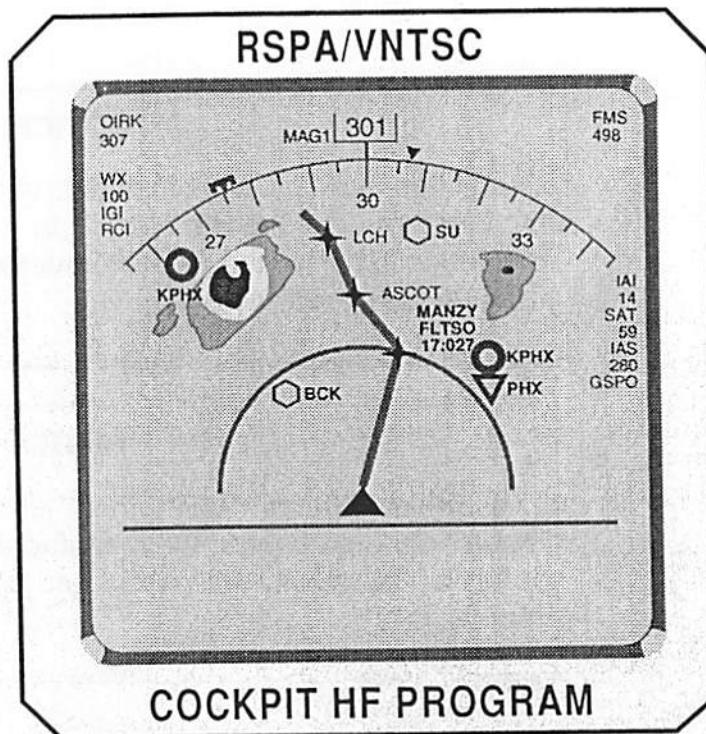


FAA 94-31

DOT/FAA/AAR-95/1
DOT-VNTSC-FAA-94-31

Research and Development
Service
Washington, DC 20591

Current Issues in the Design and Information Content of Instrument Approach Charts



R. John Hansman, Jr.
Mark Mykityshyn

Aeronautical Systems Laboratory
Department of Aeronautics & Astronautics
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Final Report
March 1995

This document is available to the public
through the National Technical Information
Service, Springfield, Virginia 22161



U.S. Department of Transportation
Federal Aviation Administration

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

NOTICE

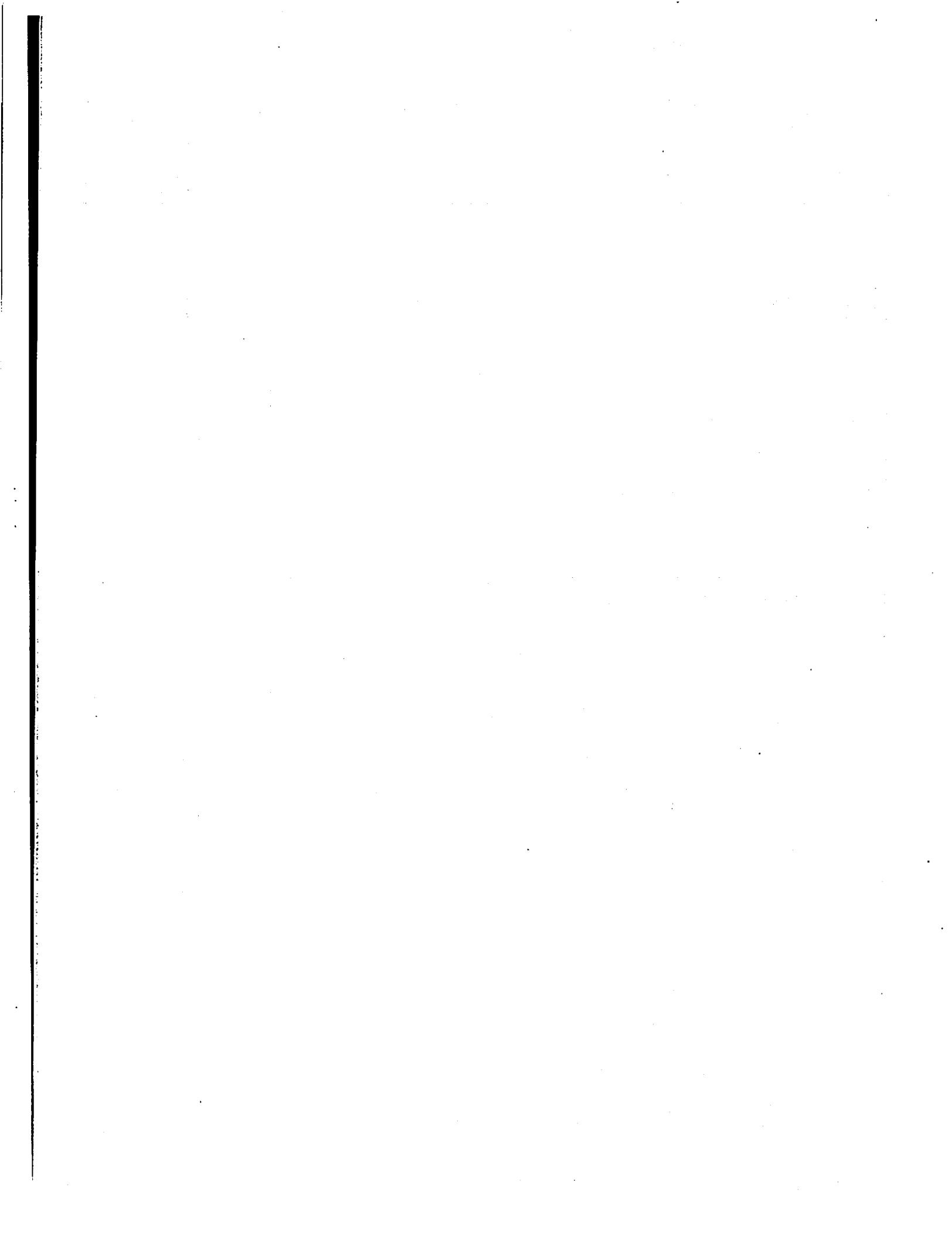
The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the objective of this report.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE March 1995		3. REPORT TYPE AND DATES COVERED Final Report - November 1990	
4. TITLE AND SUBTITLE Current Issues in the Design and Information Content of Instrument Approach Charts				5. FUNDING NUMBERS FA5007/FA5E2	
6. AUTHOR(S) R. John Hansman, Jr., Mark Mykityshyn					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Aeronautical Systems Laboratory* Department of Aeronautics & Astronautics Massachusetts Institute of Technology Cambridge, MA 02139				8. PERFORMING ORGANIZATION REPORT NUMBER DOT-VNTSC-FAA-94-31	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Federal Aviation Administration Research & Development Service Washington, DC 20591				10. SPONSORING/MONITORING AGENCY REPORT NUMBER DOT/FAA/AAR-95/1	
11. SUPPLEMENTARY NOTES *under contract to:		U.S. Department of Transportation Volpe National Transportation Systems Center Cambridge, MA 02142			
12a. DISTRIBUTION/AVAILABILITY STATEMENT This document is available to the public through the National Technical Information Service, Springfield, VA 22161				12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) This report documents an analysis and interview effort conducted to identify common operational errors made using current instrument approach plates (IAP), standard terminal arrival route (STAR) charts, standard instrument departure (SID) charts, and the preferences of pilots regarding current chart format designs. In addition, pilot preferences or comments relevant to the presentation of IAP information in advanced electronic format were solicited and noted. The analysis included data from prior studies and a variety of accident, incident, and operational error databases. Representatives from flight operation user groups and charting organizations were interviewed to gain insight into operational errors, pilot preferences and the factors which influence chart design. The IAP user groups interviewed consisted primarily of training centers and individuals representing the full spectrum of IAP users (General Aviation, Corporate Aviation, Air Taxi Part 135 Operators, and Air Carrier Part 121 Operators). Cartographic organizations interviewed included Jeppesen Sanderson Inc., NOAA and the FAA. For comparison, a non-US based carrier and chart provider (KLM) was queried by mail.					
14. SUBJECT TERMS Navigation, Charting, Instrument Approach Procedures, Approach Plates, Human Factors				15. NUMBER OF PAGES 80	
				16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified		18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified		19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	
20. LIMITATION OF ABSTRACT					



PREFACE

This work was supported by the Department of Transportation under TSC Contract DTRS-57-88-C-00078. The authors would like to thank those who consented to be interviewed and those who completed the surveys. They would also like to thank Jeppesen Sanderson, Inc. for permission to reprint example charts.

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

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

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

1 square inch (sq in, in²) = 6.5 square centimeters (cm²)
 1 square foot (sq ft, ft²) = 0.09 square meter (m²)
 1 square yard (sq yd, yd²) = 0.8 square meter (m²)
 1 square mile (sq mi, mi²) = 2.6 square kilometers (km²)
 1 acre = 0.4 hectare (he) = 4,000 square meters (m²)

AREA (APPROXIMATE)

1 square centimeter (cm²) = 0.16 square inch (sq in, in²)
 1 square meter (m²) = 1.2 square yards (sq yd, yd²)
 1 square kilometer (km²) = 0.4 square mile (sq mi, mi²)
 10,000 square meters (m²) = 1 hectare (he) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)
 1 pound (lb) = 0.45 kilogram (kg)
 1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

MASS - WEIGHT (APPROXIMATE)

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

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
 1 tablespoon (tbsp) = 15 milliliters (ml)
 1 fluid ounce (fl oz) = 30 milliliters (ml)
 1 cup (c) = 0.24 liter (l)
 1 pint (pt) = 0.47 liter (l)
 1 quart (qt) = 0.96 liter (l)
 1 gallon (gal) = 3.8 liters (l)
 1 cubic foot (cu ft, ft³) = 0.03 cubic meter (m³)
 1 cubic yard (cu yd, yd³) = 0.76 cubic meter (m³)

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
 1 liter (l) = 2.1 pints (pt)
 1 liter (l) = 1.06 quarts (qt)
 1 liter (l) = 0.26 gallon (gal)

1 cubic meter (m³) = 36 cubic feet (cu ft, ft³)
 1 cubic meter (m³) = 1.3 cubic yards (cu yd, yd³)

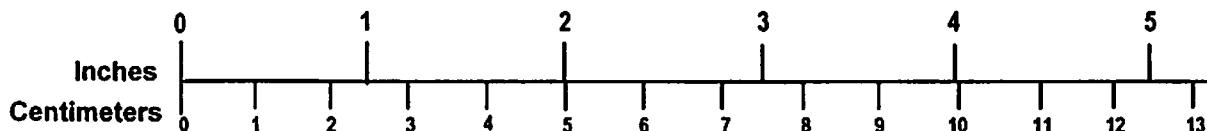
TEMPERATURE (EXACT)

$$[(x-32)(5/9)]^{\circ}\text{F} = y^{\circ}\text{C}$$

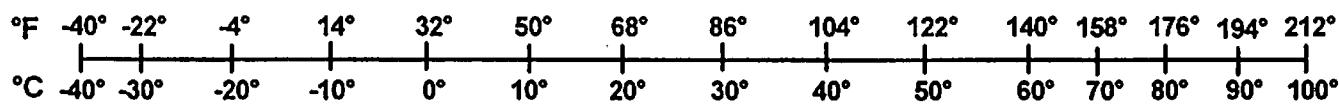
TEMPERATURE (EXACT)

$$[(9/5)y + 32]^{\circ}\text{C} = x^{\circ}\text{F}$$

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION



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

Updated 1/2/95

TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
1. INTRODUCTION	1
2. APPROACH	3
2.1 Literature Review	3
2.2 Analysis of Relevant Data	4
2.2.1 Accident/Incident Data	4
2.2.2 Operational Error Data	4
2.2.3 Aviation Safety Reporting System (ASRS) Data	5
2.2.4 NOAA Callback Comments	5
2.3 Pilot Opinion Survey Data	5
2.3.1 MIT Survey	5
2.3.2 Aviation Systems Concepts, Inc. Survey	6
2.3.3 ALPA Survey Data	6
2.4 Interviews	6
2.4.1 Training Centers	7
2.4.2 Operators	7
2.4.3 Cartographic Agencies	8
2.4.4 Equipment Manufacturers	9
3. Discussion and Findings	11
3.1 Factors Influencing Chart Evolution	11
3.2 Chart Design Tradeoffs	18
3.2.1 Chart Size Versus Legibility	18
3.2.2 Information Content Versus Chart Clutter	19
3.2.3 Cost Tradeoffs	22
3.3 Currency of Approach Information	23
3.4 Training and Operational Use Patterns	24
3.5 Operational Error	26
3.5.1 Confusion Between Primary and Secondary Navaid Frequencies	27
3.5.2 Confusion on Approach Minimums	27
3.5.3 Missing Notes	30

TABLE OF CONTENTS (cont.)

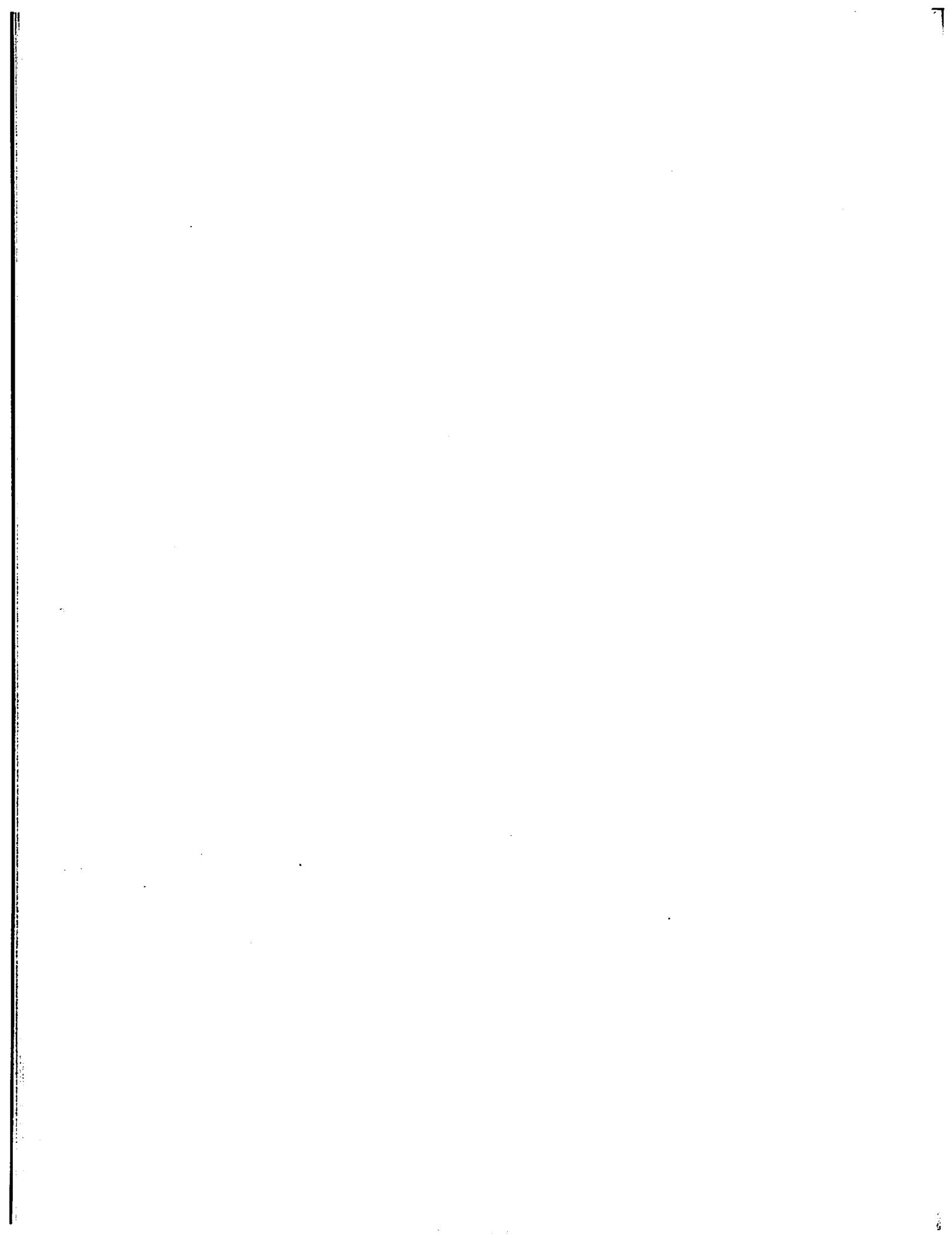
<u>Section</u>	<u>Page</u>
3.5.4 Confusion on Minimum Safe Altitudes	30
3.5.5 Complexity of the Procedures	32
3.5.6 Runway Length and Lighting Information	32
3.5.7 Awareness of Common ILS Frequencies	32
3.6 Electronic Approach Plates	33
4. CONCLUSION	35
5. REFERENCES	37
APPENDIX A	A-1
APPENDIX B	B-1
APPENDIX C	C-1

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1. Example of ICAO Instrument Approach Plate Format Taken from ICAO Circular 187-AN/114 [12]		12
2. Example of NOAA Instrument Approach Plate		13
3. Example of Jeppesen Sanderson, Inc. Instrument Approach Plate		14
4. Example of KLM Large Format Chart		15
5. Example of AIP France – Service de l’Information Aeronautique Instrument Approach Plate		16
6. Example of a Spot Elevation Symbol		17
7. ALPA Instrument Approach Chart Prototype [16]		21
8. Example of Primary Navaid Frequency Identification Boxes from NOAA and Jeppesen IAP's		28
9. Example of NOAA Chart with Minimum Modification Note Shown		29
10. Example of Safe Altitude [8]		31

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1. Typical Air Carrier Pre-Approach Briefing Items		25



EXECUTIVE SUMMARY

This report documents an explanatory effort to uncover and document human factors issues in the design of Instrument Approach Charts, sometimes referred to as Instrument Approach Plates (IAP's). The effort consisted of literature review, pilot opinion survey, data analysis, and interview components. The analysis included data from the National Transportation Safety Board, Federal Aviation Administration, Aviation Safety Reporting System, and National Oceanic and Atmospheric Administration. A small pilot opinion survey on patterns of IAP use was conducted by MIT. Prior IAP surveys were also analyzed. Focused interviews were conducted with training centers, operators, cartographic agencies, and equipment manufacturers. Because of the exploratory nature of this effort, the findings reported in this document warrant further investigation and should not be considered as necessarily representative of any IAP user group. The investigations resulted in the following findings:

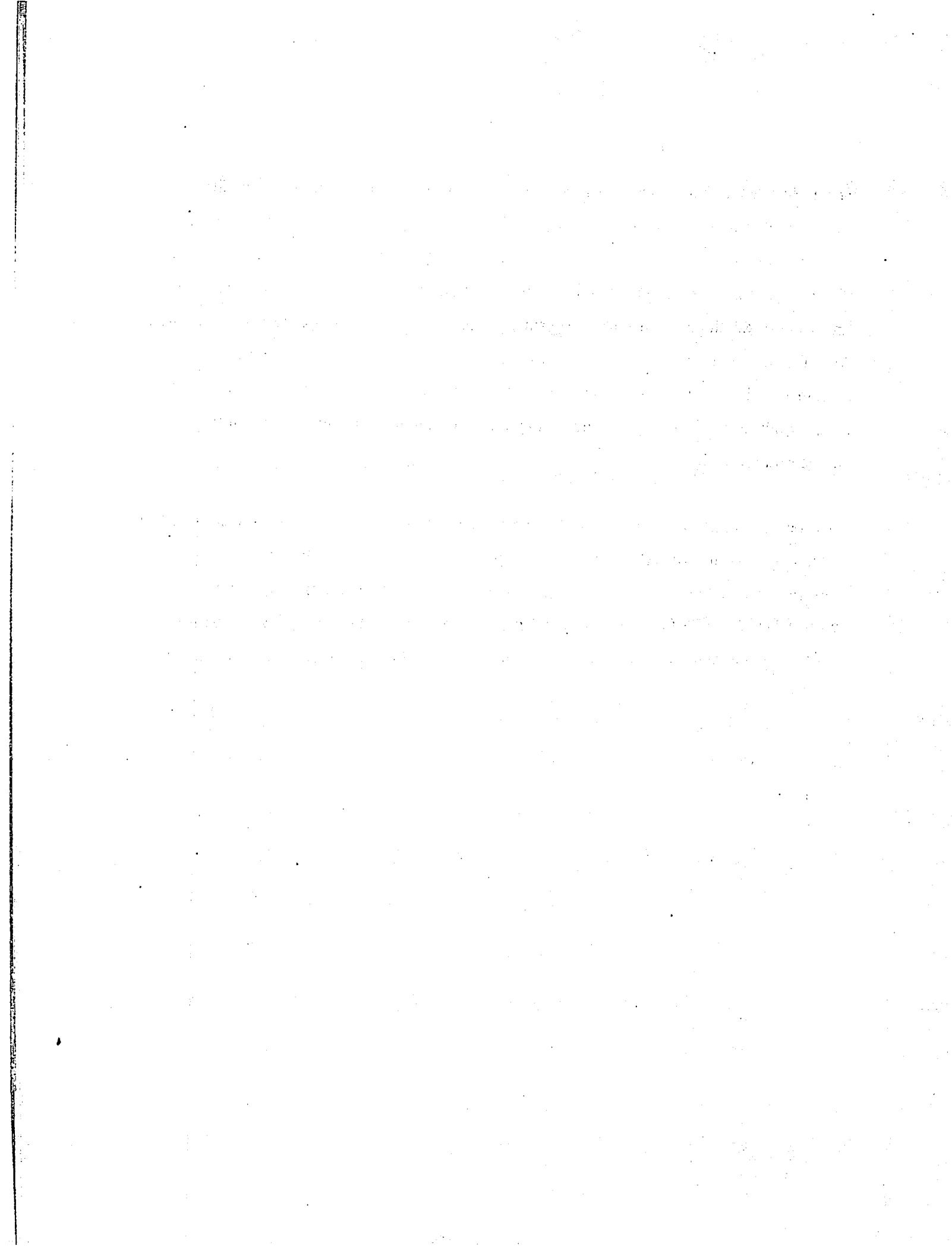
1. Current IAP's are the result of a mature evolutionary process driven by user feedback, concern over flight safety, and the liability of the charting agencies. Even though the charts have evolved in the absence of formal human factors analysis, major changes in format for paper approach charts does not appear to be indicated.
2. Current IAP's represent a balance between different chart design tradeoffs. Fundamental tradeoffs were identified in the areas of: chart size versus legibility, information content versus clutter, and cost tradeoffs.
3. Concern over "controlled flight into terrain" accidents has motivated an increased interest in terrain information on the IAP's. The current technique of presenting terrain information through spot elevations is considered ineffective and contributes to chart clutter. Smoothed contours have been used effectively to portray terrain information. However, the resulting increase in data monitoring, chart revision, and production costs has contributed to preventing full implementation by US chart producers.

4. Several problems were identified relating to the currency of information available to the flight crews both on the IAP's and through Notices to Airmen (NOTAMS).
5. Significant differences in IAP operational-use patterns were observed between user groups; particularly, between multi-crew air carrier operations and single pilot general aviation operations. Cost factors preclude IAP designs focused for specific user groups.
6. Some evidence was found that switching between IAP formats reduced the effectiveness of information transfer from the charts. This argues that a significant performance or safety improvement should be expected before major format changes are implemented. In addition, formal human factors review of proposed changes would help quantify the potential improvements.
7. In the MIT survey, 93% of the pilots felt that it was possible to make operational errors due to chart design. Several potential operational errors were identified including: confusion between primary and secondary navaid frequencies, confusion on approach minimums, missing chart notes, confusion on minimum safe altitudes, complexity of the procedures, location of runway lighting information, and awareness of dual use common ILS frequencies.
8. The potential of electronic IAP's offers the opportunity for more flexibility in the presentation of approach information. However, concerns about system reliability, data integrity, and structure and crew workload have emerged. It is generally agreed that electronically based IAP's will emerge within the next five years and it is important to reconsider the IAP human factors issues in light of the flexibility, capability, and limitations of the electronic systems.

1. INTRODUCTION

The 1985 FAA Human Factors Research Plan¹ identified chart design as one of the cockpit-related human performance problem areas which should be addressed through human factors research. Instrument Approach Charts, also referred to in this report as Instrument Approach Plates or IAP's, were chosen for initial human factors review over other chart types such as En Route or Sectional Charts for two primary reasons. First, the IAP's depict the Terminal Arrival and Missed Approach Procedures which occur at low levels with minimal terrain clearance and consequently low tolerance for procedural errors. Secondly, the IAP's often have a high level of procedural and cartographic complexity, making careful human engineering critical.

This report documents an effort to identify specific areas where improved human engineering of the design or use of IAP's could yield improvements in performance or flight safety. The work was conducted under Department of Transportation/Transportation Systems Center contract DTRS-57-88-C-00078. In the report, the procedures used to query the various information sources are described in Section 2. The findings are presented and discussed in Section 3.



2. APPROACH

The approach consisted of a broadly based analysis and review of information sources likely to yield insight into potential operational errors related to IAP usage. In addition, pilot preferences were solicited to allow identification of areas where user-centered design principles could be productively applied to IAP use or design.

The information sources used included a broadly based literature review, analysis of relevant data sources, and the analysis of several pilot opinion surveys. In addition, focused interviews were conducted to get input from both the operational and chart production communities. A brief description of the procedure used for each of the information source types is presented below.

2.1 LITERATURE REVIEW

A broadly based literature review was conducted. In addition to reviewing the aviation human factors literature, such as *Human Factors in Aviation*² edited by Weiner and Nagel, and *Flightdeck Performance*³ by O'Hare and Roscoe, the *Proceedings of the Five Symposiums on Aviation Psychology*⁴ and specific reports on charting human factors such as the *Report of Safety Survey Human Integration of Approach Charts*⁵ were also reviewed. Aircrew training material was also reviewed including the *FAA Instrument Flying Handbook* (AC-61-27C),⁶ the Jeppesen-Sanderson Flight Time video training tape *Jeppesen Approach Charts*,⁷ the *NOAA Aeronautical Chart Users Guide*,⁸ as well as a self-study guide for a major U.S. air carrier.

The regulatory and cartographic literature were also reviewed. This included the *Terminal Instrument Procedures* (TERPS)⁹ which define the criteria for instrument approach procedures in the U.S., the *Federal Aviation Regulations*,¹⁰ the *Airman's Information Manual*,¹¹ the *ICAO Instrument Approach Chart Guidance to Chart Makers* (Circular 187-AN/114),¹² the *FAA Instrument Procedures Automation Users Manual*,¹³ and *Instrument Approach Procedures from Request to Publication*.¹⁴

Finally the last three years of aviation periodicals were reviewed including *IFR Refresher*, *AOPA Pilot*, *Aviation Week and Space Technology*, *Airline Pilot, Flying*, and *Professional Pilot*.

2.2 ANALYSIS OF RELEVANT DATA

A review and analysis of available data relevant to IAP-related operational errors and pilot preferences was conducted.

2.2.1 Accident/Incident Data

In order to identify accident statistics related to IAP usage, an attempt was made to filter the FAA Accident/Incident Database for IAP-related accidents or incidents. This database is generated from the FAA and NTSB investigations of accident and incident events. It consists of a broad range of data fields and a short narrative summary of the event.¹⁵ This effort was hampered by the lack of charting-related cause factors in the data fields.¹⁵ The most relevant listing of IAP-related accidents was found in an August 18, 1982 letter from NTSB Chairman Jim Burnett to FAA Administrator J. Lynn Helms, which discussed the “belief that insufficient attention is given to human performance criteria in the development of approach procedures and in the process for reviewing the approach procedure depicted on the approach charts.” The letter, which is included as Appendix A, also summarized nine fatal accidents involving the design of approach charts or approach procedures between 1971 and 1981.

2.2.2 Operational Error Data

The FAA Operational Error Database (which is similar to the Accident/Incident Database) was reviewed for a one-year period starting in 1987. In general, the database focused on controller errors; consequently, little information relevant to this study was found.

2.2.3 Aviation Safety Reporting System (ASRS) Data

The Aviation Safety Reporting System (ASRS) data set was scanned for reports related to charting issues between January 1, 1983 and November 8, 1988. The ASRS is a program in which pilots and controllers are encouraged to report safety-related issues and errors with some degree of immunity and anonymity. A total of 86 reports were identified and analyzed further. Of these, 42 were found to be related to IAP use. These reports were summarized, categorized, and evaluated in order to identify common patterns or particularly serious problems.

2.2.4 NOAA Callback Comments

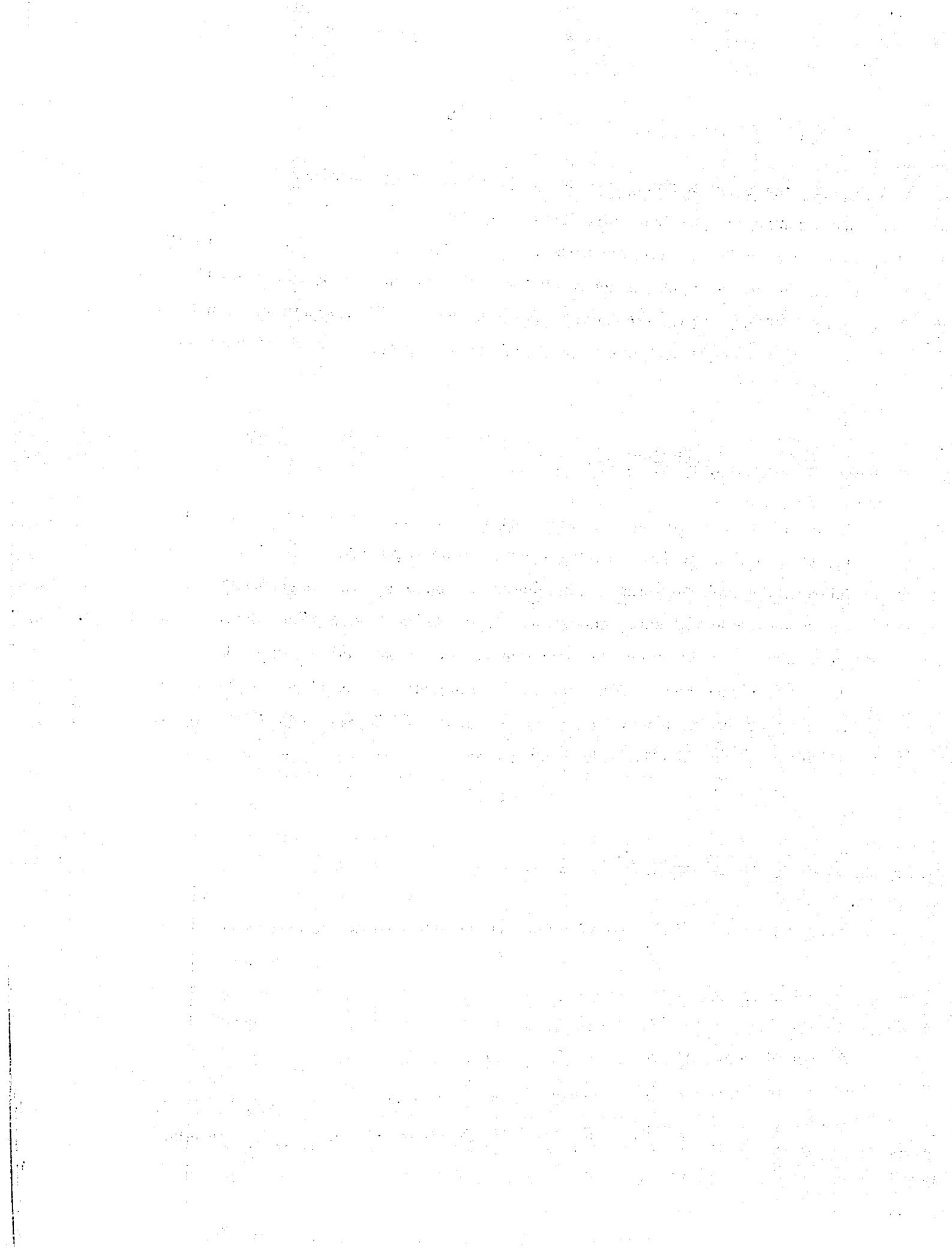
In an effort to minimize and respond to charting errors, or to answer questions of an interpretational nature, NOAA, which is the government producer of civil IAP's, provides a toll-free 800 number for users to call with chart errors or problems in chart interpretation. These calls are logged and appropriate actions are tracked. The NOAA callback comments are a valuable data set in that they represent a cross-section of errors and problems in interpretation encountered by the users. NOAA provided the investigators with 237 callback comment log sheets representing a 24-month period. The sheets contained 259 comments which were evaluated. The evaluation consisted of a review of the comments and a categorization into one of 11 comment categories.

2.3 Pilot Opinion Survey Data

Data were analyzed from several relevant pilot opinion surveys described below.

2.3.1 MIT Survey

As part of the overall effort on the design and evaluation of aeronautical charts, 300 copies of an extensive survey on approach chart information analysis were distributed to IAP users representing a full spectrum of operators from general aviation to air carrier. When this



training centers, operators, cartographic agencies, and equipment manufacturers. Unless noted, the interviews were conducted from a directed question list (Appendix C). In addition, related comments and observations by the interviewees were solicited.

It should be noted that it was decided to interview a limited number of individuals from a broad range of groups in order to obtain input from a wide range of IAP experience. As a consequence, the responses from any individual group may not be fully representative. However it was felt that this method obtained the broadest possible exposure within the scope of this effort.

2.4.1 Training Centers

Training Centers were chosen as prime interview sources because it was hypothesized that difficulties with IAP use would be most apparent in the training environment where the user (i.e., the student) tends to exhibit a higher frequency of operational errors as a result of training stress and practice in abnormal or emergency situations. In addition, the instructor has the opportunity to observe and critique those operational errors which do occur.

Representing professional pilot training, the Manager of Flight Training and the Senior Check Airman from two major air carriers were interviewed. Similarly, the Senior Instructors and Examiners at two Training Centers which primarily train corporate and Part 135 operators were interviewed. Finally, four Certified Instrument Flight Instructors (CFI-I) who provided initial instrument flight instruction to relatively low time (100 to 400 hour) non-professional pilots in single engine aircraft were interviewed, representing non-professional training operations. At the request of several of the organizations, the names and affiliations of the individuals interviewed are withheld in the report.

2.4.2 Operators

Informal interviews were conducted with a variety of pilots currently flying aircraft ranging from general aviation to fully autoflight-equipped air transport aircraft. The interviews often

occurred during jump seat observations of IAP use patterns. When possible, they followed the focused interview format (Appendix C). In addition, a representative from the Airline Pilots Association's (ALPA) Charting and Instrument Procedures Committee was interviewed.

2.4.3 Cartographic Agencies

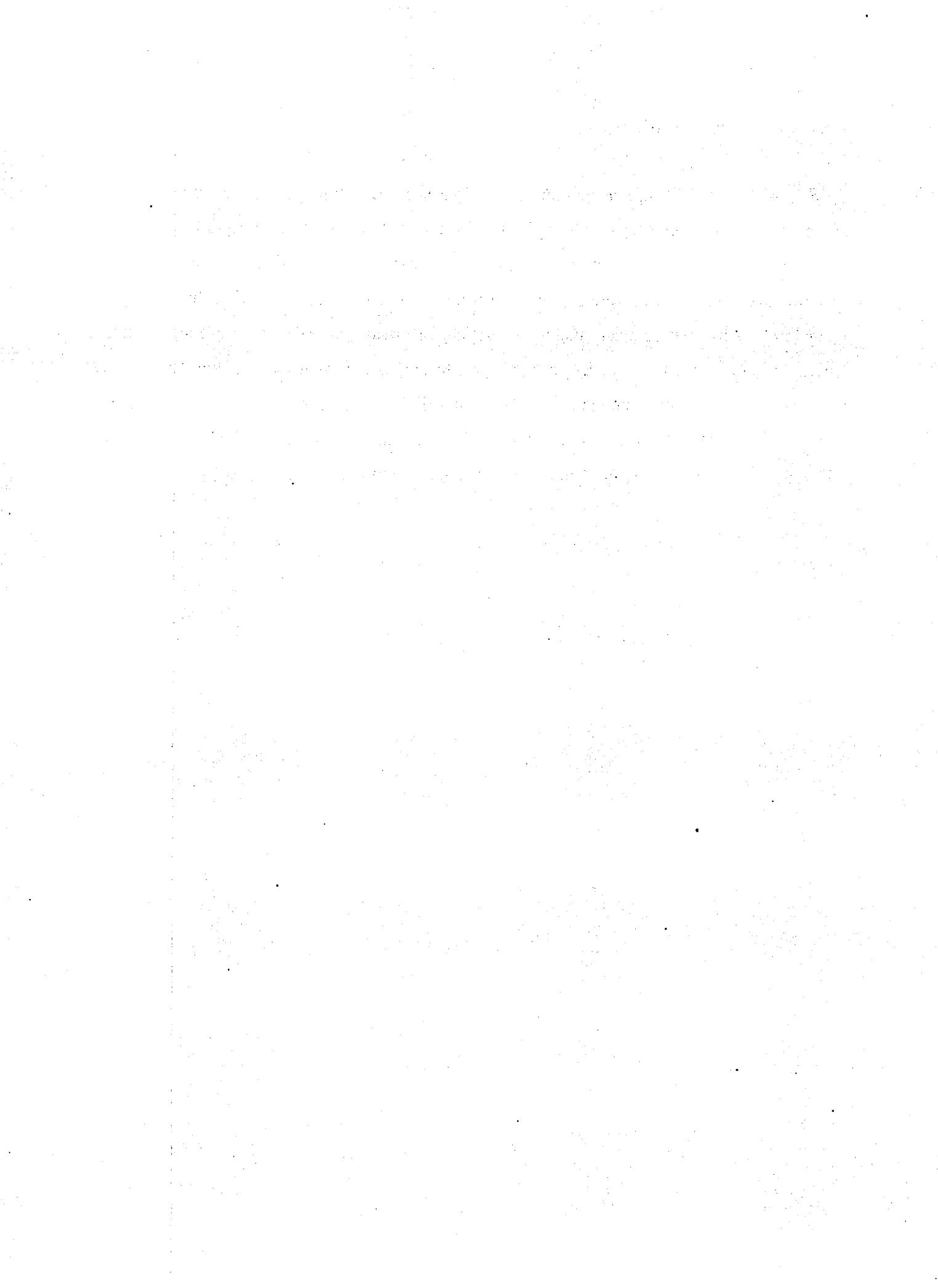
In an effort to identify the issues perceived as important by the agencies and organizations which are involved in the production of IAP's, a set of focused interviews was conducted with representatives from these groups. The interview procedure was similar to that used for the Training Centers, however, the scope and direction of the interviews was modified to reflect the issues relevant to the cartographic groups.

Within the continental U.S., the primary providers of IAP's are Jeppesen Sanderson, Inc., and the U.S. government (NOAA and DOD in cooperation with the FAA). Representing NOAA, the Chief of the Instrument Approach Division was interviewed. The Chief was extremely cooperative and provided all requested data including the "Callback" comments for the proceeding two-year period. Representing Jeppesen Sanderson, Inc., the Vice President for Research, Development and Production and the Director of Flight Information Design and Research were interviewed on two separate occasions. They were also extremely cooperative and supportive of the effort. In the following discussions, Jeppesen Sanderson, Inc. charts will simply be referred to as Jeppesen, and U.S. Government charts will be referred to as NOAA charts.

The FAA representative to the Interagency Cartographic Committee which sets the cartographic standards for the NOAA and DOD charts was also interviewed as well as a flight surgeon for the FAA Office of Aviation Medicine who reviews chart modifications. For comparison, a non-U.S. based operator and chart provider (KLM) was contacted by mail and the Head of the Navigation and Documentation Department responded with written comments and examples of KLM approach chart formats.

2.4.4 Equipment Manufacturers

To gain further insight into current and future IAP use, representatives from several equipment manufacturers were interviewed. These interviews were generally informal since the focused interview formats were not directly applicable. Representing airframe manufacturers, individuals were interviewed from several organizations within the Boeing Commercial Airplane Company including Flight Deck Research and several product groups. Representing manufacturers of Electronic Flight Information Systems (EFIS) and flight data systems, interviews were conducted with several individuals at Honeywell Inc., and Sperry Commercial Flight Systems Group. Finally, the President of Lasertrack, which manufactures and supports a printer-based electronic IAP system, was interviewed.



3. DISCUSSION AND FINDINGS

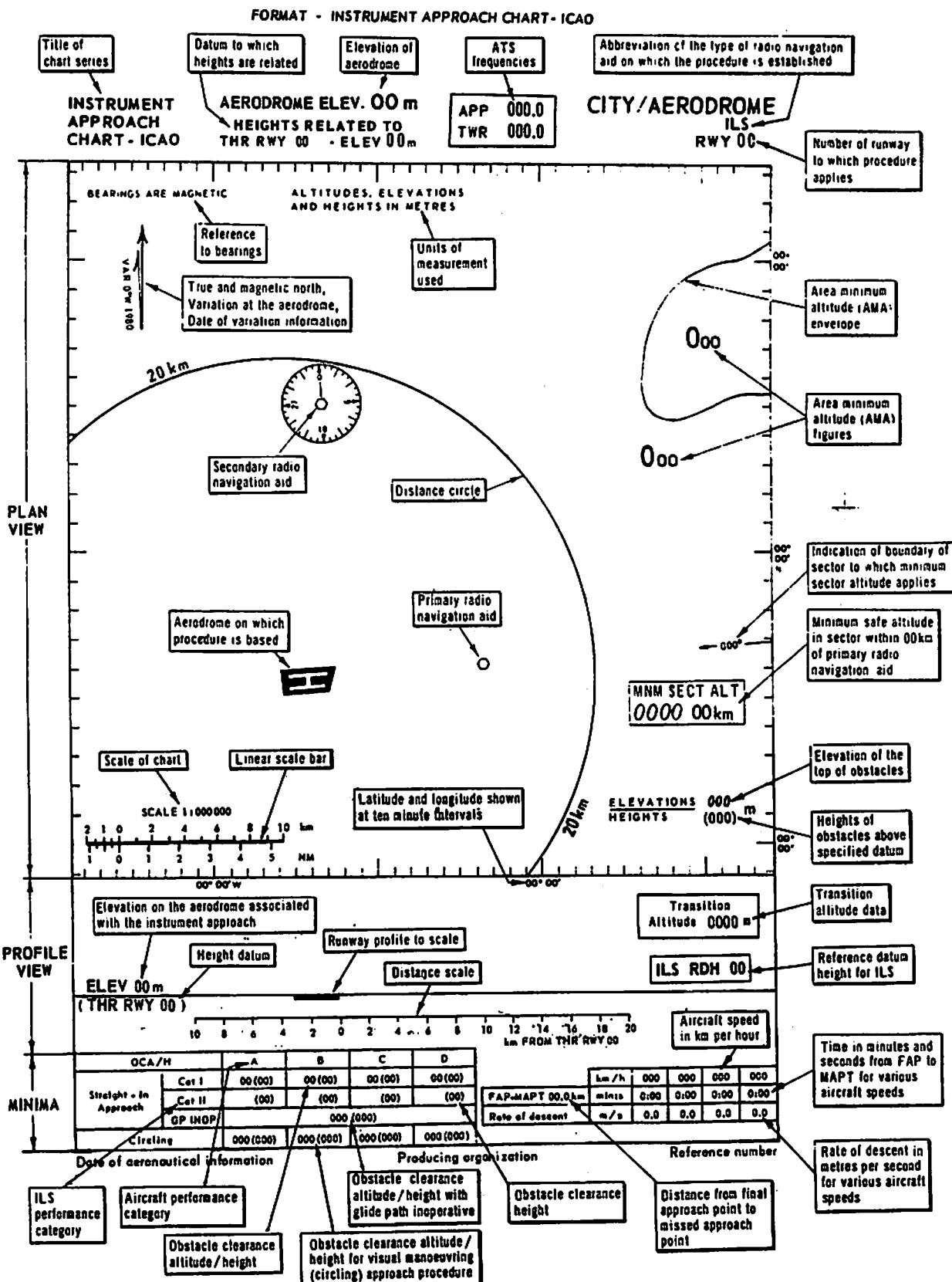
In order to provide a coherent presentation, the findings of the above review, survey, analysis, and interview effort were combined and organized into the six separate topical areas discussed below.

3.1 FACTORS INFLUENCING CHART EVOLUTION

While there are significant variations in detail, the overall format of most IAP's used in the western world are similar and generally fall within the guidelines recommended by the International Civil Aviation Organization (ICAO) Circular 187-AN/114. This can be seen by comparing the ICAO format shown in Figure 1 with examples of charts from NOAA, Jeppesen, KLM, and the French Service de l'Information Aeronautique shown in Figures 2 through 5.

For the US charts (NOAA and Jeppesen), the detailed format and design of the charts is considered to be the result of a mature evolutionary process. This process is driven by safety, legal, and market factors. When charting problems which clearly impact flight safety are identified, the charts are normally changed at the first possible opportunity. This can be seen in the response to the NTSB recommendations presented in Appendix A. At least six chart changes are a result of the nine accidents identified in the report.

Additionally, both NOAA and Jeppesen have programs which solicit user feedback to identify specific chart errors or general recommendations for improvement in chart design. This is done both for safety and for product improvement reasons, and is particularly true of Jeppesen which is extremely market-oriented in its chart design. NOAA uses a toll-free 800 telephone line to solicit user comments while Jeppesen uses a pre-paid postcard. Both NOAA and Jeppesen report that they carefully review all user inputs. This was confirmed for NOAA by reviewing two years of callback comment log sheets. Of the 259 comments, all were tracked to resolution by the NOAA staff. Jeppesen provided examples of similar response to user comments. In general, it was observed that these feedback mechanisms provided a strong positive mechanism for chart evolution.



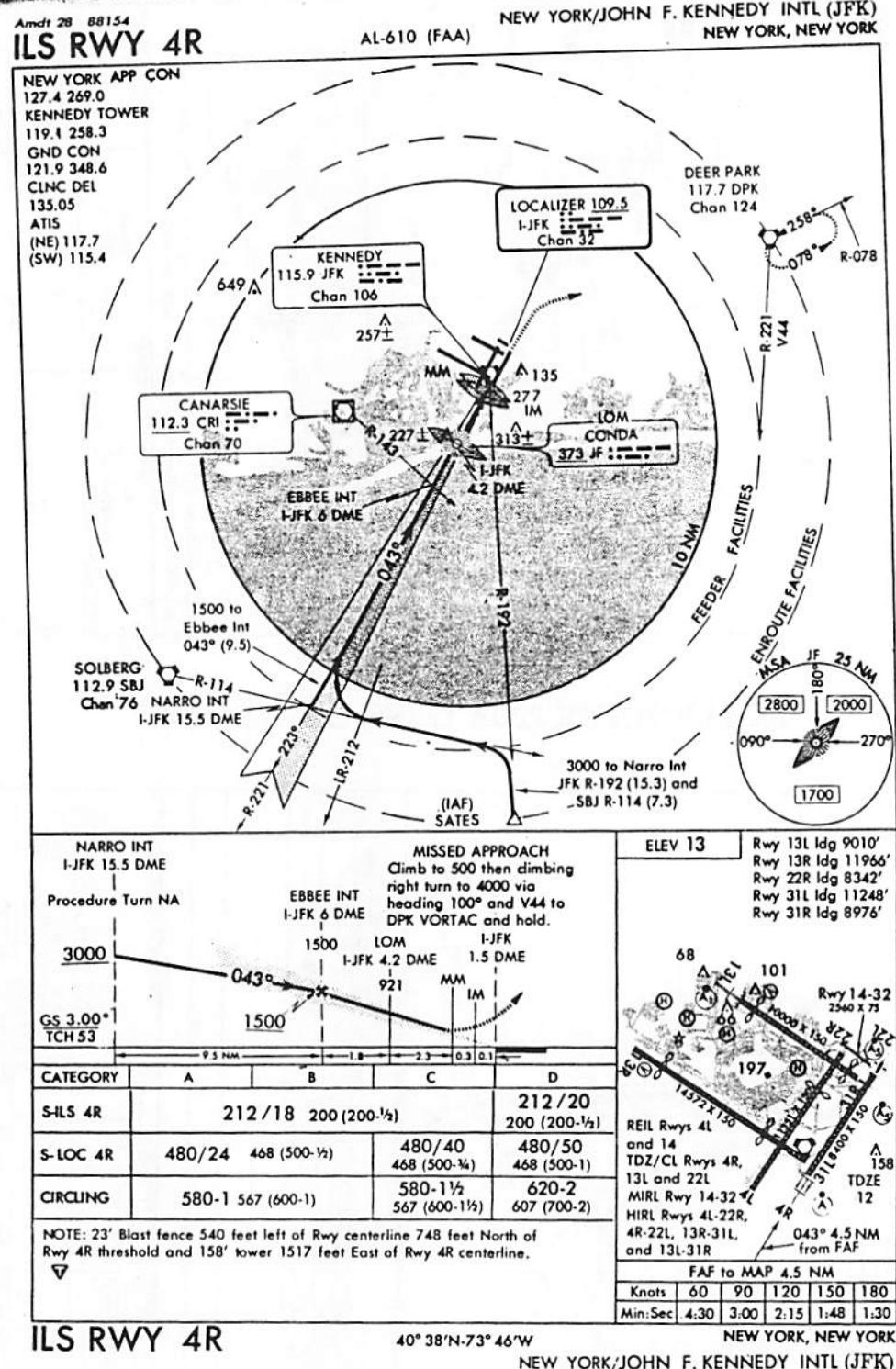
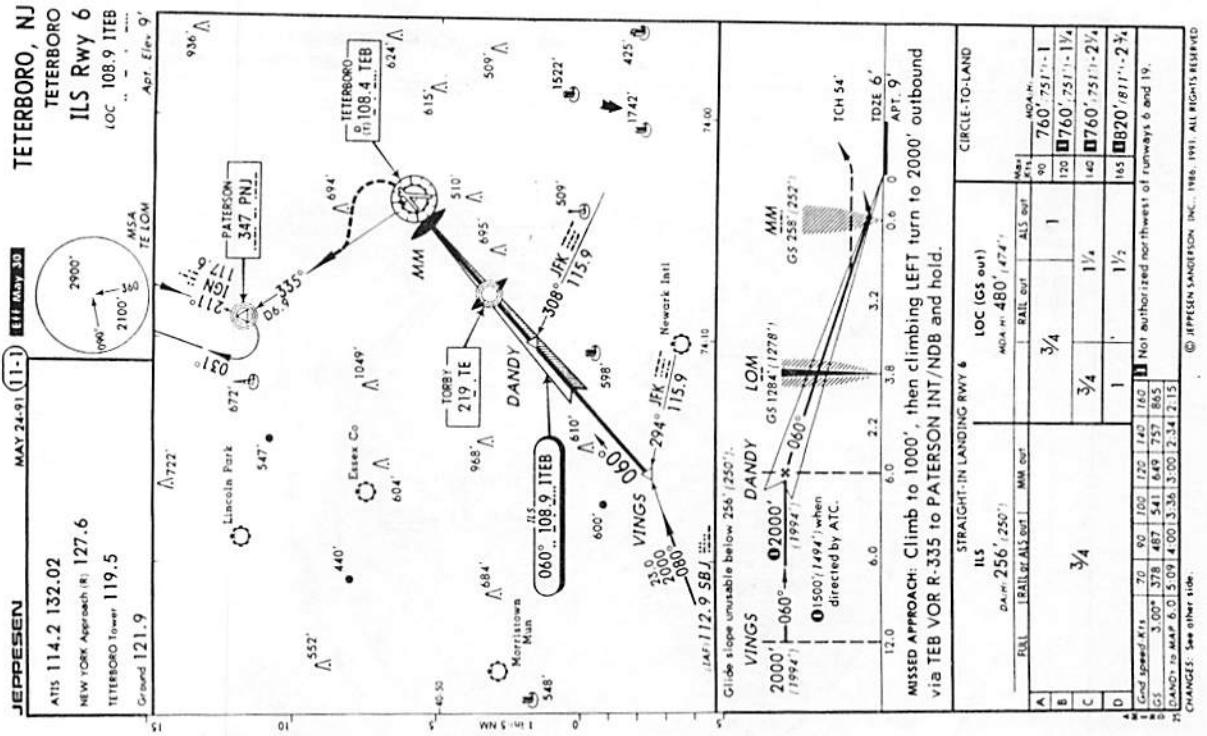
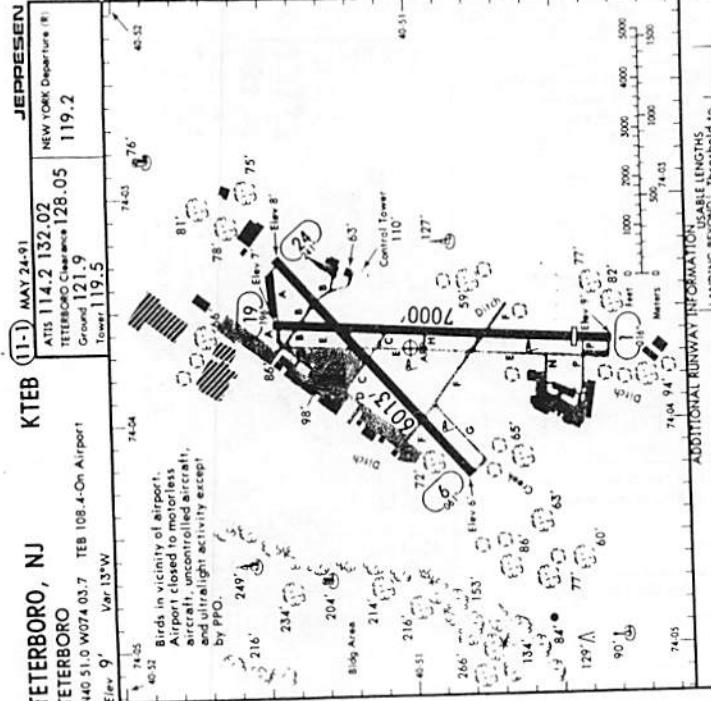


FIGURE 2. EXAMPLE OF NOAA INSTRUMENT APPROACH PLATE



NOT TO BE USED FOR NAVIGATION

FIGURE 3. EXAMPLE OF JEPPESEN SANDERSON, INC. INSTRUMENT APPROACH PLATE.

(The chart has been reduced here to allow presentation diagram sides of the chart – reprinted with permission)

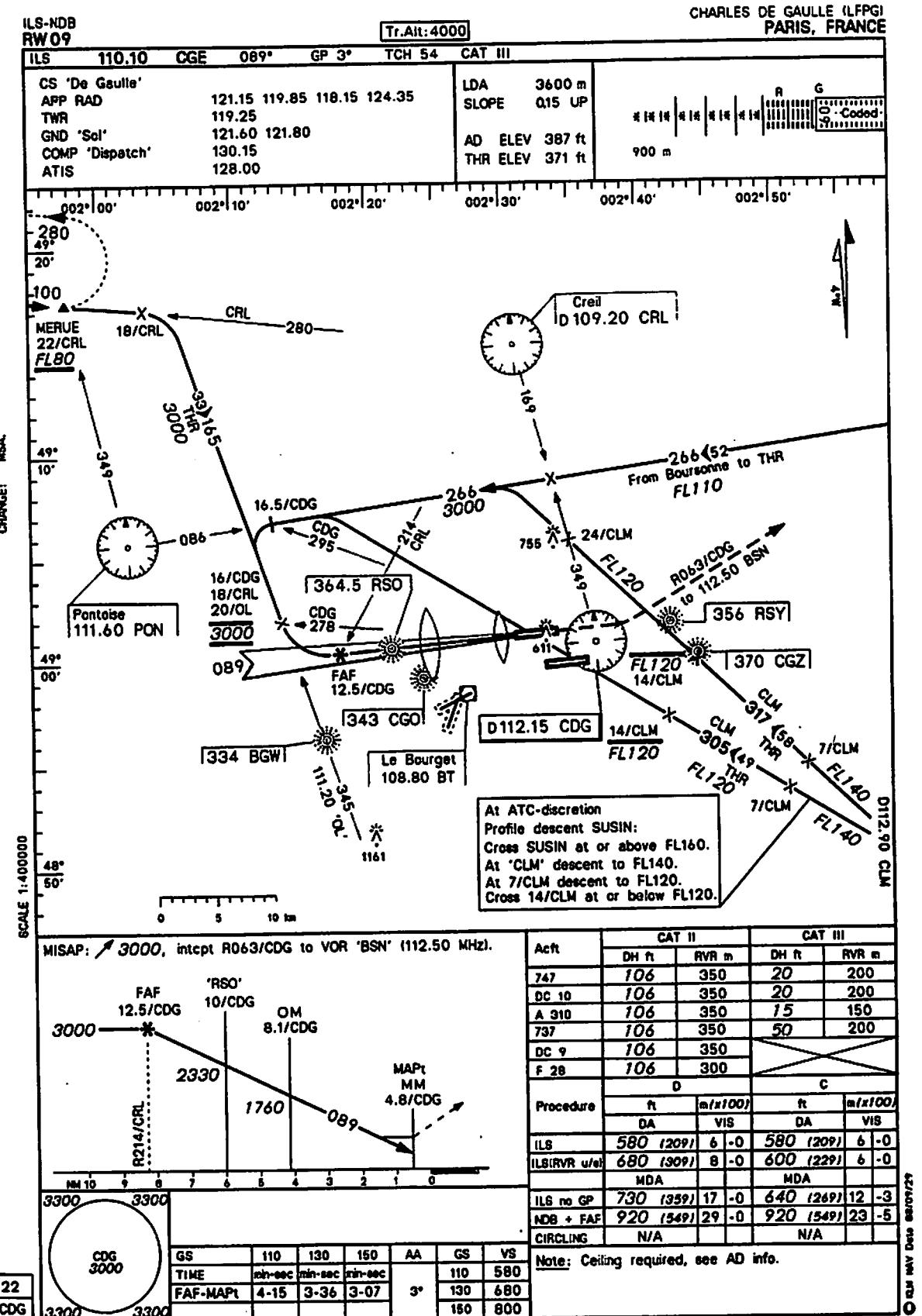


FIGURE 4. EXAMPLE OF KLM LARGE FORMAT CHART (N.B. THIS CHART HAS BEEN REDUCED BY 20 PERCENT)

NOT TO BE USED FOR NAVIGATION

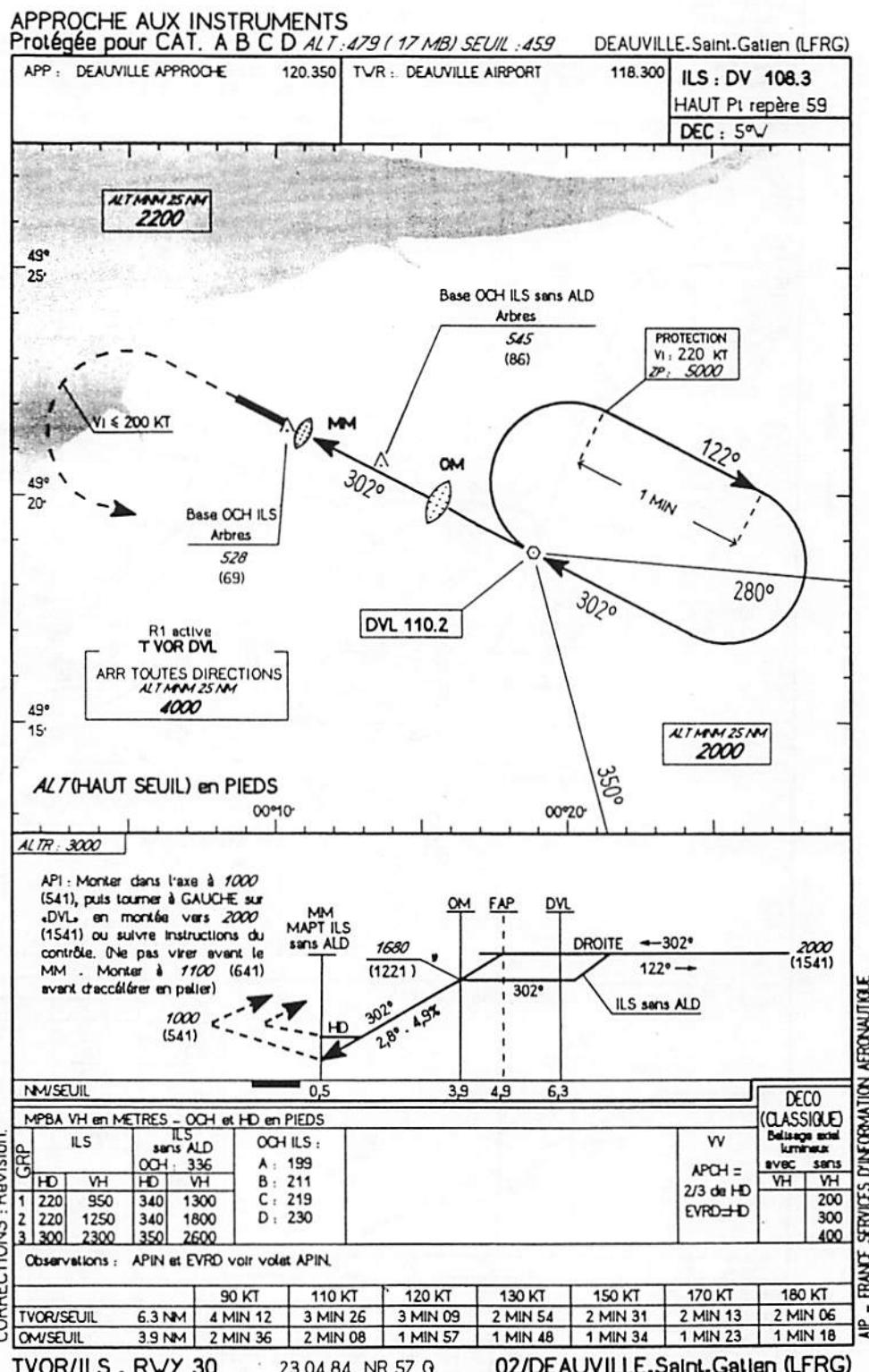


FIGURE 5. EXAMPLE OF AIP FRANCE – SERVICE DE L'INFORMATION AERONAUTIQUE INSTRUMENT APPROACH PLATE

Concern about potential litigation is also considered to have a major impact on chart evolution with both positive and negative aspects. On the positive side, litigation motivates a desire for accuracy in the information provided on the charts. Jeppesen, in particular, takes great care in corroborating the data it uses to produce the charts. On the negative side, fear of litigation makes it difficult to remove marginally useful information from the charts tending to increase chart clutter.

As an example, on both the NOAA and Jeppesen charts, terrain information is primarily displayed by point elevation symbols such as the one shown in Figure 6. This presentation is generally considered to be ineffectual (e.g., ICAO Circular 187-AW/114 recommends replacing spot elevations; 85% of the respondents to the MIT survey wanted the spot elevation information reduced or removed). This is because the information is only used in an emergency situation where there is insufficient time to carefully review the detailed spot elevations. During the interview effort, the FAA representative to the Interagency Cartographic Committee admitted the marginal utility of the spot elevation depiction but stated that the spot elevations were kept on the charts because of concern about liability exposure if the spot elevations were removed, and an aircraft was to impact that obstruction.

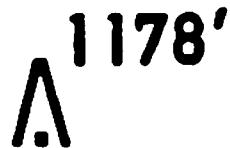


FIGURE 6. EXAMPLE OF A SPOT ELEVATION SYMBOL

In the cartographic interviews, it was noted that IAP evolution has occurred essentially in the absence of any formal human factors review. Major changes may be sent to user groups or the Office of Aviation Medicine for comment, but the changes are basically driven by the best cartographic judgment of the charting agencies.

3.2 CHART DESIGN TRADEOFFS

The detailed design of IAP formats represents the cartographic balance of natural tradeoffs which are implicit in IAP design. The variability in the IAP examples shown in Figures 2 through 5 results from the different balances chosen by each cartographic agency as a result of their design philosophy and the evolutionary factors discussed in Section 3.1. Several key tradeoffs in chart design are discussed below.

3.2.1 Chart Size Versus Legibility

One of the fundamental tradeoffs in IAP design is the balance between the size of the chart and the legibility of the print. Most IAP's are produced on small size paper (5 x 8.5 in.). The small size of the chart forces the textual print also to be quite small. Print size for most information is from 5 to 9 points on the NOAA and Jeppesen charts.

The small print size was widely recognized in the literature and supported by the surveys and interviews to be an impediment to the use of the chart.^{3,16} This situation is particularly true during night operations where cockpit lighting may be suboptimal, in turbulent conditions, or for older pilots where rapid mid-field (instrument panel) to near-field (chart) visual accommodation is difficult. KLM conducted a study of their IAP designs and elected to increase the size of their IAP's to 8.5 x 11 in. (see Figure 4).

While the limitations of small print size are well understood, most IAP's are produced in the small 5 x 8.5 in. format. There are two primary reasons for this. First is the limitation in cockpit space available for the chart. Because it is desirable for the IAP to be available for quick reference during the approach, it has become common practice to mount the IAP either on a knee pad, in the center of the control yoke, or on the periphery of the instrument panel during the approach. The 5 x 8.5 in. format is the largest standard paper size which can be conveniently mounted on a knee pad or a yoke.

For the KLM larger format IAP, the standard procedure is to position the IAP's on the map case which is normally to the left of the Captain and the right of the First Officer on most transport category aircraft. It is interesting to note that since this position is roughly twice as far from the pilot's eyes as the yoke position, the print actually subtends approximately the same or less angular resolution as a smaller IAP on the yoke. However, the larger format clearly has higher resolution when brought closer for careful inspection.

A secondary practical factor which limits chart size is related to weight and volume limitations. It is common practice for most U.S. airlines to carry two full sets of IAP's for the entire domestic or international route structure including all potential alternates. General aviation operators may only carry one set of IAP's for a limited geographical area, but have more restrictive weight and volume constraints. Increasing the chart size would increase the performance penalty for carrying additional IAP's, thereby creating pressure to reduce the number of alternate IAP's available for emergency diversion.

In the absence of increasing the chart size, it is possible to simply increase the print size as recommended by ALPA.¹⁶ However, if the information content of the charts remains the same, this will result in chart clutter. Current charts represent a balance of print size and chart clutter at the current information levels. Further discussion of information content is found in the next section. Some work has been done to increase the legibility at current print size levels. Jeppesen has designed a special font for IAP use which attempts to minimize interpretation errors. There is also active research in this area within the Department of Transportation.

3.2.2 Information Content Versus Chart Clutter

Because of the chart size limitations discussed above, there is a natural design tension between information content and chart clutter. The primary variable in IAP information content is the amount of terrain information provided. The issue of the appropriate balance of terrain information has received much debate in recent years as a result of concern, voiced in several of the interviews, over several "controlled flight into terrain accidents." Pilot opinion

in this area varies. For example, the ALPA survey indicated a high preference (97%) for terrain information enhanced by smoothed color contours over spot elevations as shown in Figure 7.

Conversely, 77% of the Jeppesen and 71% of the NOAA civil users in the ASC survey felt that there are sufficient terrain and obstruction features displayed. The MIT survey found that 85% of their respondents wanted some terrain information removed.

The reasons behind the diverse views on terrain information were explored during the interview effort and appear to be related to differences in operational patterns, environment, and presentation. For example, during normal IFR domestic U.S. operations from major airports where there is good radar and radio navigation coverage, there is considered to be little need for terrain information. Basically, if the procedure is flown correctly, terrain separation is assured by the TERPS⁹ criteria. However, the IAP's are commonly used for visual approaches where terrain separation becomes the responsibility of the pilot. Because the visual approaches may not remain within the TERPS protected airspace, terrain information becomes important. This is a common occurrence in Third World and general aviation operations where limited radar and radio facilities may be available, and is considered extremely important in regions with precipitous terrain.

Terrain information is also considered important for abnormal operations such as particular full power loss where the aircraft may not be able to maintain the Minimum Safe Altitude (MSA). Finally, terrain information is considered important during nonstandard missed approach or vectoring procedures as a check against controller error, because the ATC Minimum Vectoring Altitudes (MVA) are lower than the MSA's provided on the IAP's.

Some of the difference in pilot opinion as to the importance of terrain information appears to be due to the manner in which it is presented. In general, there is support for increased presentations of terrain using smoothed contours, particularly in mountain regions, and less support for the spot elevations. ICAO¹² has taken this position and cartographic agencies have

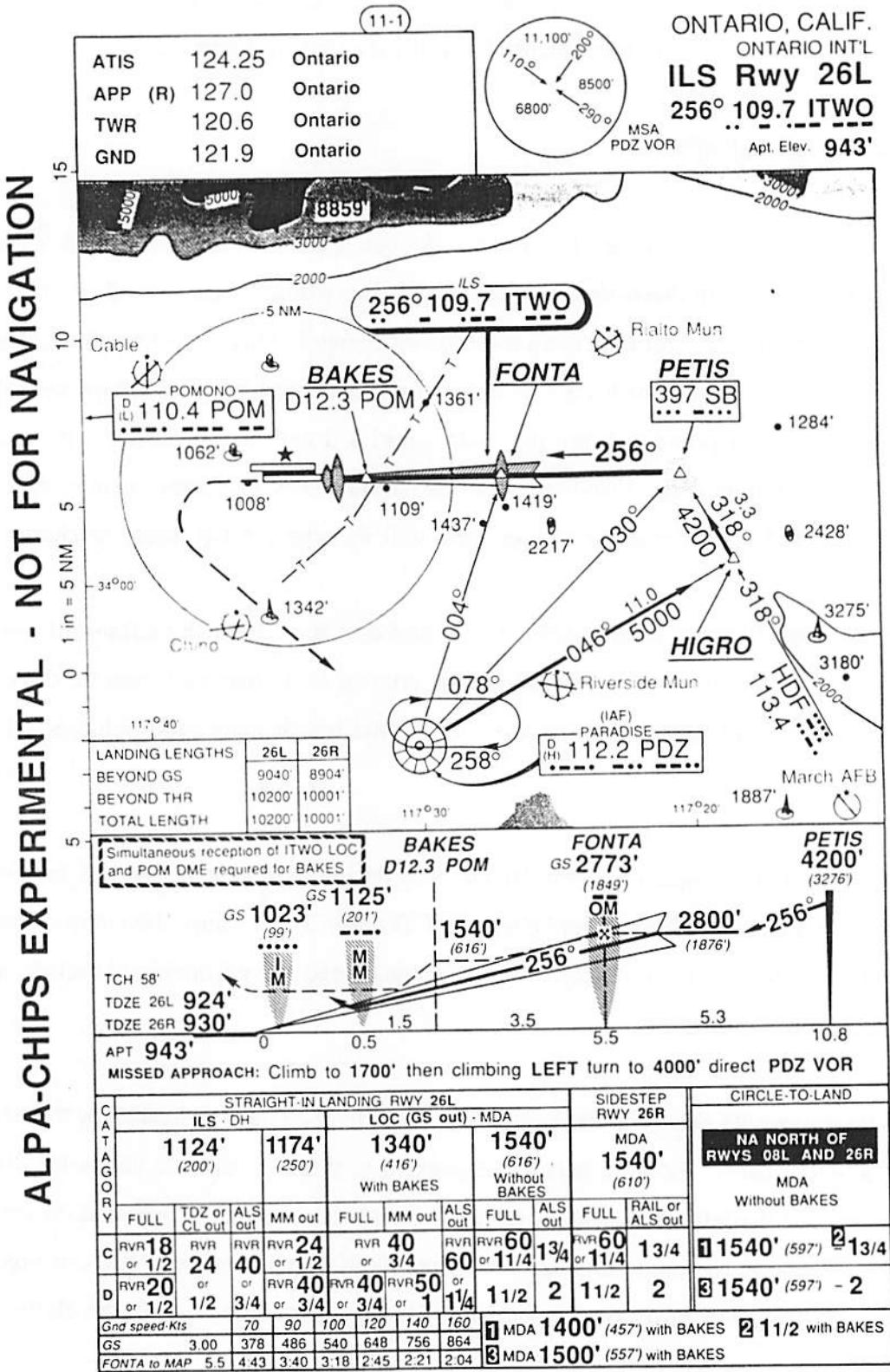


FIGURE 7. ALPA INSTRUMENT APPROACH CHART PROTOTYPE [16]

already begun to respond. For example, smoothed contours can be seen on the French IAP (Figure 5) and are being implemented in limited cases by Jeppesen.

3.2.3 Cost Tradeoffs

Cost tradeoffs are also major factors in influencing chart design; both NOAA and Jeppesen cited cost factors in discussing format design. For example, the smoothed contour representation of terrain information discussed above is most effective when presented in color¹⁶ but this adds significantly to the cost of chart production. Perhaps more important than the costs of production are the costs associated with maintaining the integrity of the underlying terrain data. Providing contours significantly increases the amount of information which must be monitored for changes and will increase the frequency of chart revisions.

The tradeoff between information content and cost transcends the terrain information issue. In general, any increase in the information content of a chart will increase the cost due to the larger number of items which must be monitored for changes and the increased frequency of revisions.

An additional example of a cost-driven chart design is the small size and location of the airport runway diagram on the NOAA IAP (Figure 2). Because the complete set of NOAA charts is reprinted on a 58-day cycle, it is considered too expensive to include a separate airport runway diagram.

A final example of cost considerations is that the charts are designed for the entire spectrum of aviation users. Because it is too expensive to produce separate charts for different user groups, all the information required for any specific operator is included on the chart. This can be seen in the minimums section of the NOAA and Jeppesen charts in Figures 2 and 3. Minima for all category operations (A to D) are included increasing the clutter in this area.

3.3 CURRENCY OF APPROACH INFORMATION

One concern which emerged from the data analysis and interview effort regarded currency of information. The primary means for dissemination of the approach information to the pilot is the IAP. Changes which occur at periods shorter than the update cycle of the IAP's are disseminated by different levels of Notices to Airmen (NOTAMS). Problems were identified both with the currency of the IAP's and the dissemination of NOTAMS.

One problem is the intentional or inadvertent use of outdated IAP's by pilots or controllers. This was identified in 3 out of 42 ASRS reports, in the Training Center interviews, and in the NOAA "Callback" comments. For example, of the 259 "callback" comments, 5% were due to the use of outdated charts. Interestingly, one ASRS report was due to the premature use of an IAP before the effective date.

The revision cycle of the NOAA and Jeppesen IAP's are quite different and result in different updating problems. The NOAA charts are completely reissued on a 58-day cycle with a Change Notice (CN) issued midway through the cycle. Because the CN is only effective for half the cycle it was reported to be common practice for it to be ignored.

The Jeppesen IAP's are revised on a 14-day cycle which allows changes to be much more rapidly implemented. However, the plates are individually reissued. Therefore, a significant amount of manual labor is required to update or "file" the IAP set and there is a large opportunity for collation error. It was reported and observed to be a relatively common practice for crews to fly with "unfiled" revisions in their flight bags and to update while en route. Since most IAP changes are relatively minor, the use of outdated IAP's does not normally result in a hazardous condition. However, clearly the potential exists whenever a significant change in a procedure is made, or a pilot uses an out-of-date IAP.

The currency of information on the IAP's is limited by the preparation and update cycle of the charting agency and the time required for notification to reach the agency. Typically, changes will come through the National Flight Data Center or the FAA, which may change the

database or issue NOTAMS. Permanent, or P NOTAMS, are typically long duration changes which are incorporated into the IAP's at the first opportunity. Temporary, or T NOTAMS, are shorter duration changes. Jeppesen often publishes the T NOTAM changes but, until recently, NOAA was prevented from publishing T NOTAMS by the Interagency Cartographic Committee, unless a hazard existed. The Chief of the NOAA Instrument Approach Chart Division estimated that this caused 800 known IAP errors at any one time. This can be seen in the NOAA "Callback" comments where 14.7% of the responses related to outdated information.

Finally, it is not clear that NOTAMS are fully disseminated to the pilot population. The MIT survey indicated that 79% of the respondents felt that their preflight briefing procedures provided them with the full set of relevant NOTAMS. However, detailed questioning during interviews indicated that the pilots rely primarily on computer-generated NOTAMS provided in their dispatch material. The completeness of these lists is questionable, particularly for Class II NOTAMS which are published on a 14-day cycle. The concern is even greater for pilots receiving voice or computer weather briefings, who reported that they often receive no NOTAMS at all. The possibility of reconsidering the NOTAM system in the light of improved communications dissemination systems is recommended.

3.4 TRAINING AND OPERATIONAL USE PATTERNS

Most training in IAP use occurs during initial instrument training. Based on the interview responses, there does not appear to be a standard procedure for IAP use which is universally applied. This is particularly true for pilots who receive their initial instrument training in civil general aviation. The most formal and standardized training in IAP usage is found in the military and at the corporate Flight Training Centers. It is interesting to note that there is very little training on IAP use at the major air carriers interviewed. Since pilots are hired with extensive experience, it is assumed that they "know how to read an IAP." While a self-study guide was available on one carrier, most of the IAP-related training focuses on specific company procedures or airports with special restrictions such as Reno or Hong Kong.

The manner in which the IAP's are used was found in the interview effort to vary across the spectrum of user groups. Air carrier operations generally involve two pilot operations flying into well-equipped and often familiar airports. The IAP's are generally reviewed during the descent and the approach is often, but not always, briefed between the two pilots who each have their own set of charts. The pilot not flying is also available to find information during the approach. The items typically found in pre-approach briefs, observed by the authors, as described in the interviews, are listed in Table 1. In interviews, operators reported significantly different IAP usage for familiar airports than for non-familiar airports. In the former, the IAP review was generally more cursory. In visual meteorological conditions, when a visual approach is expected, it is standard procedure to review the most relevant IAP, tune and use navaid for final approach guidance. In fact, it is extremely unusual for an air carrier to be equipped with charts suitable for visual only operations.

TABLE 1. TYPICAL AIR CARRIER PRE-APPROACH BRIEFING ITEMS

- Approach and Runway**
- Chart Issue Date**
- Primary Navaid Frequency**
- Inbound Course**
- Intercept Altitude at Final Approach Fix**
- Airport Elevation**
- Decision Height/MDA (MSL and AGL)**
- Missed Approach Procedure**

At the high end of corporate aviation, the IAP use patterns are quite similar to those of the air carriers. However, because of the unscheduled nature of their operations, corporate pilots are more often exposed to unfamiliar airports and non-precision approaches than their air carrier counterparts. They also report a difference in IAP use at familiar versus unfamiliar airports.

At the general aviation and low end corporate aviation level, the use of IAP's is quite different. IFR operations are predominantly flown single-pilot. As a result, there is no formal pre-approach brief and the review and use of the IAP is much less structured. Because of the high workload in single-pilot IFR operations, it is often necessary to review the IAP prior to departure. Since a second pilot is not available to aid in information retrieval, it is common practice to attempt to memorize the critical information elements such as the Decision Height and initial missed approach instructions. In addition, the level of IFR currency of many pilots is reported to be so low that there is insufficient opportunity for proficiency in IAP use.

Based on the ASC survey and the interview efforts, approximately 90% of the civil IAP users employ Jeppesen charts. Since ATC facilities are equipped with NOAA charts, there is some concern that misinterpretation may occur because of the difference in charts seen by the pilot and the controller.

Finally, there is some evidence that switching chart formats can have a negative impact on safety. In the ASC survey, pilots who used both Jeppesen and NOAA charts reported more difficulty and time in locating required information and less intuitive information transfer than those who used only Jeppesen or NOAA. Because of the negative impact of format changes on information transfer, and the extensive experience base with the current IAP format, significant performance or safety improvements must be expected before major format changes in the IAP's can be justified.

3.5 OPERATIONAL ERROR

As a result of the data analysis, interviews, and survey efforts, several areas were identified where IAP design could be improved to reduce the risk of operational errors. In the MIT survey, 93% of the respondents felt that it was possible to make errors in the cockpit which are directly attributable to charting considerations. Several of these operational errors are discussed next.

3.5.1 Confusion Between Primary and Secondary Navaid Frequencies

The most frequently cited critical operational error related to IAP design was the confusion between the primary and secondary navaid frequencies. As an example, if on the ILS runway 6 approach to Teterbury, NJ as shown in Figure 3, the collocated VOR frequency (108.4, ID=TEB) was selected instead of the ILS frequency (108.9, ID=ITEB), significant errors in lateral guidance could occur. The similarity of the ID's would make this error difficult to pick up by the ID alone. This type of error contributed to the first accident cited in the NTSB letter (Appendix A) and is relatively common (47% of the MIT respondents reported making this error).

Efforts have been made to minimize this error by distinguishing the primary navaid box as shown in Figure 8. The Jeppesen charts use a perspective line box, while the NOAA charts use a bold line box. In addition, Jeppesen repeats the primary navaid frequency in the procedure ID area of the chart. While the efforts are commendable, no objective evaluation of these improvements has been made and the effectiveness of the presentation is not known.

3.5.2 Confusion on Approach Minimums

The identification of the correct Decision Height (DH) or Minimum Decision Altitude (MDA) is a critical part of any approach. In the ASC survey, 15% of the Jeppesen and 25% of the NOAA users reported confusion in interpreting MDA's or DH's on the charts. Because of the importance of the minimums, even these relatively low numbers are unacceptable.

The differences between Jeppesen and NOAA users may be due to a difference in presentation of the minimums. In the Jeppesen charts, the different minimums are presented for all potential scenarios. While this increases the clutter in the minimums section, it reduces the cognitive effort required to find the appropriate DH or MDA.

On the NOAA charts, a basic set of minimums are presented and adjustments are made for nonstandard conditions through notes. For example, in Figure 9, the minimums notes section reads: "*When Control Zone Not in Effect: 1. Use Islip altimeter setting. 2. Increase all*



NOAA EXAMPLE



JEPPESEN EXAMPLE

FIGURE 8. EXAMPLE OF PRIMARY NAVAID FREQUENCY IDENTIFICATION BOXES FROM NOAA AND JEPPESEN IAP'S

NOT TO BE USED FOR NAVIGATION

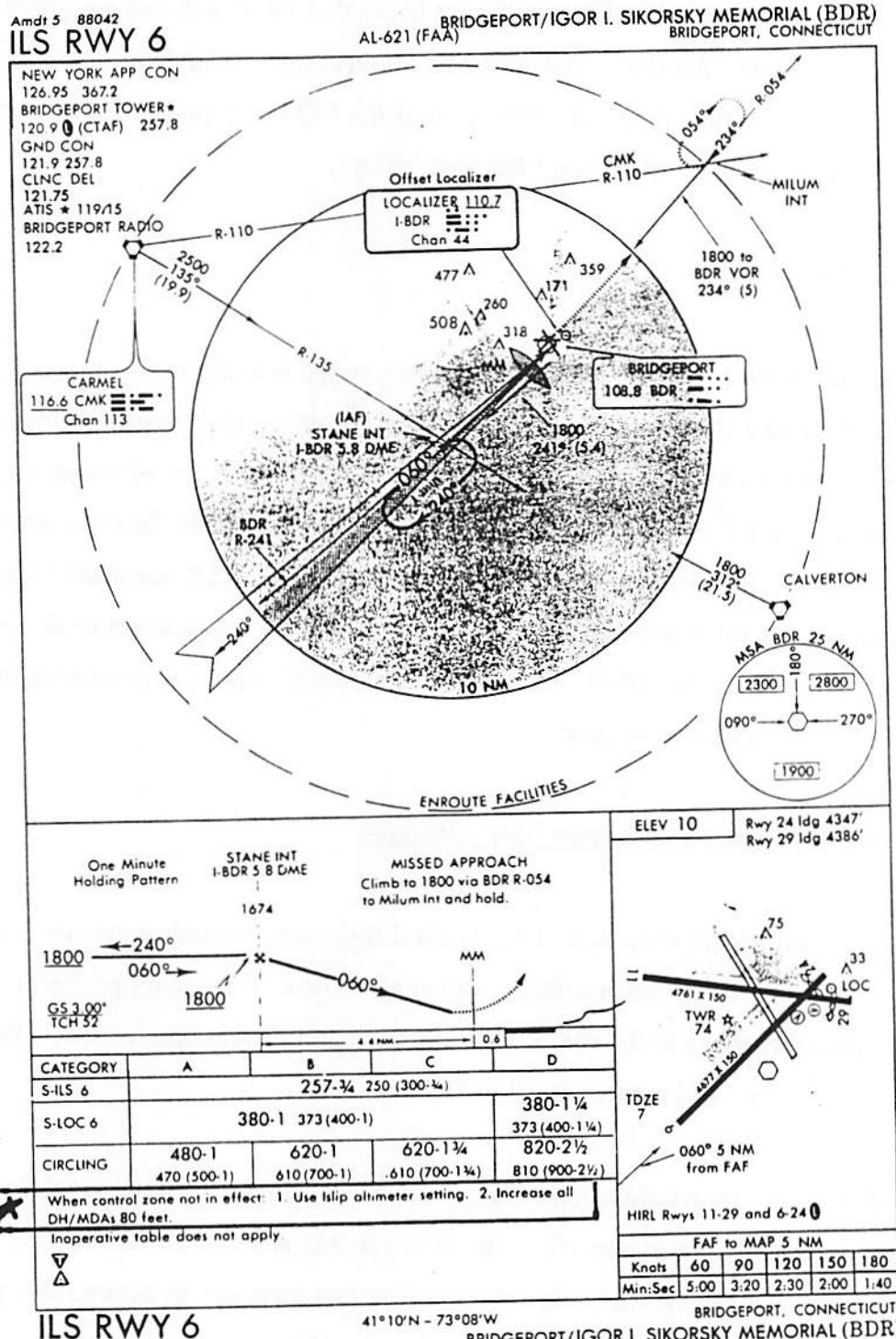


FIGURE 9. EXAMPLE OF NOAA CHART WITH MINIMUM MODIFICATION NOTE SHOWN

DH/MDA's 80 feet." While the instructions are clear, there is evidence from the interviews and the NTSB reports that supplementary notes are often missed. This combined with the additional cognitive addition step makes it likely that pilots will use the printed DH even though this means that they would descend 80 feet below minimums. This factor is considered to be the reason that 10% more of the NOAA respondents in the ASC survey reported confusion on interpreting DH and MDA's.

3.5.3 Missing Notes

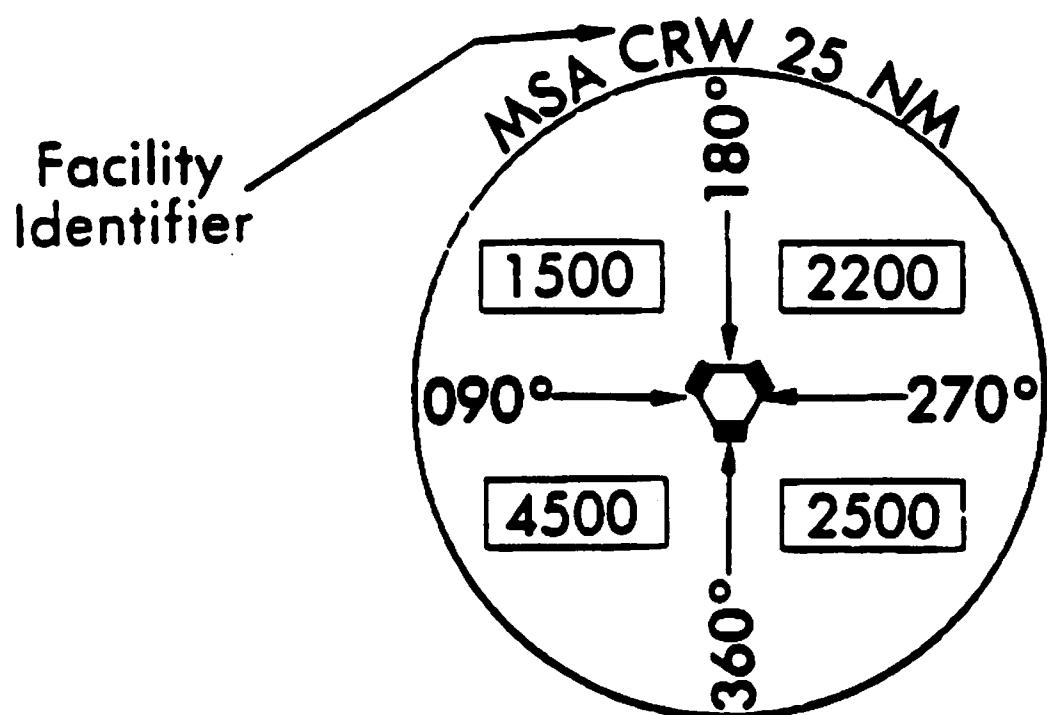
Based on the MIT survey and interview effort, supplementary notes are often a low priority item during an IAP review. Part of the reason for this is the impression that important information will be depicted in the procedure, and that notes are of secondary importance. As can be seen in the discussion of DH/MDA notes above, and the fact that misinterpretation of supplementary information was cited in two of the nine NTSB accidents (Appendix A), this impression is often not true. There is, however, no clear mechanism to distinguish the priority of notes on the IAP's. The ALPA Charting Committee recommended publishing important notes in reverse print.¹³

3.5.4 Confusion on Minimum Safe Altitudes

As discussed above, reduction of "controlled flight into terrain" accidents is currently an area of focus within the aviation safety community. There is a general preference for smoothed contours as opposed to the use of spot elevations for terrain presentation. Tradeoffs, however, exist in this area and are discussed in Section 3.

Several of the interviewees reported that the Minimum Safe Altitude (MSA) circle (an example is shown in Figure 10) is the most reliable and effective means for assuring terrain separation. One difficulty is that there is a natural tendency to assume that the MSA is centered on the airport, where it is actually centered on a navaid often not collocated with the airport. In addition, the MSA does not correspond with the ATC Minimum Vectoring Altitude (MVA). It is common practice to be vectored at altitudes below the MSA.

MINIMUM SAFE ALTITUDE (MSA)



(Arrows on distance circle identify sectors)

FIGURE 10. EXAMPLE OF SAFE ALTITUDE [8]

3.5.5 Complexity of the Procedures

It should be noted that several sources reported problems with IAP use which were actually the result of complexity of the underlying procedure. For example, there were five separate ASRS reports on the Los Angeles LAX profile descent, and various other examples. While these are not explicitly cartographic problems, it is important to retain as much simplicity as possible in the underlying procedures.

This problem can also be seen in the missed approach phase. In the ASC survey, 47% of the respondents reported that the procedures for missed approach and holding generated excessive workload during the go-around. This question was also rated as the highest priority area by the respondents. In the MIT interviews and survey, it was reported that it is unusual to fly the published missed approach procedure and often special instructions are issued by the ATC. While it is recognized that the missed approach procedures will vary with the controllers tactical situation, the published approach should as accurately as possible reflect the common missed approach procedure in current use.

3.5.6 Runway Length and Lighting Information

There were several reports of problems which arose over the lack of runway length or lighting information on the Jeppesen approach charts. While the information is on the airport runway diagram chart (10-1), it is not available on the approach side of the chart for quick reference during the approach.

3.5.7 Awareness of Common ILS Frequencies

With the more frequent use of a single ILS frequency for several runways at the same airport, several respondents requested the inclusion of some indication of this on the chart. There is concern that the ILS system could be activated on the wrong runway, giving erroneous guidance indications to the crew.

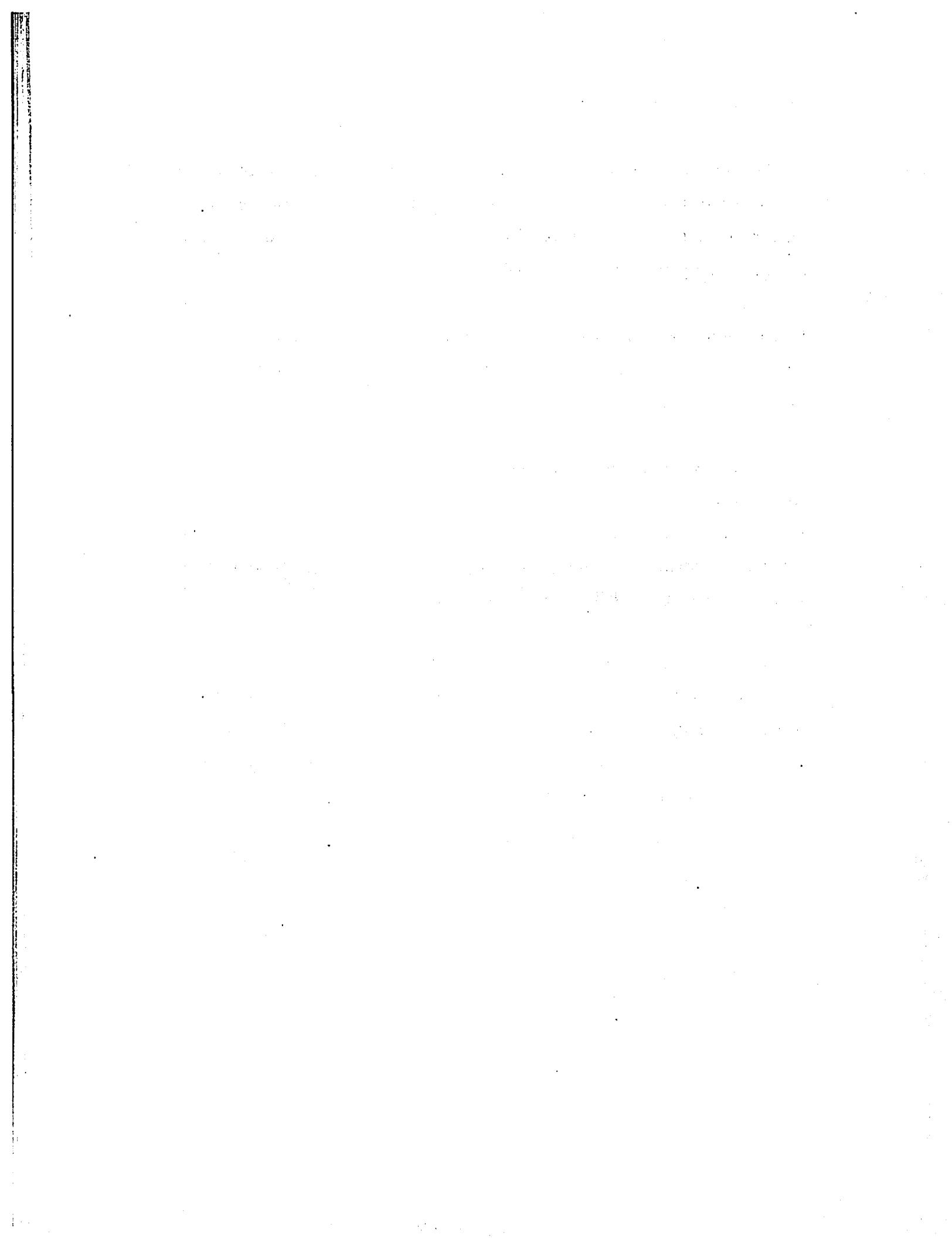
3.6 Electronic Approach Plates

The MIT survey and interview efforts included questions related to the potential for the presentation of IAP information in electronic format. There was generally overwhelming support for electronic IAP's. It was felt that issues such as currency of information will be much less of a problem in the electronic format.

Because of its potential flexibility, the electronic approach chart also allows for an increase of information such as terrain contours and the direct interface between the charts and the Flight Management Systems which would reduce operator input errors.

On the negative side, in addition to the obvious cost issues, there is a concern over increased workload, system reliability, the database integrity and the need to reformat the IAP databases to an object-oriented structure. Electronic display limitations will, in the short term, limit the amount of information which can be displayed on the screens. This has driven some organizations to use cockpit printers for electronic IAP's.

In the long term, it is generally agreed that electronically based IAP's which interact with the aircraft's Flight Management System and Communications System will emerge. This is seen as an opportunity to reconsider IAP formats in light of the flexibility and capability of the electronic systems. A significant amount of work is required to optimize these systems in terms of both human interface and functionality.



4. CONCLUSION

The literature review, pilot opinion surveys, data analysis and interview efforts, conducted to identify operational errors and crew preferences related to Instrument Approach Charts resulted in the following findings.

1. Current IAP's are the result of a mature evolutionary process driven by user feedback, concern over flight safety, and the liability of the charting agencies. Even though the charts have evolved in the absence of formal human factors analysis, major changes in format for paper approach charts does not appear to be indicated.
2. Current IAP's represent a balance between different chart design tradeoffs. Fundamental tradeoffs were identified in the areas of: chart size versus legibility, information content versus clutter, and cost tradeoffs.
3. Concern over "controlled flight into terrain" accidents has motivated an increased interest in terrain information on the IAP's. The current technique of presenting terrain information through spot elevations is considered ineffective and contributes to chart clutter. Smoothed contours have been used effectively to portray terrain information. However, the resulting increase in data monitoring, chart revision, and production costs has contributed to preventing full implementation by US chart producers.
4. Several problems were identified relating to the currency of information available to the flight crews both on the IAP's and through Notices to Airmen (NOTAMS).
5. Significant differences in IAP operational use patterns were observed between user groups particularly between multi-crew air carrier operations and single pilot general aviation operations. Cost factors preclude IAP designs focused for specific user groups.

6. Some evidence was found that switching between IAP formats reduced the effectiveness of information transfer from the charts. This argues that a significant performance or safety improvement should be expected before major format changes are implemented. In addition, formal human factors review of proposed changes would help quantify the potential improvements.
7. In the MIT survey, 93 percent of the pilots felt that it was possible to make operational errors due to chart design. Several potential operational errors were identified including: confusion between primary and secondary navaid frequencies, confusion on approach minimums, missing chart notes, confusion on minimum safe altitudes, complexity of the procedures, location of runway lighting information, and awareness of dual use common ILS frequencies.
8. The potential of electronic IAP's offers the opportunity for more flexibility in the presentation of approach information. However, concerns about system reliability, data integrity and structure, and crew workload have emerged. It is generally agreed that electronically based IAP's will emerge within the next five years, and it is important to reconsider the IAP human factors issues in light of the flexibility, capability and limitations of the electronic systems.

REFERENCES

1. *Cockpit Human Factors Research Plan*, Federal Aviation Administration, 1985.
2. Wiener, E.L. and D.C. Nagel (Eds.), *Human Factors in Aviation*, (Academic Press, San Diego, 1988).
3. O'Hare, David and S. Roscoe, *Flightdeck Performance* (Iowa State University Press, Ames, 1990).
4. *Proceedings of the Symposium on Aviation Psychology (Vols. 1-5)*, The Ohio State University, Columbus, OH, 1981-1989.
5. Cox, W.J., and C.W. Conner, *Report of Safety Survey: Human Integration of Approach Charts*, DOT/FAA/PM-87/15, 1987.
6. *Instrument Flying Handbook*, U.S. Department of Transportation, Federal Aviation Administration (AC-61-27C).
7. Jeppesen Sanderson, Inc., *Jeppesen Approach Charts*, Flight Time Video Series, 1989.
8. *Aeronautical Chart User's Guide*, National Oceanic and Atmospheric Administration, 1988.
9. *United States Standard for Terminal Instrument Procedures (TERPS)*, Federal Aviation Administration handbook 8260.3B, 1976.
10. *U.S. Federal Aviation Regulations* (Parts 61, 91, 135, 121), Federal Aviation Administration, Washington, D.C., 1990.

REFERENCES (cont.)

11. *Airman's Information Manual (AIM), Basic Flight Information and ATC Procedures*, U.S. Department of Transportation, Federal Aviation Administration, Sept. 21, 1989, Washington, D.C.
12. *ICAO Instrument Approach Chart - Guidance to Chart Makers*, Circular 187-AN/114, 1984.
13. *Instrument Approach Procedures Automation, User's Manual*, Federal Aviation Administration, Office of Flight Operations, 1988.
14. *Instrument Approach Procedures, From Request to Publication*, Federal Aviation Administration, Office of Flight Standards, undated.
15. Friend, V., "Caution: High Terrain All Quadrants," *Air Line Pilot*, June 1988.

Appendix A

NATIONAL TRANSPORTATION SAFETY BOARD WASHINGTON, D.C.

ISSUED: August 18, 1982

Forward to:

Honorable J. Lynn Helms
Administrator
Federal Aviation Administration
Washington, D.C. 20591

SAFETY RECOMMENDATION (S)

A-82-91 through -93

About 11:27 PST, on January 20, 1981, a Cascade Airways, Inc., Beech 99A aircraft en route from Moses Lake, Washington, to Spokane, Washington, crashed about 4.5 miles southwest of Spokane International Airport. The accident occurred while the pilot was making a localizer instrument approach to Runway 3. Seven persons including the flightcrew were killed and two passengers were injured seriously.

The localizer course Runway 3 approach at Spokane International Airport is served by two navigational aids which provide distance information: the Spokane VORTAC ^{1/} and the localizer distance measuring equipment (IOLJ DME). During its investigation, the Safety Board interviewed several pilots who stated that they had experienced confusion which resulted in procedural errors during the approach procedure into Spokane. The pilots indicated that they had reviewed the approach procedure and had used the Spokane VORTAC, mistakenly believing that it was the correct distance information facility to use for the localizer approach; whereas, IOLJ DME was the correct facility. However, by using the Spokane VORTAC, they had flown at too low an altitude which was not corrected until they were advised by an air traffic controller or an instructor pilot who had visual contact with the terrain. Two of the pilots further stated that they had reviewed the approach with other pilots, most of whom indicated that they would have been prone to make the same mistake.

As a result of the investigation of the January 20, 1981 accident, the Safety Board recommended that the FAA add a precautionary note on approach charts for procedures involving two DME facilities on the final approach course. (Safety Recommendations A-81-40 and -41.)

The Safety Board has investigated other accidents involving approach procedures and the approach charts design. The following is a brief summary of some of those investigations:

^{1/} A collocated very high frequency omni-directional range station (VOR) and ultra-high frequency tactical air navigation aid (TACAN).

- On October 24, 1971, a Monmouth Airlines, Inc. scheduled Air Taxi, Beech 99, descended prematurely and struck a mountain while executing a VOR instrument approach to the Allentown-Bethlehem-Easton Airport, Allentown, Pennsylvania. Four persons were killed and four persons were injured seriously. The Allentown area is served by two airports: The Bethlehem-Easton Airport and the Queen City Municipal Airport. Both airports have a VOR-1 published approach but use different VOR's. The Safety Board believes that the crew of the accident aircraft may have read the minimum altitude at the final approach fix from the wrong approach chart. Because of the similarity of the two approach plates for the contiguous airports, the Safety Board recommended that the Federal Aviation Administration (FAA): (1) required that conspicuous and distinctive markings be affixed to the two approach plates so that pilots could identify the plates more readily and quickly; and (2) review all approach charts for potential misidentification. (Safety Recommendations A-71-61 and 62.)
- On September 4, 1971, an Alaska Airlines, Inc., Boeing 727, crashed while attempting a nonprecision instrument approach to the Juneau Municipal Airport, Juneau, Alaska. All 104 passengers and 7 crewmembers were fatally injured. The investigation revealed that the published localizer directed approach (LDA) procedure had not been amended to reflect the commissioning of the DME associated with the localizer. The Safety Board recommended that the FAA amend this approach chart to include the localizer DME. (Safety Recommendation A-72-14.)
- On September 8, 1973, a World Airways, Inc., DC-8-63F, Military Airlift Command contract cargo flight crashed into a mountain (3,500 feet) near King Cove, Alaska, about 15.5 miles east of the airport. The flight had been cleared for an approach 125 miles east of the airport. The three crewmembers and three passengers were killed, and the aircraft was destroyed. As a result of its investigation, the Safety Board recommended that the FAA modify the approach chart to reflect altitude restrictions and potential hazards associated with this approach procedure. (Safety Recommendation A-74-53.)
- On December 1, 1974, a Trans World Airlines, Inc., B-727, crashed into a mountain ridge while descending for a VOR/DME approach to Runway 12 at Dulles International Airport, Washington, D.C. The 85 passengers and 7 crewmembers were killed, and the aircraft was destroyed. The Safety Board determined that a contributing factor in the accident was the inadequate depiction of altitude restrictions on the profile view of the approach chart for the VOR/DME approach to runway 12 at the airport. The Safety Board issued four recommendations to the FAA which addressed the need for uniformity and standardization of cartographic techniques and specifications in the design of approach charts. (Safety, Recommendations A-75-74 through -77.)

- On February 21, 1975, a Beechcraft BE-55 aircraft crashed during the hours of darkness while on a unauthorized instrument approach to the Lawrenceburg Municipal Airport, Lawrenceburg, Tennessee, which was not approved for night operations. As a result of its investigation, the Safety Board recommended that the FAA clarify the wording of the restriction on approach charts for locations where night approaches are not authorized so that the restrictions are clearly understood. (Safety Recommendation A-75-70.)
- On May 8, 1978, a National Airlines, B-727, crashed while executing an airport surveillance radar (ASR) approach to runway 25 at Pensacola Regional Airport, Pensacola, Florida. Three passengers were killed. As a result of its investigation, the Safety Board recommended that the FAA develop requirements for depicting final approach fixes or minimum altitudes for each mile on the final approaches for ASR instrument procedures. (Safety Recommendation A-79-10.)
- On October 31, 1979, a Western Airlines, Inc., DC-10-10, crashed while making an instrument landing system (ILS) approach to the Mexico City International Airport. Sixty-one passengers and 11 crewmembers were fatally injured; 13 passengers and 2 crewmembers were seriously injured; and one person on the ground was fatally injured. The aircraft was destroyed. The aircraft was cleared to land by means of a sidestep maneuver which was not performed by the pilot. As a result of the investigation, the Safety Board recommended that the FAA require separate standardized instrument approach charts for sidestep maneuver approaches. (Safety Recommendation A-80-59.)
- On October 24, 1980, a Beechcraft BE-18S, crashed while executing a missed approach from the Gainesville, Florida Regional Airport. The pilot had been advised by the air traffic controller to execute the published missed approach procedure after he had reported that he had missed the approach. However, the aircraft continued straight ahead and collided with a TV antenna tower. All three occupants of the aircraft were killed. As a result of the investigation, the Safety Board recommended that the Inter-Agency Air Cartographic committee amend the depiction of the missed approach track on approach charts. (Safety Recommendation A-81-34.)

All of the foregoing recommendations addressed two basic issues--our belief that insufficient attention is given to human performance criteria in the development of approach procedures and in the process for reviewing the approach procedure depiction on the approach charts--both of which are deficiencies that can lead to confusion and mistakes by the pilot users. Pilots have been criticized for misinterpreting approach charts and approach procedures, with little consideration given to the operating environment in which the procedures and charts are used and the degree to which these procedures and charts themselves may be conducive to error. The Safety Board believes that it is the obligation of the developers of approach procedures and charts to incorporate human factors considerations into their design so that the possibility for pilot confusion, misinterpretation, or error is eliminated.

In the public hearing convened by the Safety Board regarding the January 21, 1981 accident, testimony by spokesmen for the FAA revealed that there are no specific human performance criteria for developing approach procedures, or formal human performance checklists or guidelines for the procedures specialist or flight inspection pilot who flies and evaluates the approach procedure. The Safety Board believes that factors, such as user/pilot intelligibility, workload, attention demands, human memory limitations, and other sensory, perceptual, and cognitive restrictions, must be considered when designing approach procedures.

Also, the hearing testimony revealed that the FAA does not formally review the approach charts designed by the National Ocean Survey and Jeppesen Company with the above issues in mind. The Safety Board believes that human performance standards should include design criteria for presentation of information and chart configuration to promote user/pilot interpretability and usability, as well as such issues as visual detection, identification, coding, attention-getting characteristics, and human memory considerations.

On July 2, 1981, the Presidents's Task Force on Aircraft Crew Complement said "Enroute, terminal area, and approach charts are frequently designed in a way that makes them difficult to use." Further, the Task Force said, "The design and content of these charts should be improved."

Currently, two committees address the charting and flight information issues: the Inter-Agency Air Cartographic (IACC) Committee and the Intra-Agency Committee for Flight Information (IACFI). The IACC Committee consists of members from the Department of Defense, the Department of Commerce, and the FAA; its function is to develop specifications for acceptable cartographic means of depicting aeronautical information. The FAA's role on this committee is directed to the civil aviation user requirements. The IACFI is an in-house FAA multidimensional technical group that addresses particular issues relating to aviation information and standards. No member of the IACFI is specifically trained in the human performance area.

As a result of past Safety Board recommendations, the FAA has taken action to modify specific procedures on a case-by-case basis; however, an attack on the aggregate problem by alleviating individual approach procedure problems on a post-accident basis is not satisfactory. A better, more efficient method would be to incorporate human factors design considerations into the development, design, and evaluation of all approach procedures and approach charts before accidents occur.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

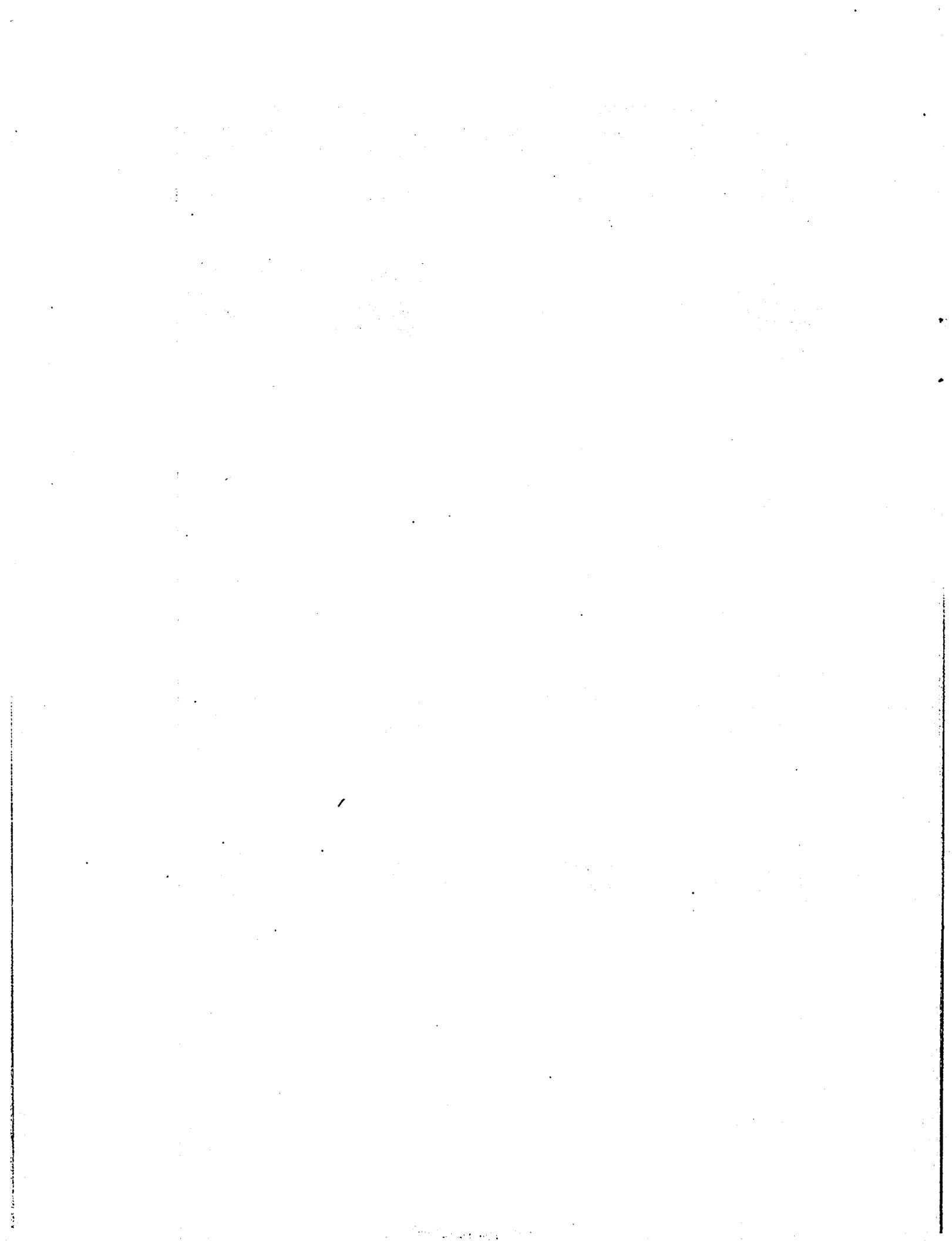
Establish formal human performance criteria for the development and evaluation of instrument approach procedures and instrument approach charts. (Class II, Priority Action) (A-82-91)

Establish human performance checklists or guidelines for use by procedures specialists and flight inspection pilots when evaluating new approach procedures. (Class II, Priority Action)(A-82-92)

Assign personnel trained in human engineering and human performance to the Interagency Air Cartographic Committee and the Intra-Agency Committee for Flight Information. (Class II, Priority Action)(A-82-93)

BURNETT, Chairman, GOLDMAN, Vice Chairman, and McADAMS and BURSLEY, Members, concurred in these recommendations.

Jim Burnett
By: Jim Burnett
Chairman



Appendix B

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's), 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 IAP's 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 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.

Faculty Representative:

Prof. R. John Hansman, Jr.
Aeronautical Systems Laboratory
MIT, Rm. 33-115
77 Massachusetts Ave.
Cambridge, MA. 02139
(617) 253-2271

Research Assistant:

Mark G. Mykityshyn
Aeronautical Systems Laboratory
MIT, Rm. 37-442
77 Massachusetts Ave.
Cambridge, MA. 02139
(617) 253-7748

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.

Not enough
information

Too much
information

1

2

3

4

5

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

Never Occasionally Always

1

2

3

4

5

*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.

An acceptable
amount

An unacceptable
amount

1

2

3

4

5

Category

Time spent (approximate)

1. "An acceptable amount"

5. "An unacceptable amount"

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.

An acceptable
amount

An unacceptable
amount

1

2

3

4

5

Category

Time spent (approximate)

1. "An acceptable amount"

5. "An unacceptable amount"

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.

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 nonprecision approach? If no, what information is different?

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

13. Have you ever observed anyone using noncurrent charts?

Never

Frequently

1

?

3

4

5

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 Jeppesen-Sanderson and NOAA charts:

1. What problems do you encounter when switching back and forth from NOAA charts to Jeppesen-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 comments.

Yes

No

Please answer the following two questions only if you have any experience flying nonprecision 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 nonexhaustive 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

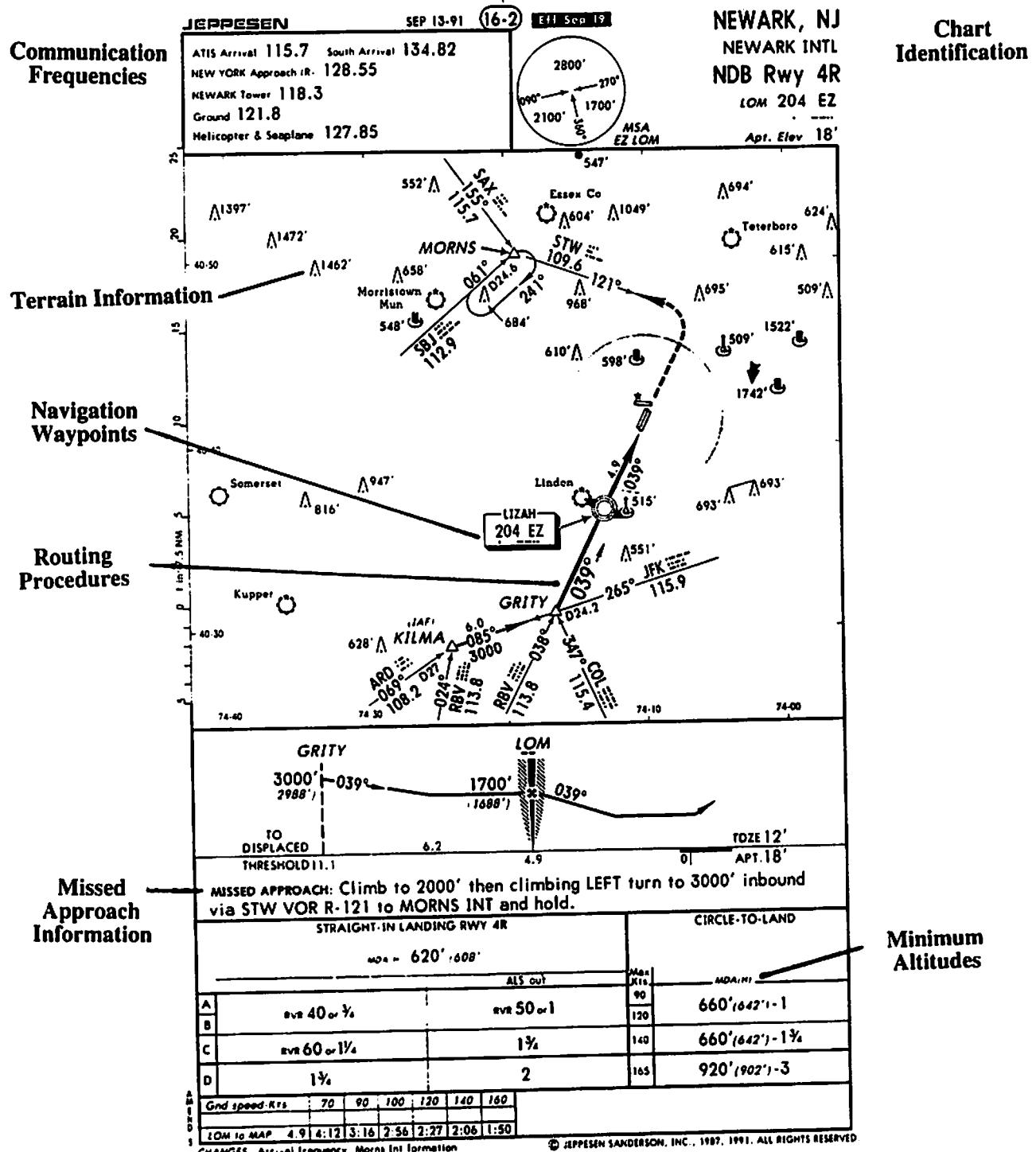
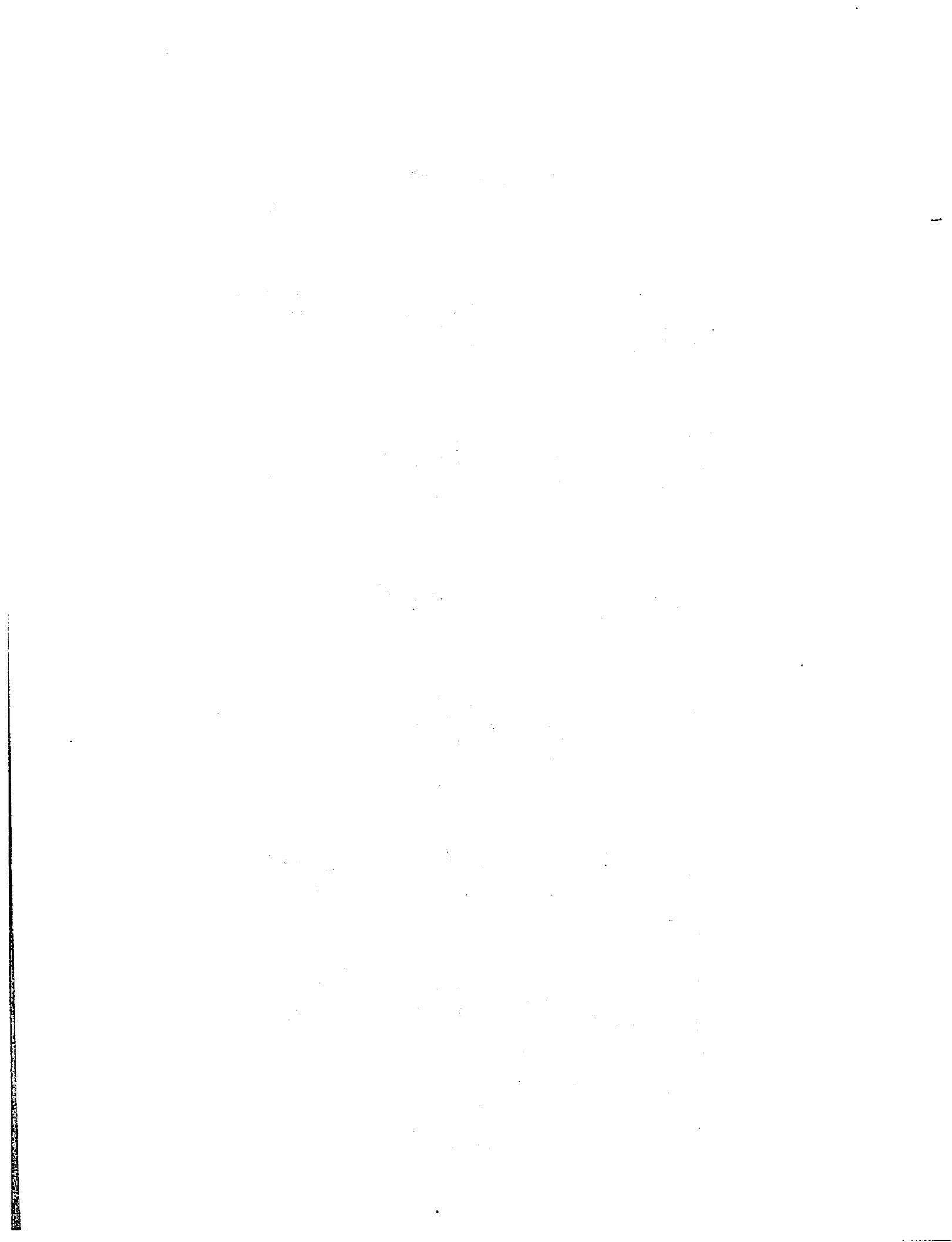


FIGURE I.

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

1.	Chart Identification Info	1 No clutter	2	3	4	5 Significant clutter
2.	Airport Information	1 No clutter	2	3	4	5 Significant clutter
3.	Terrain Information	1 No clutter	2	3	4	5 Significant clutter
4.	Navigation Waypoints	1 No clutter	2	3	4	5 Significant clutter
5.	Routing Procedures	1 No clutter	2	3	4	5 Significant clutter
6.	Missed Approach Information	1 No clutter	2	3	4	5 Significant clutter
7.	Communication Frequencies	1 No clutter	2	3	4	5 Significant clutter
8.	Minimum Altitudes	1 No clutter	2	3	4	5 Significant clutter



NOT FOR NAVIGATION

Information Content of Your Instrument Approach Brief

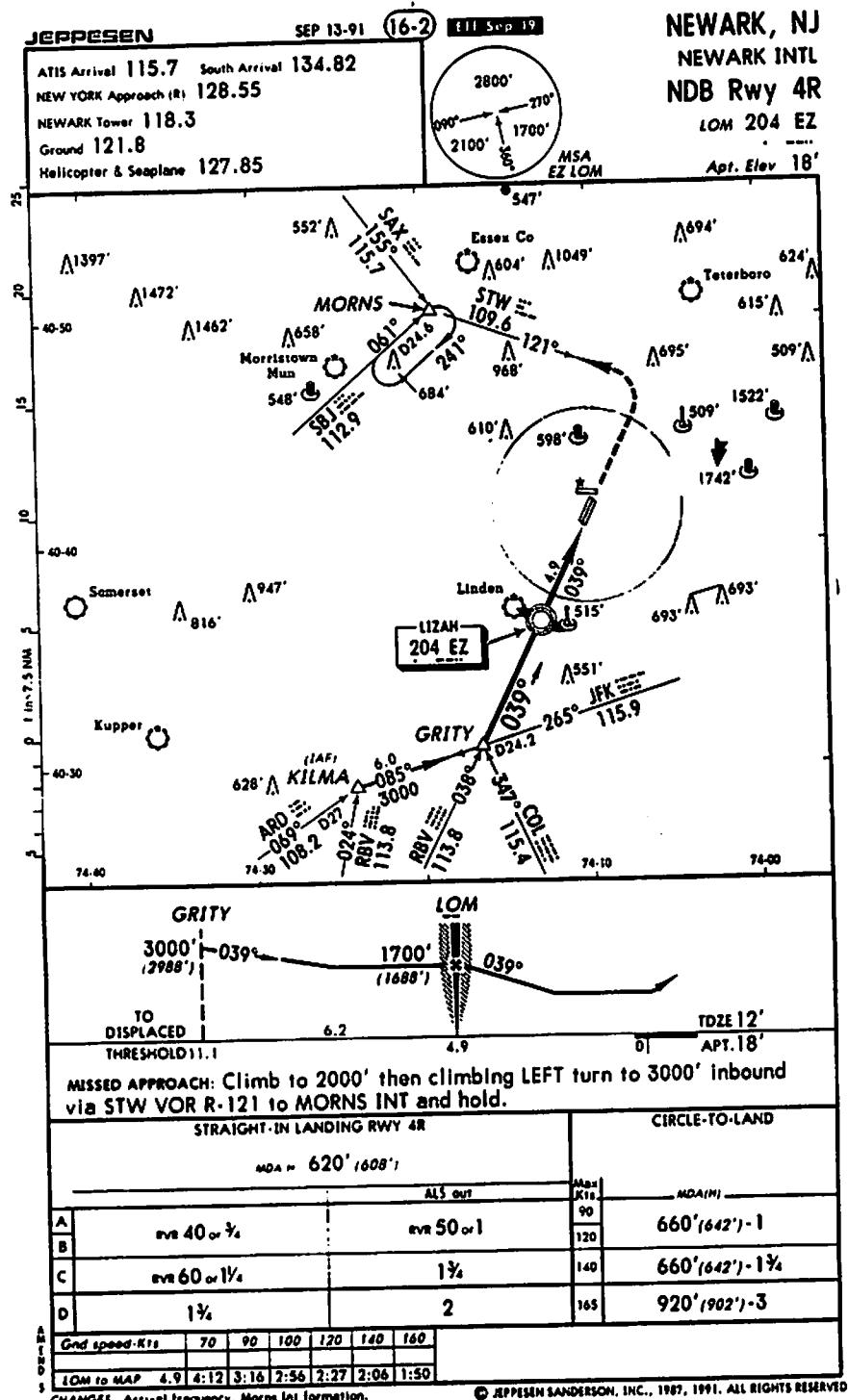


FIGURE II.

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 that 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 nonprecision 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 Jeppesen-Sanderson precision and nonprecision 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 "Gritty".

C. Directions

Please evaluate the information content of both the precision and nonprecision 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.

NOT FOR NAVIGATION

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

A. Precision Approach

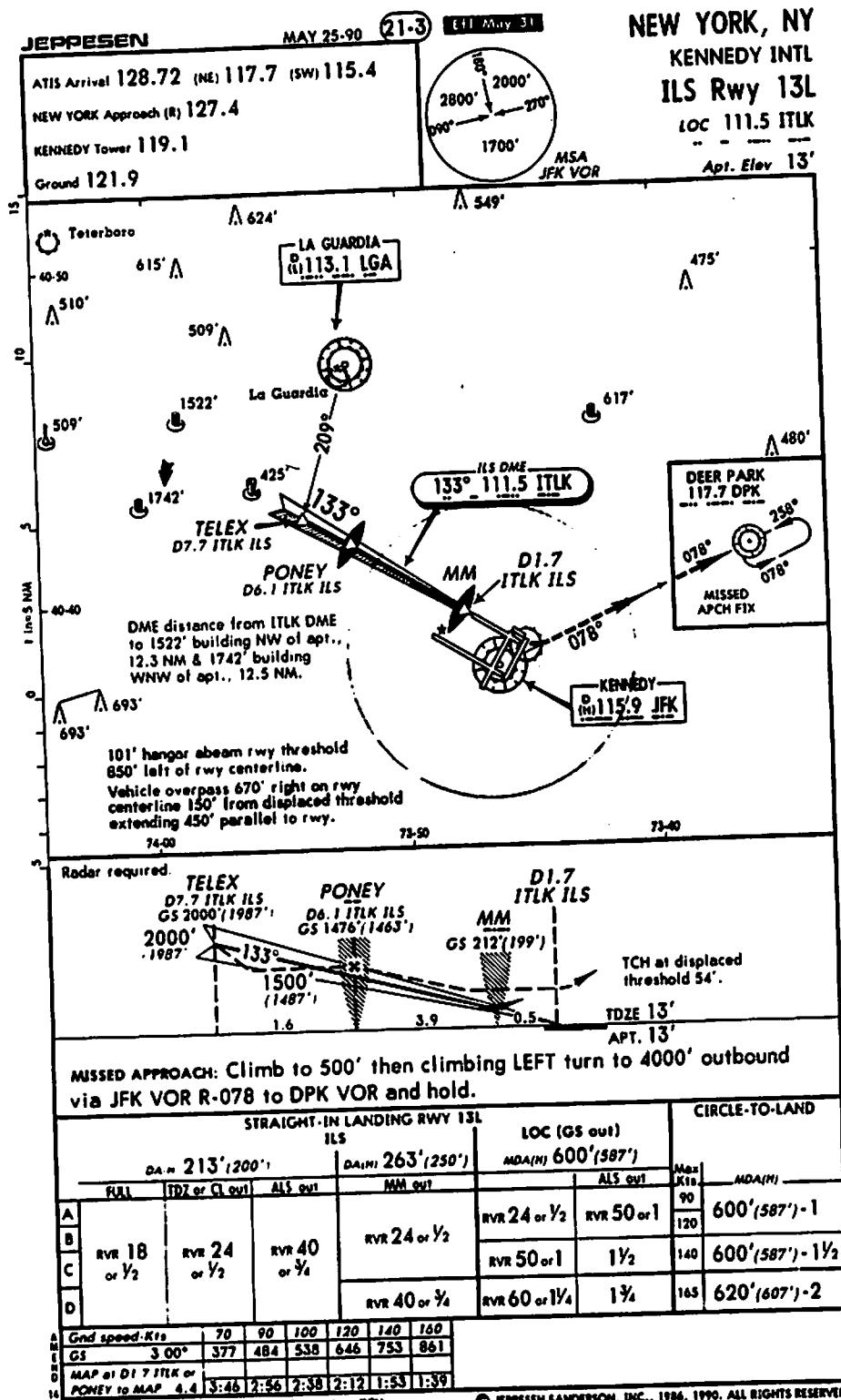


FIGURE III.

NOT FOR NAVIGATION

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

B. Non-Precision Approach

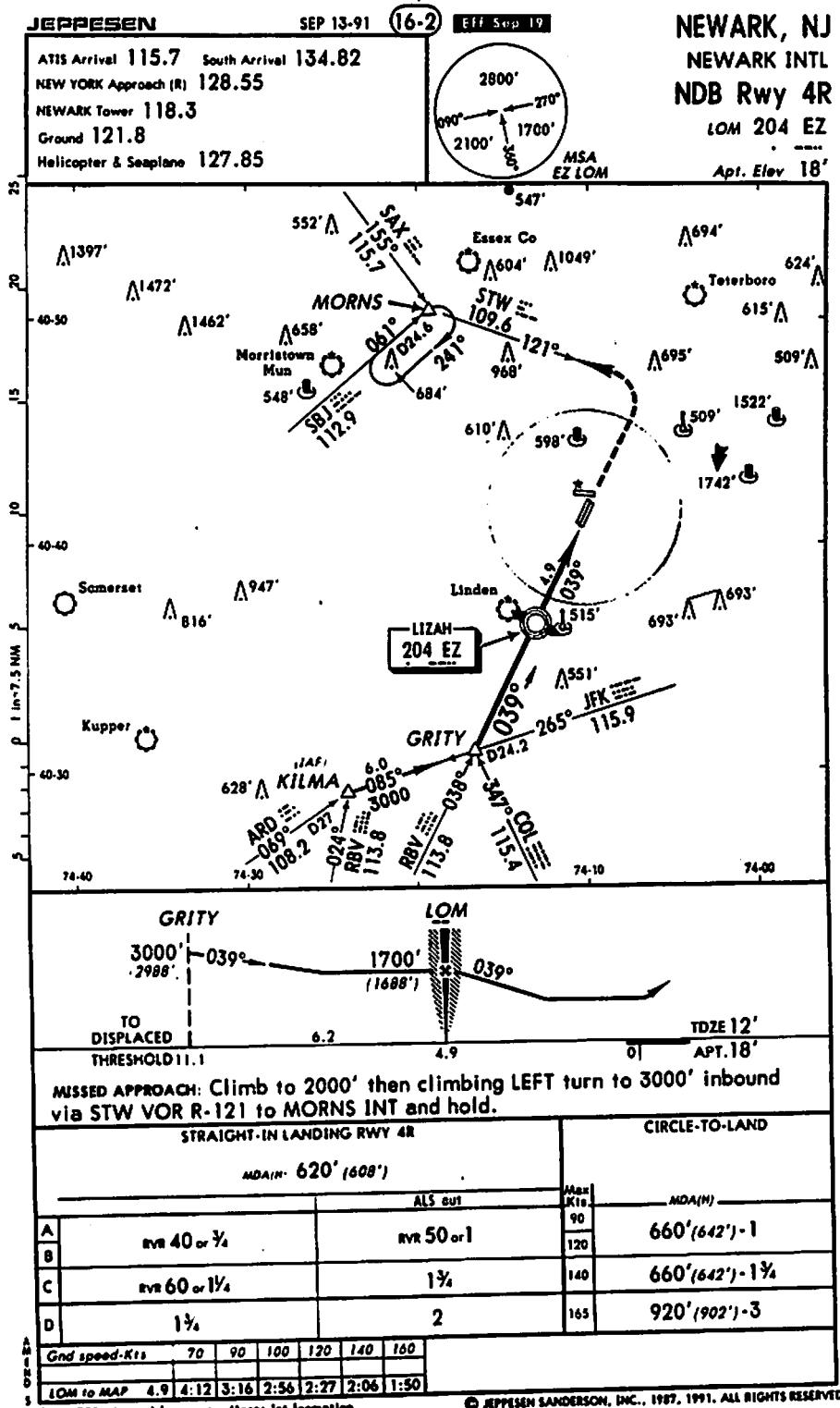


FIGURE IV.

NOT FOR NAVIGATION

Phase II: Approach A, Precision Approach

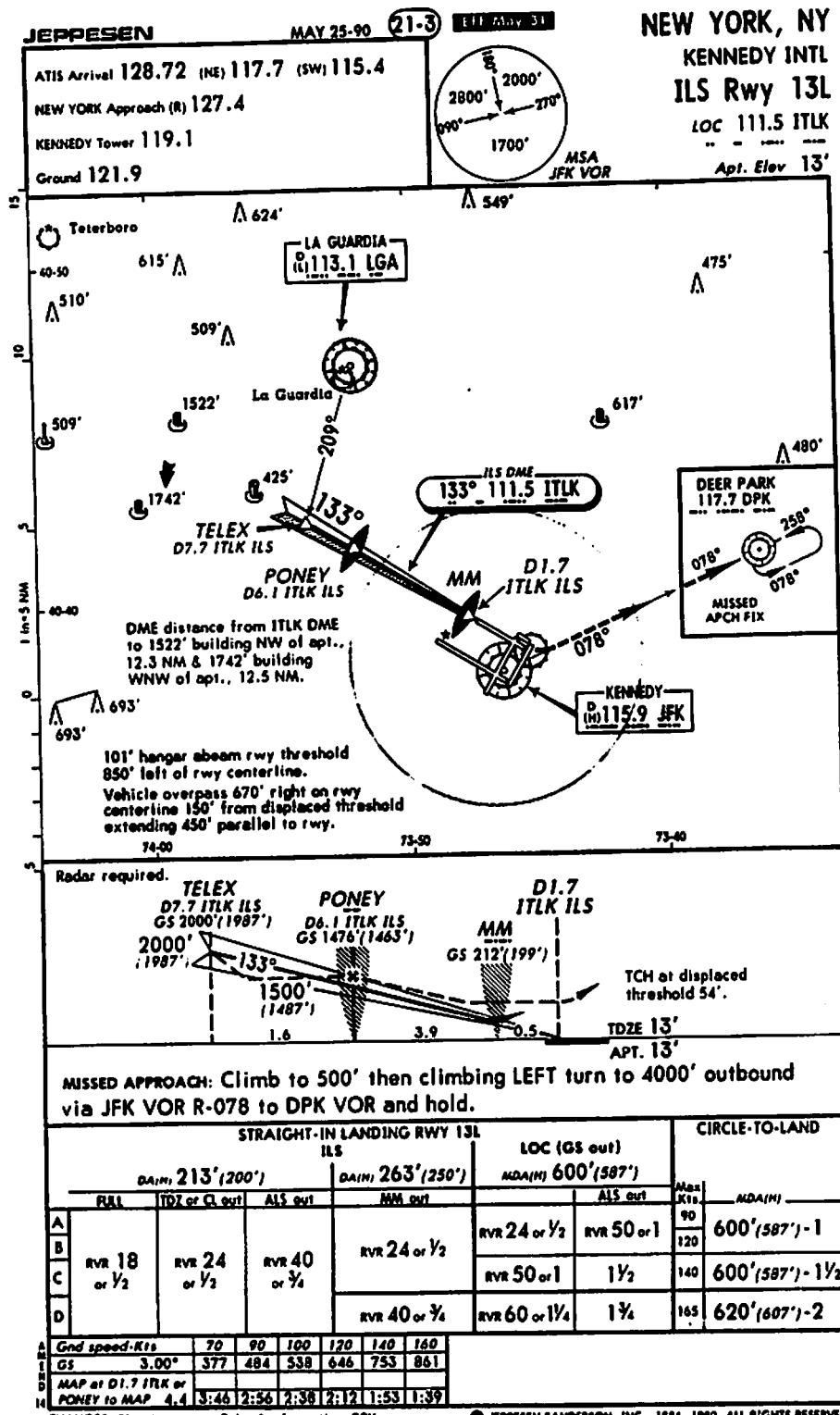


FIGURE V.

NOT FOR NAVIGATION

Phase II: Approach B. Non-Precision Approach

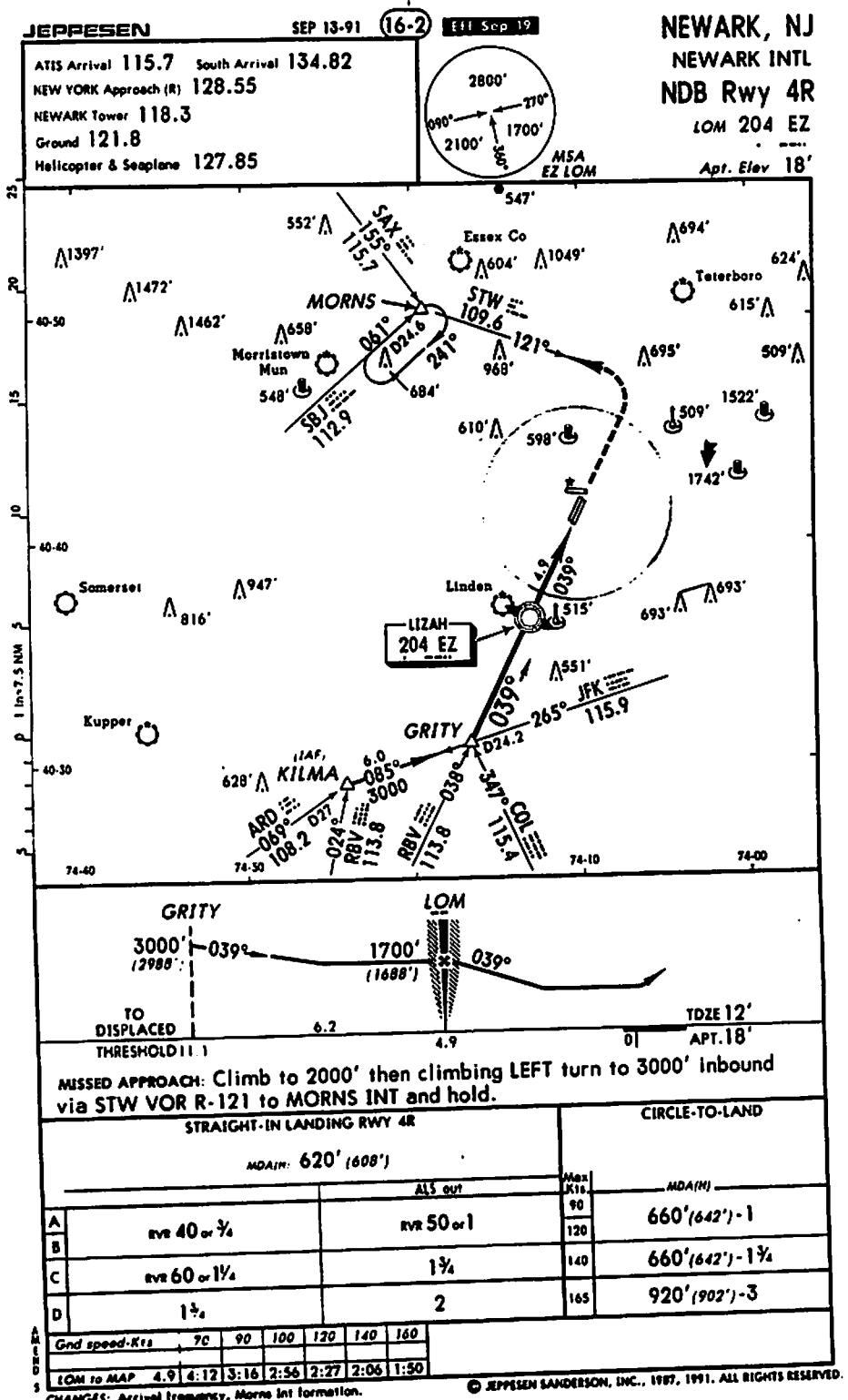


FIGURE VI.

NOT FOR NAVIGATION

Phase III: Missed Approach

A. Precision Approach

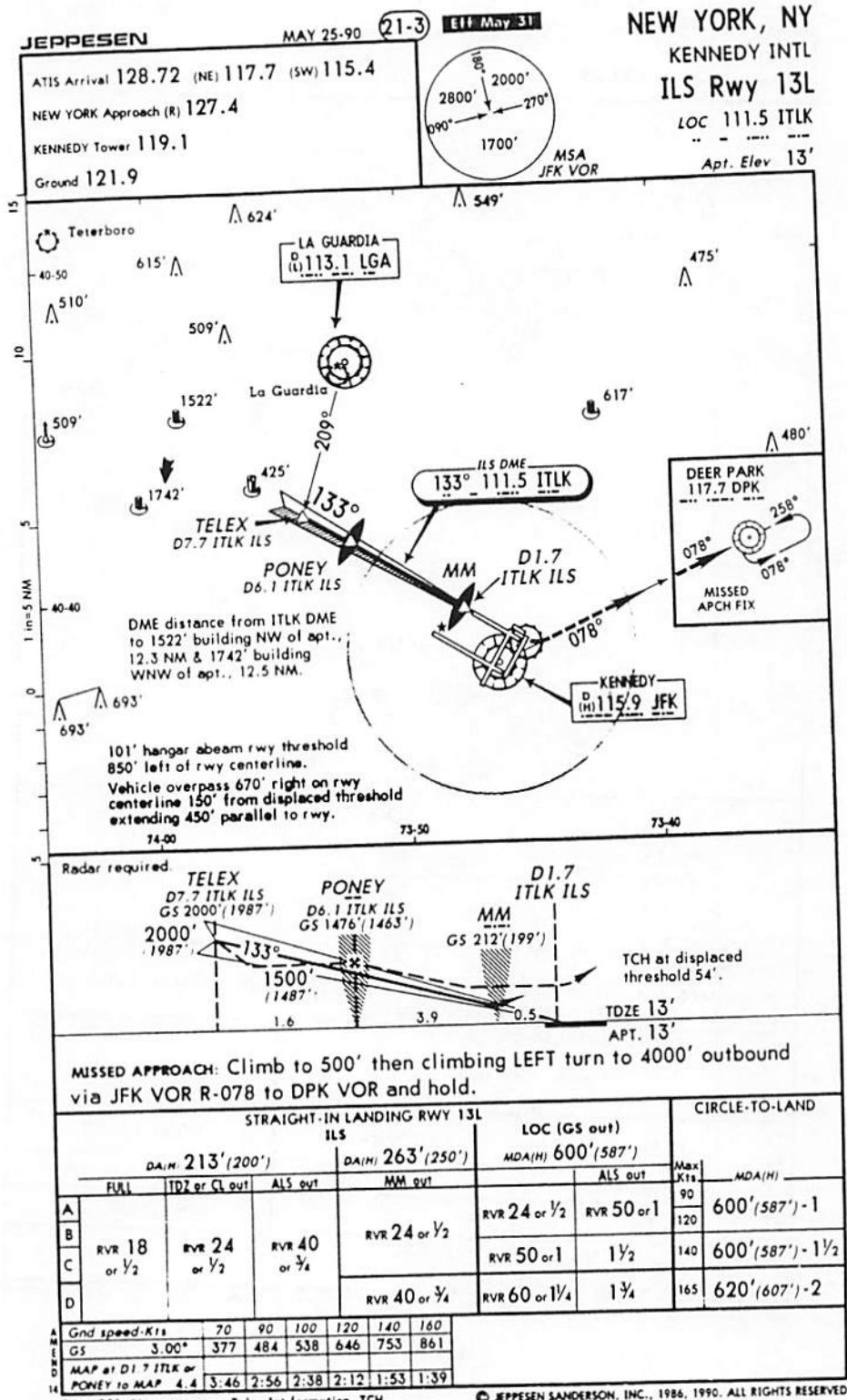


FIGURE VII.

NOT FOR NAVIGATION

Phase III: Missed Approach B. Non-Precision Approach

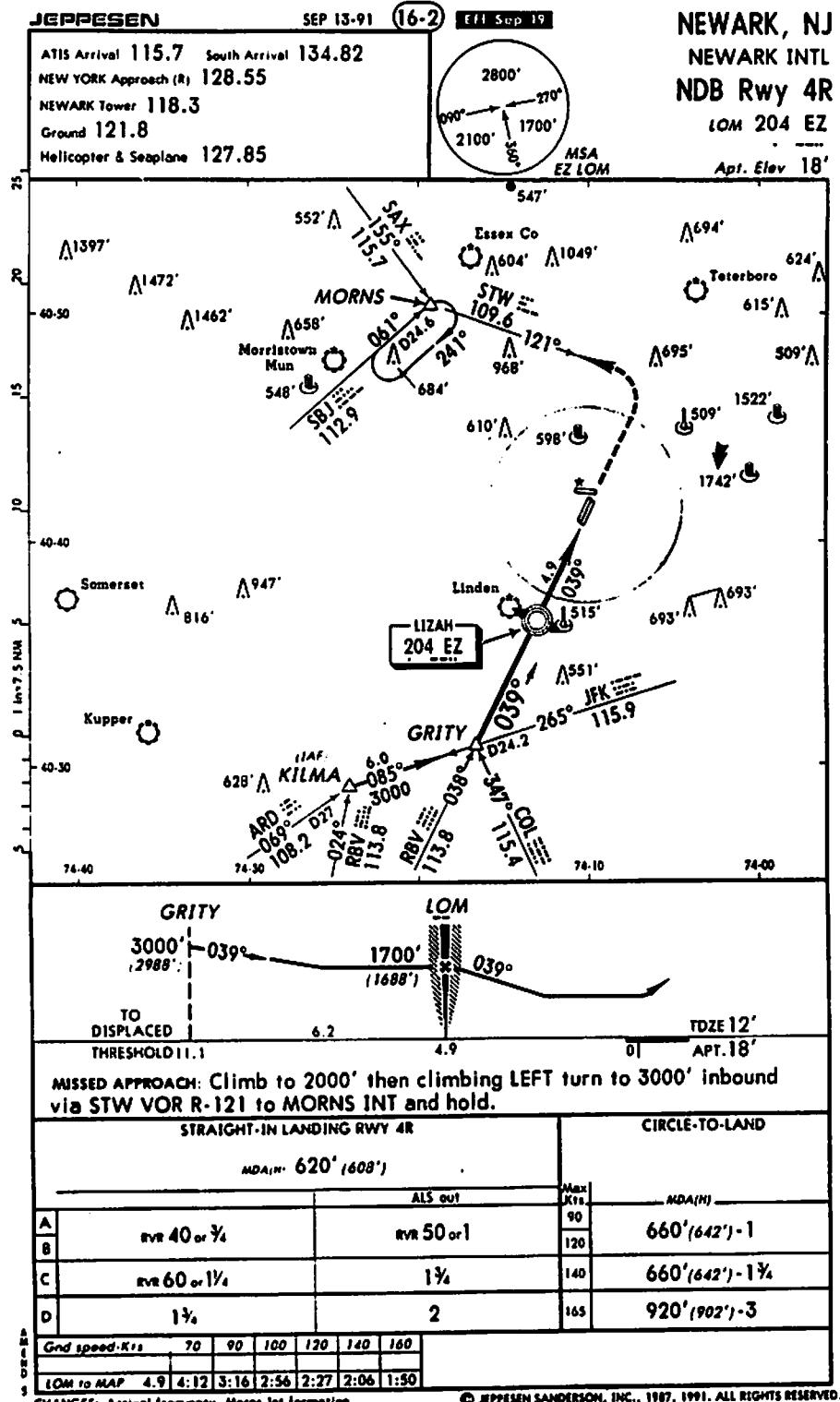


FIGURE VIII.

NOT FOR NAVIGATION

Phase IV: Ground Operations

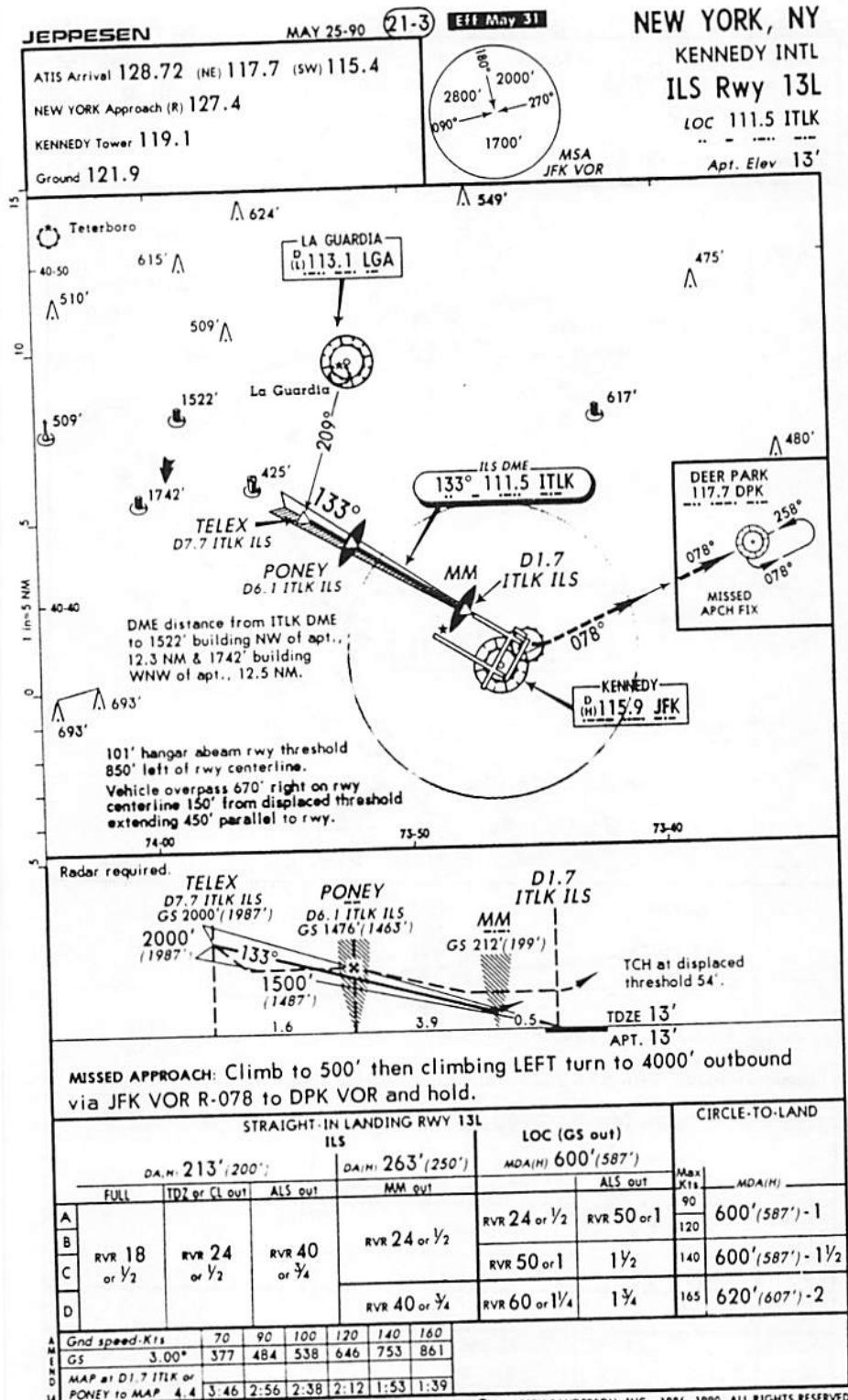


FIGURE IX.

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 platform 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?

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

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 C

Question List for Operator Interviews

What type of approach charts, SID's and STAR's does your organization use?

What are the best features of the charts?

What are the worst features of the charts?

Describe how you teach the use of approach charts. (What is company policy?)

What do you include in your pre-approach briefing?

Have you observed or heard of operational errors which could be related to the design of current charts?

Are the current charts:

- Lacking information
- Cluttered
- Optimal

Do you feel that more terrain information should be included in the charts? (Why, Where)

Are there any procedures or operations relating to the interpretation of approach chart information which students find particularly difficult?

In terms of presentation, what would you like to change about the charts you are currently using?
Please be specific.

Under what conditions do you use the charts when you are out of the airplane?

How difficult is it to keep your plates current?

How current is the plate information?

Are NOTAMS dealt with satisfactorily with the charts you are using? How do you check for the latest NOTAMS?

Do you teach the use of approach plates on visual appearances? (What info?)

Have you had any experience with CD ROM systems such as "Lasertrack" which print on paper in the cockpit?

What differences in approach plate usage is familiar versus unfamiliar airport?

What physical considerations are important to use of charts? (lighting, size, print...)

How do you feel that advanced approach chart formats should be evaluate?

What do you feel are the advantages, disadvantages and potential hazards associated with the presentation of approach information in electronic (EFIS like) format?

On autoflight equipped aircraft is it possible to make a safe approach in IMC without paper approach plates? Why? Have you heard of instances of this occurring?

What do you think about the reliability of electronically based systems for approach information?

General comments.

