therefore, a mechanism for pilots to individually control the information contained on EIAPs was evaluated.

4. The prototype information selection and decluttering capability was preferred by each subject pilot. Pilot comments indicated that this feature should be an integral part of EIAPs. No negative comments were received concerning the impact of information selection on flight crew workload.

5. The strongest pilot preference was for a North-Up (Static) chart which was ranked first by twelve of thirteen subject pilots. This preference was thought to be attributed to the incorporation of a moving aircraft symbol and past experience with north-up
oriented IAPs. The North-Up (Static) chart provided the highest degree of situational awareness as indicated by the high task rank score it attained.

6. Prototype charts with information selection scored higher than the non-selectable experimental charts. The greater preference for the prototype charts is thought to be due to information selectability and the depiction of real-time aircraft position information. This result was consistent with pilot preferences for the North-Up (Static) prototype chart.

7. Depiction of terrain information by spot elevations does not appear to be effective. When given erroneous vectors into terrain, the subject pilots were uniformly unable to identify the problem when provided with spot elevation terrain information.

8. Higher than expected error rates were observed; however, there was a significant difference depending on the perceived importance of the information.

9. Differences in error rates imply that pilots may commit critical approach information to memory. The lowest error rates were recorded in response to performance questions that contained information that pilots felt was critical. Conversely, the highest error rates were recorded in response to performance questions that contained information that was considered to be extraneous. This indicates that pilots may be more susceptible to error while extracting information that is considered to be unnecessary.
References


Appendix A:

Survey of Approach Chart Information Requirements
SURVEY OF APPROACH CHART INFORMATION REQUIREMENTS

Purpose

The Department of Aeronautics and Astronautics at the Massachusetts Institute of Technology is currently evaluating the design and format of aeronautical charts. The focus of this survey is to evaluate the importance of instrument approach information available to the pilot, and to determine at what point during the approach procedure it is most desirable to have this information.

By investigating crew preferences related to Instrument Approach Plates (IAP), and surveying the information content of these plates, we hope to gain an understanding of pilot preferences concerning the categorization and prioritization of approach chart information as it pertains to phase of flight. This information will help us to determine what information should be contained on advanced electronic instrument approach plate designs.

Structure

This survey consists of four parts and will take approximately 30 minutes to complete. As an introduction to each individual section, a brief description and background is provided. Section I consists of questions concerning your aviation background. The second section asks you to describe your preferences concerning the utilization of the information currently contained on instrument approach plates. In the third section, you will be presented with sample precision and non-precision Jeppesen-Sanderson IAPs and asked to identify, per phase of flight, the approach information you feel is critical to complete that particular phase of flight. The final section seeks to determine your preferences regarding electronic instrument approach plates.

Please remember that this is only a survey of your opinions and that there are no "correct" answers to these questions. Your assistance in this survey is crucial to helping us prioritize the information content of current IAP's.

**All information provided will remain strictly confidential.**

The Survey Team

The individuals conducting this survey are experienced aviators well versed in instrument approach procedures. We are always available and interested in your opinions. Please feel free to call or contact us at any time if you have any questions regarding the survey or wish to discuss anything concerned with this project.

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I BACKGROUND INFORMATION

A. Purpose

Information concerning your aviation background will help us to more accurately assess the variables that affect pilot preferences. Remember, all information you provide will remain completely anonymous.

B. Personal Data/ Miscellaneous Information

1. Age: _______ Sex: Male ( ) Female ( )

2. Highest Education Level:
   ( ) High School ( ) College ( ) College Degree ( ) Graduate Work/ Degree

3. Highest math level:
   Arithmetic : Beyond Calculus
   1 2 3 4 5

4. Do you have any experience on Flight Management Computer (FMC) equipped aircraft?
   Yes ( ) No ( )

5. Computer experience (other than FMC) as a user:
   No knowledge of software packages : Knowledge of several software packages
   1 2 3 4 5

6. How often do you use computers (hours per week) as a(n):
   Recreational User ( ) Operational User ( )
   (Workplace only)
   Do not use computers if I don’t have to ( )
C. Aviation Experience

1. How were you initially trained to fly?
   Civil ( )  Military ( )

2. Civil Experience:
   A. Total civil pilot flight time: __________
   B. Pilot ratings held:
      Fixed Wing:  ATP ( )  Commercial Pilot ( )  F.E. Written ( )
      Rotary Wing:  ATP ( )  Commercial Pilot ( )  Other___________
   C. Civil flight experience by aircraft type:
      Rotary Wing ( )  Fixed Wing ( )  ( ) Both

3. Military Flight Experience:
   A. Total military flight time: ______
   B. Military flight experience by aircraft type:
      Rotary Wing ( )  Fixed Wing: Tactical ( )  Transport ( )  Both ( )
   C. Do you currently fly in the military reserves?
      Yes ( )  No ( )

D. Transport Category Aircraft Flying Experience

   1. AIRCRAFT TYPE  FLIGHT HOURS (Approximate)  POSITION*
      1. __________________________________________________________
      2. __________________________________________________________
      3. __________________________________________________________
      4. __________________________________________________________
      5. __________________________________________________________

*Captain, First Officer, Second Officer, Flight Instructor/ Check Pilot

2. Estimated Flight Hours in 1989 _______
II GENERAL IAP USAGE

A. Purpose

The purpose of this section of the survey is to help us evaluate the information content of the two most widely used domestic IAP's, Jeppeson-Sanderson Inc., and the U.S. government (NOAA and the Department of Defense in conjunction with the FAA).

Please evaluate the information content of these IAP's with regard to factors that contribute to approach plate clutter, for example, terrain and obstruction information, and describe your preferences concerning the use of available instrument approach plate information.

B. Information Content

1. With which IAP have you had the most experience? If other, please specify.

( ) Jeppeson-Sanderson  ( ) NOAA/DOD  ( ) Other

2. Which IAP do you currently use the most often?

( ) Jeppeson-Sanderson  ( ) NOAA/DOD  ( ) Other

*For questions 3-7, please answer based on the response given for question (1) above.*

3. Aviators have stated that there can be both too much and too little information contained at the same time on an IAP. How do you feel about the quantity of information presented on IAP's? Please comment.

<table>
<thead>
<tr>
<th>Not enough information</th>
<th>Too much information</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2 3 4 5</td>
</tr>
</tbody>
</table>


4. Is the critical information, i.e., a localizer frequency, difficult to locate or interpret? Please comment.

<table>
<thead>
<tr>
<th>Never</th>
<th>Occasionally</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

*NOTE: For questions 5 and 6, assume that the terminal area is defined as the area within a 30NM radius of the airfield. You are the pilot "hand flying" the approach in IFR conditions under radar control.

5. What percentage of your time, on average, do you spend in the terminal area finding and selecting approach information from the IAP? Please circle one of the following and comment on your interpretation of how much time comprises the two categories provided.

<table>
<thead>
<tr>
<th>Category</th>
<th>Time spent (approximate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. &quot;An acceptable amount&quot;</td>
<td></td>
</tr>
<tr>
<td>5. &quot;An unacceptable amount&quot;</td>
<td></td>
</tr>
</tbody>
</table>

6. During peak workload conditions; i.e., when you are performing a difficult instrument approach procedure to an unfamiliar airfield, what is the maximum percentage of time you spend in the terminal area interpreting and selecting approach information? Please comment on your interpretation of how much time comprises these categories.

<table>
<thead>
<tr>
<th>Category</th>
<th>Time spent (approximate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. &quot;An acceptable amount&quot;</td>
<td></td>
</tr>
<tr>
<td>5. &quot;An unacceptable amount&quot;</td>
<td>74</td>
</tr>
</tbody>
</table>
7. Instead of "hand flying" the approach, assume that you are performing an autoflight approach. Please describe any differences in the time spent interpreting approach information.


8. Do you feel that it is possible to make errors in the cockpit that can be directly attributed to charting considerations? If yes, please comment on the nature of these errors.

( ) Yes ( ) No


9. What are the most common errors you make or are aware that others have made reading the instrument approach plate?


10. What mistakes, if any, have you made looking for communication frequencies?


11. Do you require the same approach information for a precision and non-precision approach? If no, what information is different?

( ) Yes ( ) No


12. Do you follow a certain procedure that allows you to have access to a full set of NOTAMS?

( ) Yes ( ) No


13. Have you ever observed anyone using non-current charts?

<table>
<thead>
<tr>
<th>Never</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

75
14. Under which conditions do you experience more problems reading the chart? Please comment on what information is hard to read.

( ) Bright Light ( ) Low Light

Please answer the following three questions only if you use both Jeppeson-Sanderson and NOAA charts:

1. What problems do you encounter when switching back and forth from NOAA charts to Jeppeson-Sanderson charts?

2. Do you confuse the primary navaid frequency for the approach with other navaid frequencies? If yes, please comment.

   ( ) Yes ( ) No

3. Is a major change in approach chart format warranted or desirable? If yes, please comment.

   ( ) Yes ( ) No

Please answer the following two questions only if you have any experience flying non-precision loran approaches.

1. Have you flown loran approaches as part of recreational flying?

2. What are the problems, if any, that you have experienced while flying these approaches?
C. Factors Affecting Chart Clutter

Chart clutter can degrade pilot performance by detracting from his/her ability to extract relevant information from the IAP to perform an instrument approach procedure.

The following represents a non-exhaustive list of categories of information that can contribute to approach chart clutter:

1. Chart Identification Information
2. Airport Identification
3. Terrain Information
4. Navigation Waypoints
5. Routing Procedures
6. Missed Approach Information
7. Communication Frequencies
8. Minimum altitudes
9. Airport Notes

An example from each of these categories (if applicable) is shown on the following page (Figure I). Each sample IAP contained throughout this document has been reduced to 95% of its original size.

*These charts have been reproduced for illustrative purposes only*
NOT FOR NAVIGATION

Information Categories Contributing To Chart Clutter

Communication Frequencies

Terrain Information

Navigation Waypoints

Routing Procedures

Missed Approach Information

Minimum Altitudes

Figure 1

---

Figure 78
Using the scale provided, please indicate how much each category contributes to chart clutter.

<table>
<thead>
<tr>
<th>Category</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Chart Identification Info</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Significant clutter</td>
</tr>
<tr>
<td>2. Airport Information</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Significant clutter</td>
</tr>
<tr>
<td>3. Terrain Information</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Significant clutter</td>
</tr>
<tr>
<td>4. Navigation Waypoints</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Significant clutter</td>
</tr>
<tr>
<td>5. Routing Procedures</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Significant clutter</td>
</tr>
<tr>
<td>6. Missed Approach Information</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Significant clutter</td>
</tr>
<tr>
<td>7. Communication Frequencies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Significant clutter</td>
</tr>
<tr>
<td>8. Minimum Altitudes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Significant clutter</td>
</tr>
</tbody>
</table>
Please comment on how you might like to reduce approach chart clutter.

More on Approach Chart Clutter...

1. Would you like to see the level of terrain information on the IAP increased or decreased? Please comment.
   ( ) Increased   ( ) Decreased

2. Trade-offs exist between the presentation of terrain information and chart clutter. HOW should terrain information be presented? Some possibilities are the depiction of "spot elevations"; i.e., height of communication towers, prominent terrain features, or the depiction of terrain contours in color. Please comment.

D. Operator Preferences

1. Do you use the IAP while landing in VFR conditions?
   ( ) Yes   ( ) No

2. How do you use an IAP differently, if at all, if you are familiar/unfamiliar with the airport?

3. Does your company require you to brief an instrument approach procedure in a specified manner?
   ( ) Yes   ( ) No

4. If not, do you brief an instrument approach procedure the way you were initially trained?
   ( ) Yes   ( ) No

5. Procedurally, do you brief a precision and non-precision approach procedure in the same manner?
   ( ) Yes   ( ) No

The following page (Figure II) contains a sample Jeppeson-Sanderson IAP. Please highlight in yellow the information you normally include in your approach brief, if applicable.
Figure II
III APPROACH PLATE INFORMATION ANALYSIS

A. Purpose

Depending on company training policy and/or aviation background, pilots/flight crews may group, and subsequently utilize, the information contained on an IAP differently. We would like to determine the instrument approach information pilots would prefer to have available to them as it pertains to phase of flight.

Individuals within the Aeronautical Systems Laboratory have subjectively divided an instrument approach procedure into four phases of flight. It should be noted here that the phases of flight remain constant for both precision and non-precision approaches. They are as follows:

1. Pre-Approach (Prior to arrival in the terminal area)
2. Approach (Execution of the approach procedure)
3. Missed Approach (If required)
4. Ground Operations (Taxi for take-off, taxi to parking)

Assume IFR conditions, and flight operations conducted in a radar controlled environment.

B. Procedure

On each of the following pages (Figures III-IX), sample Jeppeson-Sanderson precision and non-precision approach plates are provided for each of the four instrument approach phases of flight.

A. ILS 13R at Kennedy

You will be approaching from the north and can expect to receive vectors to intercept the localizer.

B. NDB 4R to Newark

You will be approaching from the south and have been told to expect your own navigation direct to "Grity".

C. Directions

Please evaluate the information content of both the precision and non-precision IAP as it pertains to phase of flight in the following manner:

- Using the yellow highlighter, indicate the information you feel is critical to have access to during the given phase of flight. For example, if you feel that it is critical to have missed approach information available to you during the pre-approach phase of flight, highlight this information.

- Using the pink highlighter, highlight the information you would suppress if you had the opportunity to customize the IAP for this particular phase of flight.

- Please note that each piece of information contained on the plate does not have to be highlighted.
Phase I: Pre-Approach (Prior to entering the terminal area)

A. Precision Approach

Diagram showing approach and holding patterns with altitude and course information.

Figure III
Phase I: Pre-Approach (Prior to entering the terminal area)

B. Non-Precision Approach

NOT FOR NAVIGATION

Figure IV

84
Phase II: Approach

A. Precision Approach
NOT FOR NAVIGATION

Phase II: Approach

B. Non-Precision approach

Figure VI
Phase III: Missed Approach

A. Precision Approach

Missed Approach:

- Climb to 500', then climbing left turn to 4000' outbound via JFK VOR R-078 to DPK VOR and hold.

Figure VII
NOT FOR NAVIGATION

Phase III: Missed Approach

B. Non-Precision Approach

Figure VIII
NOT FOR NAVIGATION

Phase IV: Ground Operations

Figure IX
IV Electronic Approach Charts

A. Purpose

Replication of paper approach plates in electronic format may limit the amount of approach information available to the pilot due to limitations in display technology. However, electronic approach plates may also provide the pilot with the flexibility to select only desired approach information.

The following questions seek to determine your preferences regarding some of the options currently available for electronic replication of approach plates, given the available technology.

1. Would you favor the replication of paper instrument approach plates in electronic format?
   ( ) Yes  ( ) No

2. Would you feel comfortable using solely electronic plates with no paper approach plates available as a back-up?

3. Two prototype designs for electronic approach plates are static and dynamic. The static plate is a replication of the paper chart with a north-up orientation, while the dynamic chart has a moving map planform view similar to the EHSI and a track-up orientation. Which would you prefer and why?

For the following three questions, "customizing" an approach plate refers to being able to select or deselect approach information of your choice in an attempt to have a "cleaner" presentation with reduced chart clutter. Selection of information could be accomplished prior to departure; however, all information would be constantly accessible to you at any time you desire to select it. Also, in the event of a missed approach, missed approach information will automatically be displayed.

4. Would you find it desirable to be able to customize your approach plate? Why?
   ( ) Yes  ( ) No

5. Would this procedure cause a significant workload increase during the approach phase of flight? How?
   ( ) Yes  ( ) No
6. Would you require the same information display if you were hand flying the approach as opposed to performing an autoflight approach? If yes, how?

( ) Yes  ( ) No

7. Would a moving map display of the airport be useful while taxiing to the gate?

( ) Yes  ( ) No

Conclusion

The information you have provided will be extremely useful in our research. Your participation in this survey is greatly appreciated.

Please keep the highlighters, and return the survey to us as soon as possible; preferably within one week of receipt. Thank you again for your participation!
Appendix B:

Phase I Evaluations
Phase I: "Post-Format"

To be Filled Out By Experimenter

Date:
Subject # (  )
Scenario # (  )
IAP Format Used:

☐ Paper
☐ Full Static Electronic, Non-Selectable (Monochromatic)
☐ Full Static Electronic, Non-Selectable (Color)

A. Task Rating the Chart

Using the rating scale discussed in the brief (and that you have in front of you), please rate how the chart helped you to perform the following tasks.

Please remember to rate the chart completely on its own merits; there are no right and wrong answers.

<table>
<thead>
<tr>
<th>Rating Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>Better Your Chart Worse</td>
</tr>
</tbody>
</table>

1. Do you find the chart to be acceptable? Yes No

Why? ____________________________________________
_______________________________________________
_______________________________________________
_______________________________________________
_______________________________________________
_______________________________________________
2. TASK: "Shooting" the approach.

Rating Assigned:

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Better</td>
<td>Your Chart</td>
<td>Worse</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Why? ________________________________________________________________

3. TASK: General Orientation and "Situational Awareness"

Rating Assigned:

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Better</td>
<td>Your Chart</td>
<td>Worse</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Why? ________________________________________________________________

4. TASK: Missed Approach (If applicable)

Rating Assigned:

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Better</td>
<td>Your Chart</td>
<td>Worse</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Why? ________________________________________________________________

Why? ________________________________________________________________

Why? ________________________________________________________________

Why? ________________________________________________________________

Why? ________________________________________________________________
Phase I Debrief

Part I: To be Filled Out By Experimenter

Date: ________________________________

Subject # ( )

IAP Formats Used:

☐ Paper
☐ Full Static Electronic, Non-Selecteble (Monochromatic)
☐ Full Static Electronic, Non-Selecteble (Color)

1. Ranking The Chart Formats

Please rank the three charts that you just flew (in order) from the most desirable (1) to the least desirable (3).

☐ Paper
☐ Full Static Electronic, Non-Selecteble (Monochromatic)
☐ Full Static Electronic, Non-Selecteble (Color)

** NOTE: It would be useful to have a picture available to the pilot to facilitate an easy comparison between the two.

1. In order to review each of the charts that you just flew, and based on the rankings that you just assigned, would you say that there is a single best and/or worst feature of each chart? Please comment.

A. Paper

Best: __________________________________________________________

Worst: _______________________________________________________

95
B. Full Static Electronic, Non-Selectable (Monochromatic)

Best

Worst

C. Full Static Electronic, Non-Selectable (Color)

Best

Worst

2. General IAP Format Questions

1. Do you require both the AGL and MSL altitudes to be displayed on the profile view of the IAP in order to safely execute the approach? If not, which altitude do you prefer and why?

   □ Strongly Agree □ Strongly Disagree □ Neither Agree □ Nor Disagree □ Disagree □ Strongly Disagree

   Why?

   Why?
2. Primarily, where do you look on the IAP in order to find the ILS frequency?
   Why?

3. In the minimums section of the IAP that you currently use, do you prefer to see minimums for all category aircraft, or would you desire to see only those minimums that pertain to your category aircraft?
   Why?
Appendix C:

Phase II Evaluations
Phase II "Post-Format"

To be Filled Out By Experimenter

Date:
Subject # ( )
Scenario # ( )
IAP Format Used:

☐ EFIS Integrated, Selectable (Color)
☐ Static Selectable (Color)
☐ Remote Dynamic, Selectable (Color)

A. "Task Rating" the Chart

Using the rating scale discussed in the brief (and that you have in front of you), please rate how the chart just flown helped you to perform the following tasks.

Please remember to rate the chart completely on its own merits; there are no right or wrong answers.

<table>
<thead>
<tr>
<th>Rating Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>Better</td>
</tr>
</tbody>
</table>

1. Do you find this chart to be acceptable?

Why? ____________________________________________

_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
2. TASK: "Shooting" the approach.

Rating Assigned:

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Better</td>
<td>Your Chart</td>
<td>Worse</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Why? ______________________________________________________

3. TASK: General Orientation and "Situational Awareness"

Rating Assigned:

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Better</td>
<td>Your Chart</td>
<td>Worse</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Why? ______________________________________________________

4. TASK: Missed Approach (If applicable)

Rating Assigned:

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Better</td>
<td>Your Chart</td>
<td>Worse</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Why? ______________________________________________________
5. TASK: Selecting and Deselecting Information

Rating Assigned: 1 2 3 4 5 6 7
Better Your Chart Worse

(Comment On the Number of Switches)

Why?


B. General IAP Format Questions

Please answer the following questions with respect to the chart that you just used.

1. When flying in the worst conditions; i.e., at night in IFR conditions down to minimums, you would like to fly an aircraft that is equipped with this type of electronic IAP.

   □ Strongly Agree □ Agree □ Neither Agree Nor Disagree □ Disagree □ Strongly Disagree

   Why?

   

   

   

   

   

2. If the EHSI failed, you would have enough information available to orient yourself during each phase of the approach.

   □ Strongly Agree □ Agree □ Neither Agree Nor Disagree □ Disagree □ Strongly Disagree

   Why?

   

   

   

   

   

   

101
3. This chart compelling enough that I found myself using it, instead of the needles, as the primary means of navigation.

[☐] Strongly Agree  [☐] Agree  [☐] Neither Agree  [☐] Disagree  [☐] Strongly Disagree

Why?__________________________________________________________________________________________
__________________________________________________________________________________________
__________________________________________________________________________________________
__________________________________________________________________________________________
Part I: To be Filled Out By Experimenter

Date:
Subject # ( )
IAP Formats Used:

- [ ] EFIS Integrated, Selectable (Color)
- [ ] Static Selectable (Color)
- [ ] Remote Dynamic, Selectable (Color)

1. Ranking The Charts

Please rank the three charts that you just flew (in order) from the most desirable (1) to least desirable (3).

- [ ] EFIS Integrated, Selectable (Color)
- [ ] Static Selectable (Color)
- [ ] Remote Dynamic, Selectable (Color)

** NOTE: It would be useful to have a picture available to the pilot to facilitate an easy comparison between the two.

1. In order to review the charts, and based on the rankings that you just assigned, would you say that there is a single best and/or worst feature of each chart? Please comment.

A. EFIS Integrated, Selectable (Color)

Best ____________________________________________________

_______________________________________________________

Worst __________________________________________________

_______________________________________________________
B. Static Selectable (Color)

Best

Worst

C. Remote Dynamic, Selectable (Color)

Best

Worst

2. Ranking the Charts

Now that you've had the opportunity to use each of the six charts, please rank them (in order) from the most desirable (1) to the least desirable (6).

Note: Have pictures of each format

☐ Paper
☐ Full Static Electronic, Non-Selectable (Monochromatic)
☐ Full Static Electronic, Non-Selectable (Color)
☐ EFIS Integrated, Selectable (Color)
☐ Static Selectable (Color)
☐ Remote Dynamic, Selectable (Color)

Why?
4. Electronic IAP's

1. After your practical experiences here today, do you favor the replication of paper instrument approach plates in electronic format?

   ( ) Yes  ( ) No

   Why?

   ________________________________________________________________

   ________________________________________________________________

   ________________________________________________________________

2. Do you trust the technology available today; would you feel comfortable using electronic IAP's with no paper approach plates available as a back-up?

   Why?

   ________________________________________________________________

   ________________________________________________________________

   ________________________________________________________________

3. As you have experienced, two prototype designs for electronic IAP's are static and dynamic. The static plate is a replication of the paper chart with a north-up orientation, while the dynamic chart has a moving map planform view similar to the EHSI and a track-up orientation. Based upon your experiences here today, which do you prefer?

   Why?

   ________________________________________________________________

   ________________________________________________________________

   ________________________________________________________________

For the following three questions, "customizing" an approach plate refers to being able to select or deselect approach information of your choice in an attempt to have a "cleaner" presentation with reduced chart clutter. Selection of information could be accomplished prior to departure; however, all information would be constantly accessible to you at any time you desire to select it. Also, in the event of a missed approach, missed approach information will automatically be displayed.

4. Do you find it desirable to be able to customize your approach plate?

   ( ) Yes  ( ) No
5. From your experience today, do you think that this procedure caused a significant workload increase during the approach phase of flight? How?

( ) Yes  ( ) No

Why? __________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________

6. Would a moving map display of the airport be useful while taxiing to the gate?

( ) Yes  ( ) No

Why? __________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________
Appendix D:
Statistical Analyses
Experimental Statistical Analyses

by

Ricardo Paxson
Mark Mykityshyn

Experimental Chart Task Ranking

A description of the statistical procedure used to determine pilot preferences regarding specific tasks while using each of the experimental and prototype charts is presented. Each subject "flew" two approaches using each experimental chart, and was asked to provide his preferences regarding specific tasks. Preferences were ranked using a 7 point scale where the mid-point was suggested to be equivalent to the paper IAP currently used. Since subjects "flew" two approaches using each chart, each approach was ranked twice. The average of the two ranks was then used in the statistical analysis of each respective task. Data was arranged according to task for each of the experimental and prototype charts as depicted in the following table.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Paper</th>
<th>Monochrome</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>4.5</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>2</td>
<td>1.75</td>
</tr>
<tr>
<td>4</td>
<td>3.5</td>
<td>4</td>
<td>2.5</td>
</tr>
<tr>
<td>5</td>
<td>4.5</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>2.5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>4.5</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>3.5</td>
<td>5.5</td>
<td>4.25</td>
</tr>
<tr>
<td>9</td>
<td>4</td>
<td>3</td>
<td>1.75</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>4</td>
<td>2.5</td>
</tr>
<tr>
<td>11</td>
<td>4.5</td>
<td>3.5</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

Acceptability Task Ranking for Experimental Charts.
The objective of this statistical procedure was to determine any statistically significant differences between the mean rank (across all subjects) for each chart. The method used to examine differences between average ranks per task was a Paired t-test. A Paired t-test is equivalent to performing a one-sample t-test; however, in order to compare two means, the data used is the difference between one column (for example the ranks for the Paper presentation) and the column desired to compare with. As such, the statistical procedure is now equivalent to having one set of data. In order to determine if the means are statistically different, the following hypothesis was used.

\[ H_0: \Delta = 0 \]

\[ H_1: \Delta \neq 0 \]

"\(\Delta\)" is the difference between the columns of data that are being compared. Acceptance of the null hypothesis indicates that the means are statistically equivalent. However, if the null hypothesis is rejected, we can conclude that the means for the two experimental charts (or prototype charts) are statistically different.

Assuming that the probability distribution for the group is normal; i.e., that the rankings obtained by the group for each task would be normally distributed, then the sample's distribution follows a t-student. The data is therefore normalized to a t distribution as follows.

\[ \lambda = \frac{\overline{d} \sqrt{n}}{S_d} \]

In the equation, "\(d\)" is the average difference, \(n\) is the sample size (12 in this case) and \(S_d\) is the sample standard distribution. The computed \(\lambda\) value is then compared to a t distribution to verify that it is contained within the acceptance region, in which case we accept the null hypothesis. If \(\lambda\) is outside this region, the null hypothesis is rejected. A typical t distribution showing the acceptance and rejection regions is presented in the following figure.
In the figure, the region of acceptance is defined as the area that sums to $1-\alpha$ symmetrically around the mean. Therefore, the tails on both sides sum to $\alpha$. As is depicted in the figure, the acceptance criterion is the following.

$$|\lambda| \leq t_{n-1,1-\alpha/2}$$

It can also be seen that the rejection criterion is the following.

$$|\lambda| \geq t_{n-1,\alpha/2}$$

A sample calculation is presented for reference. Using the data presented in the previous table, the difference between Paper and Monochrome, and between Paper and Color is computed. For each case, the average of the difference, as well as the sample standard deviation is computed. The t-statistic is computed and compared to the t-distribution. Using a 5% ($\alpha=.05$) significance of the test and a sample size of 12, the value for the t-distribution can be found from most statistics books. For this case $t_{12,1-0.025} = 2.201$.

The computed lambda values were the following for each case described above.
Paired t-Test  $X_1$: paper task 1  $Y_1$: mono task 1

<table>
<thead>
<tr>
<th>DF</th>
<th>Mean X - Y:</th>
<th>Paired t value:</th>
<th>Prob. (2-tail):</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>-0.042</td>
<td>-0.119</td>
<td>0.9076</td>
</tr>
</tbody>
</table>

Paired t-Test  $X_1$: paper task 1  $Y_1$: color task 1

<table>
<thead>
<tr>
<th>DF</th>
<th>Mean X - Y:</th>
<th>Paired t value:</th>
<th>Prob. (2-tail):</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>1.521</td>
<td>4.278</td>
<td>0.0013</td>
</tr>
</tbody>
</table>

Since the null hypothesis was accepted; i.e. the computed t-statistic was -0.119 and was contained within -2.201 and 2.20, the Paper and Monochrome experimental charts were equivalent. The Paper and Color charts were not equivalent since the t-statistic was 4.278 (>2.201). Therefore, the null hypothesis was rejected.

It can be concluded that the Paper and Monochrome experimental charts were equally preferred. The Color chart was preferred over the Paper chart. Another comparison between Monochrome and Color would complete the possibilities for comparison sake. This comparison was completed, but has not been included. However, since the paper and Monochrome charts were equally preferred and Color was preferred to Paper, it followed that Color was preferred to Monochrome.

Analysis of Variance

The following procedure was used for the analysis of pilot performance data. Response time to explicit performance questions that were asked during the approach was the variable used to measure pilot performance. Videotapes of all cockpit communications between the subject pilot, the PNF, and ATC were reviewed during a post run analysis in which an experimenter used a stopwatch to record response times to each performance question asked during Phase I. Even though response times were subjectively recorded, care was taken to maintain a high level of consistency throughout the measurement process. The average response time for question “A” for each experimental chart was tabulated across all pilots and is depicted for reference below.
A one way analysis of variance was conducted for each question in order to determine any significant differences in pilot performance when using each experimental charts.

A one factor linear statistical model was used to analyze the data.

\[ y(ij) = \mu + B(i) + e(ij) \]

In the above equation, \( y(ij) \) is the time observed for subject \( j \) in the \( i \) format, \( \mu \) is the overall mean of all times measured (for each question), \( B(i) \) is the effect of the experimental chart used, and \( e(ij) \) is the experimental error.

The statistical hypothesis that is tested in an analysis of variance is equivalent to the statistical hypothesis that is tested in a t-test. However, it is tested across multiple samples. Therefore, the null hypothesis being tested relates to the equality of the response times averages for each chart.

\[ H_0: \mu(\text{paper})=\mu(\text{monochrome})=\mu(\text{color}) \]
Therefore, if the null hypothesis is rejected, it must be true that for at least one pair of the charts being analyzed:

\[ H_1: \mu(i) = \mu('i) \]

\( \beta(i) \) represents a deviation from the mean caused by the influence of each chart. Therefore, if the above null hypothesis is true, it also must be true that:

\[ \sum_{i=1}^{a} \beta(i) = 0 \]

Therefore, the statistical hypothesis can be rewritten as follows:

\[ H_0: \beta(1) = \beta(2) = \ldots = \beta(a) = 0 \]
\[ H_1: \beta(i) = 0 \text{ for at least one } i. \]

The procedure used to determine the truth of this hypothesis was Analysis of Variance (ANOVA). This analysis consisted of partitioning the sources of variation that are contained in the data, and is accomplished by calculating the sum of squares. The total sum of squares for the experimental matrix was computed as follows:

\[ SST = \sum_{i=1}^{a} \sum_{j=1}^{n} (y_{ij} - \bar{y}_j) \]

In the statistical model, it was assumed that it is possible to partition the measure of variability into two different sources: different experimental charts, and the experimental error.

\[ SS_T = SS_{TREATMENTS} + SS_E \]

In the statistical model, SS(treatments) is the sum of squares of the treatments. SS(E) is the source of variability due to experimental error, plus any other effect that was not explicitly accounted for in the statistical model, but that might contribute to the variability of the data. The sum of squares for the treatments was computed as follows:

\[ SS_{TREATMENTS} = \sum_{i=1}^{a} (\bar{y}_i - \bar{y})^2 \]
In the above equation, a period (subscript) denotes summation over the index it replaces. As such, $\bar{Y}_i$ denotes the summation over subjects; therefore, the above expression is simply the difference of average time per chart and the overall average squared multiplied by the number of subjects. Once the sum of squares of the treatments was obtained, the sum of squares for the error term can be found by subtracting the treatments sum of squares from the total sum of squares:

$$SS_E = SS_T - SS_{TREATMENTS}$$

The mean sum of errors was computed by spreading the sum of errors over all the error degrees of freedom, which was done for each variable. Therefore, in order to compute the mean square of the treatments, $SS_{TREATMENTS}$ was divided by the degrees of freedom of the treatments.

$$MS_{TREATMENTS} = \frac{SS_{TREATMENTS}}{a-1}$$

In order to test the hypothesis, the statistical model previously described was assumed. Accordingly, it is assumed that the residuals $e(ij)$ are normally and independently distributed with mean zero and variance $\sigma^2$, and that the observations $y(ij)$ were normally and independently distributed with mean $\mu + \tau_i$ and variance $\sigma^2$. Therefore, the sum of squares divided by the variance $\sigma^2$ is distributed like a chi-square with the respective degrees of freedom. If the null hypothesis is true, then $SS(\text{treatments})/\sigma^2$ would be chi-square distributed with $(a-1)$ degrees of freedom. As such, the mean square of the TREATMENTS and the residual would be independent. Under these circumstances, if the null hypothesis is true, the ratio of the treatment and error mean squares is F-distributed with $a-1$ and $N-a$ degrees of freedom. By comparing the ratio of these means to the F distribution, a determination can be made as to whether or not to accept the null hypothesis.

The first step in the procedure was to verify the assumption of normality. In order to investigate if this assumption is satisfied, various tests were performed. Only one such test was performed with satisfactory results. This test consisted of plotting a histogram of the residual term $e(ij)$. It was convenient to first standardize these residuals by plotting the histogram for $d(ij)$ instead of $e(ij)$ where $d(ij)$ is given by:
The mean of the new probability distribution remained unchanged, but the standard deviation became one. Usually, most data must fall within 3 standard deviations from the mean to remain within the normality assumption. A sample histogram using performance question “B” is presented below.

This is a typical histogram of the data that was analyzed. Note the occurrence of the bar at 3.25 standard deviations from the mean. This represents a potential outlier. The statistics for this distribution are the following:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum: -1.631</td>
<td>Maximum: 3.393</td>
<td>Range: 5.024</td>
<td>Sum: -4.526E-6</td>
<td>Sum Squared: 33.021</td>
<td># Missing: 0</td>
<td></td>
</tr>
</tbody>
</table>

Note from the figure that the mean is nearly zero, and the standard deviation is 0.971. This value is close enough to a normal distribution so as to proceed with the analysis of variance. It should be noted that additional tests such as checks for the independence of the variables in the statistical model were not completed.
After conducting analysis of variance on all questions, it was found that only in question "I" (obstruction information) the means of the treatments were significantly different. The ANOVA table for this question is the following:

One Factor ANOVA-Repeated Measures for X1 ... X12

<table>
<thead>
<tr>
<th>Source:</th>
<th>df:</th>
<th>Sum of Squares:</th>
<th>Mean Square:</th>
<th>F-test:</th>
<th>P value:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between subjects</td>
<td>2</td>
<td>340.133</td>
<td>170.066</td>
<td>3.912</td>
<td>.0299</td>
</tr>
<tr>
<td>Within subjects</td>
<td>33</td>
<td>1434.761</td>
<td>43.478</td>
<td></td>
<td></td>
</tr>
<tr>
<td>treatments</td>
<td>11</td>
<td>412.365</td>
<td>37.488</td>
<td>.807</td>
<td>.6336</td>
</tr>
<tr>
<td>residual</td>
<td>22</td>
<td>1022.396</td>
<td>46.473</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>35</td>
<td>1774.894</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Reliability Estimates for- All treatments: .744 Single Treatment: .195

The F statistic for 95 % significance was 3.293. Since Fo is 3.912 for question "I", it was concluded that the mean response time was statistically different between at least one pair of charts.

In order to determine which means within the group are different, a Duncan test was performed. The results from the Duncan test suggest that there is no difference in the means between the Paper and the Monochrome chart but that both are different than the Color chart. The mean response time for this question is depicted below.

<table>
<thead>
<tr>
<th>Paper</th>
<th>Monochrome</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.72</td>
<td>9.53</td>
<td>2.64</td>
</tr>
</tbody>
</table>

Therefore, it was concluded that Color had a faster response time than the other charts.