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16. ABSTRACT

This study addressed the use of data-driven charts (DDC), which are electronic information charts that are drawn from an onboard chart database onto the forward displays. The DDC management system is intended to display only the electronic chart data that is relevant to the mission on the moving map or navigation display. It could have an important role in the depiction of RNAV RNP procedures to assist the flightcrew in the proper execution of complex NextGen routings. To develop initial recommendations and suggest areas of further research, we investigated how to integrate electronic IFR chart data into an avionics suite. The research can also be used to develop human factors guidelines for evaluating new systems that incorporate and manage electronic IFR chart procedure data in an integrated avionics platform. The integration of chart data on the front displays will allow the pilot to fly an IFR procedure without referral to a paper or fixed electronic chart. **Findings and recommendations**: Results suggest that data-driven chart systems should support briefing and tactical modes and allow the pilot to quickly cross-check entry of procedural data into the FMS. This intended function informs other initial recommendations for crew operating practices (SOPs), chart databases, information presentation, declutter techniques, and human-machine interaction for chart notes and data management. We developed initial recommendations for operational and certification approval guidance for DDC systems that will enable more efficient operations in the NextGen environment. Our recommendations were centered on two areas: (i) recommended human factors guidance for operational approval of electronic information charts and (ii) recommended human factors guidance for certification approval for electronic information charts. A number of recommendations address integration of chart elements, including intuitive display, quick access to the electronic fixed chart viewer with all notes and procedures, chart declutter, and allocation of chart data across displays. We anticipate that the utility of such electronic information charts will increase as the FAA transitions to NextGen operations in performance-based navigation airspace.

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NextGen Flight Deck Information Displays

Recommendations for Managing Display Complexity with Electronic Chart Information

February, 2014

Revision No.: 02

Instrument Procedures R&D Plan Section 5: Electronic Charts
Task 7 - Instrument Procedures
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ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	Definition
AC	Advisory Circular
ADS-B	Automatic Dependent Surveillance - Broadcast
AFM	Aircraft Flight Manual
ANP	Actual Navigation Performance
ARP	Aerospace Recommended Practice
ATC	Air Traffic Control
ATIS	Automatic Terminal Information System
ATS	Air Traffic Services
ATSU	Air Traffic Services Unit
B-RNAV	Basic Area Navigation
C-ATSU	Current Air Traffic Services Unit
CCD	Cursor Control Device
CDTI	Cockpit Display of Traffic Information
CDU	Control Display Unit
CFR	Code of Federal Regulation
CNS	Communication, Navigation, and Surveillance
CPDLC	Controller-Pilot Data Link Communication
CPT	Cockpit Procedures Training
DDC	Data-Driven Charts
DQR	Data Quality Requirements
ECL	Electronic Check List
EFB	Electronic Flight Bag
EICAS	Engine Indication and Crew Alerting System
EPE	Estimated Position Error
EPU	Estimated Position Uncertainty
ER	En Route
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FCOM	Flightcrew Operating Manual
FDMS	Flight Deck Merging and Spacing
FIM-S	Flight Deck-based Interval Management – Spacing
FIR	Flight Information Region
FL	Flight Level
FMC	Flight Management Computer
FMF	Flight Management Function
FMS	Flight Management System
HF	Human Factors
HITL	Human in the Loop
HMI	Human Machine Interface
HSD	Horizontal Situation Display
HSI	Horizontal Situation Indicator

Acronym/Abbreviation	Definition
IAF	Initial Approach Fix
IAP	Instrument Approach Procedure
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
ISA	Instantaneous Self-Assessment
MCDU	Multifunction Control and Display Unit
MDU	Multifunctional Display Unit
MEL	Minimum Equipment List
MFD	Multifunction Display
MOC	Means of Compliance
MOCA	Minimum Obstacle Clearance Altitude
MSL	Mean Sea Level
NAS	National Airspace System
NAV	Navigation
NextGen	Next Generation Air Transportation System
NM	Nautical Mile
OEM	Original Equipment Manufacturer
PBN	Performance Based Navigation
PDU	Primary Display Unit
PED	Portable Electronic Device
PFD	Primary Flight Display
POI	Principal Operations Inspector
QRH	Quick Reference Handbook
R-ATSU	Receiving Air Traffic Service Unit
RNAV	Area Navigation
RNP	Required Navigation Performance
RTA	Required Time of Arrival
SA	Situational Awareness
SID	Standard Instrument Departure
SOP	Standard Operating Procedure
STAR	Standard Terminal Arrival Route
T-ATSU	Transferring Air Traffic Service Unit
TCA	Terminal Control Area
TCAS	Traffic Collision Avoidance System
TERR	Terrain
VFR	Visual Flight Rules
VNAV	Vertical Navigation
VSD	Vertical Situation Display
WX	Weather

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EXECUTIVE SUMMARY

In the Federal Aviation Administration's (FAA) Next Generation Air Transportation System (NextGen) airspace environment, instrument procedures based on RNAV and RNP will offer significant safety improvements as well as new levels of flexibility to negotiate terrain, airspace, and environmental considerations. More RNAV procedures, both with and without RNP segments, are being developed each year. However, there are human factors issues associated with the design, depiction, and implementation of these new procedures.

This study addressed the use of data-driven charts (DDC), which are electronic information charts that are drawn from an onboard chart database onto the forward displays. The DDC management system is intended to display only the electronic chart data that is relevant to the mission on the moving map or navigation display. It could have an important role in the depiction of RNAV RNP procedures to assist the flightcrew in the proper execution of complex NextGen routings. We anticipate that the utility of such electronic information charts will increase as the FAA transitions to future operations envisioned for the NextGen such as performance-based navigation airspace.

NextGen operations will involve more complex and precise operations, for example instrument flight rule (IFR) procedures. To develop initial recommendations and suggest areas of further research, we investigated how to integrate electronic IFR chart data into an avionics suite. The research would also be used to develop human factors guidelines for evaluating new systems that incorporate and manage electronic IFR chart procedure data in an integrated avionics platform. The integration of chart data on the front displays will allow the pilot to fly an IFR procedure without referral to a paper or fixed electronic chart.

Initial findings and recommendations from our analysis suggest that data-driven chart systems should support briefing and tactical modes and allow the pilot to quickly cross-check entry of procedural data into the FMS. This intended function informs other initial recommendations for crew operating practices (SOPs), chart databases, information presentation, declutter techniques, and human-machine interaction for chart notes and data management. A prototype DDC design enabled pilots to perform tasks such as accessing, viewing, selecting, and placing notes and chart data onto an integrated map layer. The study findings are considered preliminary and must still be validated in pilot-in-the-loop simulations that measure impact on flightcrew performance. This body of work will ultimately help FAA personnel who evaluate and provide certification and operational approval of such electronic information charts.

We developed initial recommendations for operational and certification approval guidance for DDC systems that will enable more efficient operations in the NextGen environment. Our recommendations were centered on two areas: (i) recommended human factors guidance for operational approval of electronic information charts and (ii) recommended human factors guidance for certification approval for electronic information charts. A number of recommendations address integration of chart elements, including intuitive display, quick access to the electronic fixed chart viewer with all notes and procedures, chart declutter, and allocation of chart data across displays.

We also recommend future human-in-the-loop evaluations to validate and iterate the recommendations and guidelines we developed in this study. For example, many, if not all, of the DDC concepts in this study can be exported to portable electronic device (PED) applications. However, because PEDs are often side mounted, electronic information chart access, presentation, ergonomics, and crew procedures for PEDs may differ from front displays of chart data as described in this paper. We recommend future research on these differences so that display and control concepts can be used consistently across the flightdeck. Future research should also compare flightcrew performance with DDC in either the PED or installed front flight deck displays.

SYNOPSIS

OBJECTIVE OF THE STUDY

The evolutionary trend for flight decks has been to eventually integrate new technology with the forward display systems. Although legacy aircraft form, fit, and function may initially drive new functionality to peripheral displays (e.g., electronic flight bags (EFB)), new production aircraft generally try to incorporate the new functions within the modular architecture of the front display units.

This project investigated how to integrate electronic instrument flight rule (IFR) chart data into an avionics suite. The study results contribute to the development of operational and certification guidance in the future Next Generation Air Transportation System (NextGen) airspace environment. The goal of the work is to make it possible to integrate and display the electronic IFR chart data on the flight deck forward displays such as the primary flight display (PFD), multi-functional display (MFD), and vertical situation display (VSD) so the pilot can fly a procedure without a paper chart or an electronic fixed chart viewer.

This project investigated how to integrate IFR chart data into an avionics suite to be available on the flight deck forward displays such as the PFD, MFD, and VSD. Integration should make it possible to fly a procedure without referring to a paper chart or electronic fixed chart viewer.

Data-driven charts are electronic information charts that are drawn from an onboard chart database onto the forward displays. Data quality requirements (DQRs) are used to define the chart database, which is then provided per specification by a chart supplier. The chart database is composed of chart elements (e.g., courses, altitudes, distances, notes, etc.) that can be individually manipulated by the display system and logically placed on the front panel displays such as the moving map, vertical situation display, or primary flight display.

Data-driven charts that are integrated with an avionics platform and presented on the front displays is new technology that has yet to receive certification approval, and not much is known about what is needed for design, declutter, certification or operational approval of such systems.. Displaying chart data with other data on the MFD presents many challenges. One set of challenges is the human factors issue of integrating IFR chart data with other map layers, such as flight management system (FMS) navigation data, while preserving the intended function of IFR chart data. Quick access, readability, and interpretation of IFR chart data are critical for the successful execution of any IFR procedure. The study assumed that electronic fixed chart viewers would be available on the MFDs for briefing any procedure, while the navigation display used to tactically fly the procedure would incorporate the moving map display.

The advantage and power of data-driven charts is that the chart symbology, constructed from individual manipulated elements, can be made mission-specific. What this means for the pilot is that only chart data relevant to the mission, conditions, and procedure would be displayed. Pilot-customizable, powerful decluttering methodologies can further enhance charts. Another advantage of putting chart data on a navigation display is that the chart data can be layered with other map information such as terrain, weather, traffic, and/or FMS flight plan data.

With data-driven charts, symbology can be mission-specific, so that only chart data relevant to the mission, conditions, and procedure are displayed. Pilot-customizable, powerful decluttering methodologies can further enhance charts, and chart data can be layered with other map information such as terrain, weather, traffic, and/or FMS flight plan data.

Instrument flight rules (IFR) charts can be very detailed, having large quantities of symbols, lines, text, and notes. Users must be able to access chart data information with ease and be able to easily verify it against the chart database and FMS. Information must also be presented and manipulated in a manner that allows the pilot to use it as intended (e.g., strategically, tactically, or in a briefing mode).

The electronic information chart system, as exemplified in this study, is known as a data-driven chart (or DDC) display system. This system differs from other chart display systems in a number of ways, including:

1. The chart data is overlaid onto a navigation display (moving map display) and integrated with other navigation, weather, and traffic symbology.
2. The chart symbology and notes are stored individually as elements in a chart database.
3. The display system uses the database chart elements to display and place the symbology individually on the moving map display, VSD, or PFD.
4. The display system can assign grid placement coordinates to chart elements, assign priority drawing levels, and use other aircraft data such as speed, altitude, or position to create phase of flight logic for displaying data.
5. The electronic data-driven chart system is integrated with the FMS so that information can be passed back and forth between the two systems. Such integration allows FMS to tell the chart system what chart to display once the FMS is programmed. Conversely, it allows the chart system to insert a procedure into the FMS.
6. The DDC system allows more options for the display of chart notes. Because of the display flexibility (e.g., windows management, and controls such as cursor control devices (CCD) and, touch, etc.), note organization can be more standardized and logical. Specific guidance for standardization of note placement location options and movement of notes has yet to be developed.
7. Today, charts are presented on paper or via an electronic fixed chart viewer (on a portable electronic display such as an EFB, iPad®, or display unit window). With few exceptions (e.g., visual approaches, Engine Out Standard Instrument Departure, etc.), data-driven charts can display all charts in a chart subscription service.

These characteristics of a DDC system give the designer unique flexibility in creating a chart system with powerful decluttering and presentation capabilities. However, such a system also presents unknowns or risk in the areas of human factors, certification, and operational approval. To explore these areas, this study used a variety of techniques, such as engineering analyses, card sort techniques, Honeywell Aerospace lessons learned, prototyping, pilot focus groups, and a review of current industry, university, and FAA guidance documents to make recommendations in the following areas:

1. Human factors guidelines for displaying IFR chart procedure data on the moving map display.
2. Human factors guidelines for integrating FMS-produced data and chart data when shown together on a moving map display.
3. Human factors guidelines for displaying chart data with other moving map symbology such as traffic, weather, etc.
4. Guidelines for the allocation (display) of chart data on the PFD and MFD.
5. Recommendations for operational approval.
6. Recommendations or considerations for certification approval.
7. Recommendations for future research.
8. Contributions to Next Gen.

METHODS

The Honeywell Research team used a pilot-centered approach involving a variety of analytical methods.

Overview: The Honeywell Research team used a pilot-centered approach involving a variety of analytical methods. Detailed descriptions of each method used in the study are presented in respective sections of the main body of the report. The methods were based on a variety of sources of information and expertise, including a literature review, structured walkthroughs with subject matter experts, human factors and flight deck design expertise, a card sorting task, pilot structured focus groups, pilot evaluations with prototype software FAA stakeholder feedback, and collaboration with researchers at Volpe.

Literature review and analysis: We conducted a literature review of applicable Title 14 CFRs, advisory circulars, and published scientific literature, industry, and academic research regarding the integration of procedural chart data with aircraft displays (primarily moving map displays). The literature review included research focused on defining the state of the art in each research area, implications of existing work for the current study, and gaps or areas for future research. We also analyzed human factors issues related to electronic information charts. We used feedback from FAA stakeholders and input from researchers at Volpe in our issue analysis.

Card sorting: The purpose of the card sort was to identify common themes with the placement of IFR chart data on the PFD, MFD, or VSD. We conducted this exercise to develop a pilot-centered taxonomy of structured information relating to paper instrument procedural charting elements. The card sort was administered through a commercial card sorting web-site, which allowed flight test and corporate pilots from Honeywell's internal pilot pool to participate from several Honeywell locations. They sorted the cards independently on their own computers. Each pilot was given specific instruction prior to participating in the evaluation (Appendix A). The instructions summarized the objectives of the study, the assumed platform configurations, and definitions of the levels of criticality.

Design: We exercised our combined subject matter expertise in airspace operations and piloting, flight deck design, human factors, and certification to develop actual display concepts in the form of a software prototype. The software prototype was designed so that the pilot could access, view, select, and place notes and chart data onto the DDC map layer. The chart management system is intended to display only the electronic information chart data that is relevant to the flight on the moving map or navigation display. It was also intended to be a preflight task. The prototype allowed the pilot to select chart information that was relevant to the flight plan, mission, and conditions, while filtering out all other information. The display concepts were based on the results, identified issues, specifications, and requirements gathered throughout the study.

Pilot evaluation: Internal Honeywell flight test pilots evaluated display concepts in a web-based review. Ten pilots participated in the evaluation, which was conducted during four separate sessions. During a session, the pilots received a general overview of the background and basic functionality of the display concepts. Once the initial orientation was completed, we conducted a formal walkthrough using the prototype to demonstrate various design features, during which the pilots provided their opinions on the suitability of the concept.

LIMITATIONS

- We did not investigate integration of chart data with side displays, EFBs, or tablet devices.
- Even though we used a pilot-centered approach, based on the defined scope of the study, we did not use empirical evaluation methods.
- Study findings are considered preliminary until they have been validated in a pilot-in-the-loop simulation study.

FINDINGS

Although data-driven charts have been in development for several years, many risks are involved in the integration of chart data with navigation displays. This study attempted to list areas that need further clarification and provide recommendations on human factors design, certification, and operational approval. Some of the key findings are listed below.

1. We defined the intended function of the various display components of a data-driven chart system. These descriptions drove recommendations to support the pilot tasks associated with the intended function.
2. Data-driven chart systems should support briefing and tactical modes and allow the pilot to quickly cross-check entry of procedural data into the FMS.

Data-driven chart systems should support briefing and tactical modes and allow the pilot to quickly cross check entry of procedural data into the FMS.

3. The intended functions of a data-driven chart system should support pilot tasks. The pilot tasks define what chart information is required. For instance, for a NextGen operation such as required time of arrival (RTA), an avionics vendor may require additional chart information to support a pilot's navigation to include compliance with RTA clearances. This chart information would be specified

according to a set of data quality requirements. The chart vendor would then supply new chart elements that could be drawn on a front display to support the RTA navigation task.

4. Chart symbol precision, stored in the chart database as digital elements, should be defined by data quality requirements (accuracy and resolution). Symbol precision should support a pilot task, which is defined by intended function.
5. In a paperless cockpit, a chart system should support integration of chart notes. Electronic information chart notes should be logically and consistently grouped in a standardized way. An information selection mechanism could ensure that only notes relevant to the mission are displayed.
6. If pilots use an electronic fixed chart viewer, a single button press (toggle) should be available for toggling between the chart viewer and the data-driven chart layer on the moving map display.
7. We used structured pilot walkthroughs, card sort techniques, and other analytical methods to determine if some of the chart information can or should be allocated to other display areas such as the VSD and PFD. Pilots reported that they would like to see final approach information on the PFD such as visual approach slope indicator (VASI) symbols, glideslope intercept altitudes, minimums and missed approach information. The pilots did not want a lot of clutter on the PFD and were very specific that DDC displays should provide sufficient information on the PFD to help with instrument scan and situation awareness (SA), but without increasing clutter.
8. We used pilot focus groups, engineering analysis, and guidance from *Aerospace Recommended Practice: Electronic Display of Aeronautical Information (Charts), SAE ARP 5621*[1] (SAE Aerospace, 2011) to determine recommended declutter design requirements. SAE ARP 5621 provided guidance on chart symbology for primary and secondary chart information. Even when a chart layer is turned OFF, primary information should be displayed—that is, decluttering should not be able to remove it. (See Item 6 in the Concept of Operations section below for a more detailed description.) Pilots should be able to view and declutter secondary information. An important finding was that pilots wanted selection mechanisms that allowed them to display only chart data relevant to the mission.
9. We developed recommendations for certification approval requirements from Honeywell's lessons learned and subject matter expertise, including Honeywell's Airworthiness/Organization Designation Authorization (ODA) experts. Some important findings are:

    a. The DDC map layer should clearly indicate what chart is being displayed.
    b. Crew advisories should be provided if the chart database is out of date or is corrupt.
    c. Ownship position on the navigation display should not be obscured by chart data.
    d. Declutter should allow the de-selection of chart course data (e.g., symbols, route lines, courses and altitudes, waypoint symbols, waypoint crossing restrictions, changes in minimum altitudes, etc.) from the navigation display.

10. One recommendation for operating limitations is that the DDC should not be used when briefing the procedure to be flown. With an electronic information chart system, pilots should brief the procedure from the electronic fixed chart viewer. The electronic fixed chart viewer contains 100% of all chart procedure data; whereas, the data-driven chart layer on the moving map display contains only the

In a paperless cockpit, a chart system should support integration of chart notes. Electronic information chart notes should be logically and consistently grouped in a standardized way. An information selection filtering mechanism could ensure that only notes relevant to the mission are displayed.

An important finding was that pilots need selection mechanisms that allowed them to display only chart data relevant to the mission.

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[1] SAE ARP 5621 was developed prior to the revision of SAE ARP 5289A, which specifies symbols for electronic displays. SAE ARP 5621 was not coordinated with the FAA, and its guidance may conflict with FAA regulatory and guidance material.

information necessary to tactically fly the current and upcoming part of the procedure, providing just enough information in the display that the pilot does not have to refer to the paper chart or its equivalent display on an electronic fixed chart viewer.

Electronic Information Chart Concept of Operations

Preflight

1. The pilot checks that a current and valid chart database is installed.
2. The flightcrew checks that no advisories are displayed relative to the electronic information chart.
3. During pre-flight, the pilot brings up the electronic chart, loads, and then activates the procedure in the FMS per the ATC clearance. Once the FMS is loaded with the correct procedure, the FMS sends a signal to the DDC system for which chart procedure to queue up when the pilot sets the DDC layer to ON.
4. Once the FMS is programmed with the procedure, the pilot turns on the moving map DDC layer and confirms that the correct chart is being displayed.
5. The pilot again checks for any advisory messages relevant to DDC.
6. The pilot then enters a chart set-up menu and, based on intended flight path, customizes the chart notes and data for the specific mission. Through a chart notes and data interface, the pilot selects the notes and data to be displayed (the exception being chart data defined as Category 1 by SAE ARP 5621[2]). Category 1 data is the highest priority or criticality level assigned by ARP 5621. This means that Category 1 data is necessary for safety of flight and is necessary to properly fly a procedure. Category 1 data, as defined, can never be decluttered. It must always be displayed when the chart layer is ON. This action further declutters the display when the chart data layer is turned OFF.
7. Crew briefing. The crew should brief the takeoff and departure by reviewing the electronic fixed chart viewer. This requirement is supported by 14 CFR 91.503 that states that all information relative to the flight must be available and reviewed by the flightcrew.

In-flight operation

We recommend including a DDC certification approval requirement that decluttering mechanisms be used in-flight. In this case, we recommend two embedded and automatic decluttering mechanisms. The first decluttering mechanism makes use of airplane position and altitude. For example, if the aircraft is at FL 350, then the display of information like minimum enroute altitude (MEA), minimum obstacle clearance altitude (MOCA), etc., is not displayed. Similarly, if the aircraft is more than a pre-set/customizable distance from a NAVAID or waypoint, then that data is not displayed. The second decluttering device is range control. As the pilot selects a different display range (i.e., ranges in or out), the system manages the volume of chart data displayed to avoid chart clutter. Conventionally, the symbology displayed at specific ranges is determined by the airframe original equipment manufacturers (OEM), based on their customers specific mission profiles. However, additional research, including review of currently used display symbology, is needed to determine what chart symbology should be used to indicate off-screen information at the end of the display range. For instance, if the chart data is showing a step change in altitude, or a turn at a waypoint, it might be important to display information at the edge of the display range to give the pilot some 'heads up anticipatory preparation' for an event that is just off screen. An analogous situation might be a TCAS target that is just outside the display range but the symbol gets "parked" at the screen edge of the display to alert the pilot that traffic is just off screen.

INITIAL RECOMMENDATIONS

The following recommendations are based on the broad analytical methods used in our study. Additional flight deck human factors research is needed to better specify and support our initial recommendations

[2] SAE ARP 5621 was developed prior to the revision of SAE ARP 5289A, which specifies symbols for electronic displays. SAE ARP 5621 was not coordinated with the FAA, and its guidance may conflict with FAA regulatory and guidance material.

before they are incorporated into regulatory guidance. At the beginning of each recommendation (in parenthesis), the following legend indicates the sources of the recommendation.

- LRA – Literature Review and Analysis
- CS – Card Sorting
- PE – Pilot Evaluation
- HON SME – Honeywell Subject Matter Expertise (Human Factors, flight test pilots, certification and internal flight deck engineering display developers).

1. Human-centered chart design [HON SME; CS, PE]

- Each IFR chart can be decomposed into individual chart elements and stored in a chart database. Chart elements **should** be integrated so that displayed information is intuitive—easy to understand and interpret. The integrated chart database elements **should** form a more intuitive whole than that represented on paper charts or an electronic fixed chart viewer. Figure 1 illustrates this recommendation for a terminal area arrival (TAA) chart. Integrating chart information electronically assures minimizing confusion and errors.

Chart elements should be integrated so that displayed information is intuitive—easy to understand and interpret. The integrated chart database elements should form a more intuitive whole than that represented on paper charts or an electronic fixed chart viewer.

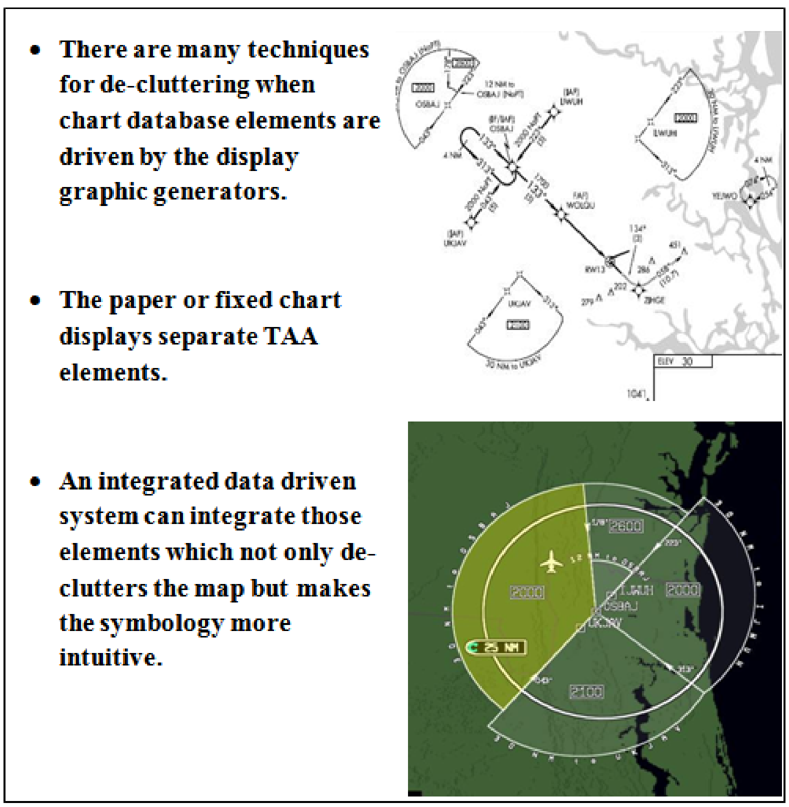

Figure 1. TAA paper version reconfigured to be more intuitive

2. Chart declutter

- **Phase of flight and declutter [HON SME; PE, LRA]:** Phase of flight **may** be used as a trigger mechanism to declutter electronic information charts by using aircraft altitude, position, speed, and other contextual variables to change chart information on the moving map display. This technique can give the pilot "the right information at the right time." For instance, showing airway MEA or MOCA when the aircraft is on an airway at FL 360 may not add any operational value.

Phase of flight can be a trigger mechanism to declutter electronic information charts by using aircraft altitude, position, speed, and other contextual variables to change chart information on the moving map display. This technique can give the pilot "the right information at the right time."

- **Allocation of chart data across displays [HON SME; CS, PE, LRA]:** Chart data allocated across the front displays (PFD, MFD) **may** be used to declutter the navigation display and logically assign data to displays in a way that congregates data specific to a pilot task. For approach tasks, some chart information collocated with the PFD will improve pilot scan for the approach task while decluttering the moving map display. For instance, our card sort analysis indicated a strong pilot preference for presenting final approach and missed approach information on the PFD so that the pilot would not have to split scanning between the MFD and PFD. As another example, presenting chart data on the moving airport display (diagram) lets the pilot see all information on one display (e.g., aircraft position, ADS-B traffic, and airport chart data), eliminating the need to flip back and forth between the airport moving map the airport diagram on the electronic fixed chart viewer or paper. Presenting chart data on the front displays will also make it possible for the pilot to taxi or fly a clearance without referring back to the airport diagram or IFR procedure on the electronic fixed chart viewer. Thus, all necessary information for taxi and the IFR procedure to be flown needs to be tactically displayed on the moving map. Analysis, pilot focus groups, and demonstrations will enable electronic information chart designers to select the right information to be displayed. However, specific guidance for standardization of note placement location options and movement of notes has yet to be developed.

Some charts have extensive pages of notes. Our design objectives address the potential for clutter due to chart notes.

- **Procedure notes [HON SME; PE]:** Some charts have extensive pages of notes for the pilot to read. The following design guidelines **should** be considered to address the potential for clutter due to chart notes:
  - Display only notes that are relevant to the mission.
  - Allow the pilot to customize the notes into a briefing format.
  - Allow the pilot to insert additional (free text) notes for display, as relevant to the mission.
  - Allow the pilot to place a note, designated by a unique icon, on the moving map display.
    This capability will make it possible to tie the notes to the appropriate phase of flight or segment of the flight plan. The benefit is that it creates 'memory prompts' for important notes and mitigates the need to refer back to mission-relevant notes in the notes display box.

One decluttering technique is to allow the pilot to define or customize chart data relevant to the mission.

- **Chart data layers and declutter [HON SME; CS, PE, LRA]:** One decluttering technique is to allow the pilot to define or customize chart data relevant to the mission. Chart data, as differentiated from chart notes, contains symbols, lines, courses and altitudes. The pilot **should** be able to customize the layers so that only chart data relevant to the mission is displayed. All other chart data is suppressed but can be turned on again with a simple action.

- Chart data defined as Category 1 data by ARP 5621[3] **must** not be suppressed. Category 1 data is the highest priority or criticality level assigned by ARP 5621. This data is necessary for flight safety and to properly fly a procedure and **must** be displayed when the chart layer is ON.

FMS and data-driven chart data should be clearly distinguishable as separate entities. Chart course-lines, bearings, distances, waypoints and EXPECT altitudes should be clearly distinguishable from FMS flight plan data.

3. Integration of chart data with other navigation display symbology [HON SME; CS, PE]

- IFR chart data rendering **should** integrate within the overall priority drawing level philosophy of the target OEM (original equipment manufacturer).
- FMS and data-driven charts data **should** be clearly distinguishable as separate entities. Chart course-lines, bearings, distances, waypoints and EXPECT altitudes should be clearly distinguishable from FMS flight plan data.
- Only data-driven chart data that supplements FMS data **should** be shown. That is, once a procedure is loaded into the FMS, the FMS will pull all waypoints, courses, bearings, altitudes, etc. from the NAV Procedure Database. In a tactical mode (versus a briefing mode), data-driven chart data that conflicts with FMS computed data should be suppressed.
- Chart data that replicates altitudes, waypoints, courses, and bearings in the FMS **should not** be displayed on the moving map. Avoiding replication reduces clutter and prevents confusion over chart distances and course bearings that may disagree with the FMS calculations.
- Common symbology sets **should** be required. OEM data and chart data should use the same symbology. OEM moving-map displays have a certified symbol set for displaying NAVAIDS, runways, airports, and the like. Pilots should not have to learn and remember different symbology sets that represent the same entity.

Our generalizable guidelines flow from an operational philosophy grounded in the intended function of a data-driven charts system.

4. Operational approval [HON SME]

- Our generalizable guidelines flow from an operational philosophy grounded in the intended function of a data-driven charts system (analogous to paper charts or electronic fixed chart viewers). The data-driven chart system **should** support crew tasks such as:
  - Finding the relevant chart through an indexing system.
  - Changing charts as ATC clearances or flight conditions change.
  - Checking chart validity.
  - Using chart data to configure the navigational systems and cross check.
  - Using the chart data to fly the procedure tactically. That is, the chart data should be available for review of forgotten items or to refresh the pilot on the procedure.
- The pilot **should** always have quick access to the electronic fixed chart viewer. It contains all notes, procedures applicable to a given procedure that a pilot may need to review. Initial implementations of the DDC layer would contain adequate information to fly a procedure under nominal conditions but not for all unforeseen conditions. For instance, with approach minimums, there may be an

[3] SAE ARP 5621 was developed prior to the revision of SAE ARP 5289A, which specifies symbols for electronic displays. SAE ARP 5621 was not coordinated with the FAA, and its guidance may conflict with FAA regulatory and guidance material.

unexpected component out situation (e.g., centerline lights INOP) that may require the pilot to quickly review the new minimums associated with a loss of centerline lights.

- Since data-driven charts are comprised of several components that add complexity compared to paper charts, each displayed component in a DDC system **should** have traceability back to a crew task so that crew procedures can be defined. Although electronic information charts have multiple components, their design should be flexible so that the crew can set-up, fly, and then change the procedure, all from the same interface on the MFD. Currently, the intended function of the electronic fixed chart viewer is to brief the crew on a procedure since it contains 100% of all information related to any given procedure, including off nominal events such as component out minimums. Once the pilots are briefed on the procedure they can fly the procedure with the DDC layer (rather than the electronic fixed chart viewer), since the DDC contains adequate information to fly the procedure under normal or nominal conditions. An electronic fixed chart viewer or paper chart will still be required for flightcrew optional reference, and particularly in case of an off nominal condition requiring more information than is displayed in the DDC system.

5. Approval of data-driven charts

- Regulations [**LRA**]: The approval basis for the electronic information chart system will be TSO-C165, *Electronic Map Display Equipment for Graphical Depiction of Aircraft Position*. However, other important rules or standards related to HF will also apply, including AC 25-11A - *Electronic Flight Deck Displays*, the new AC 25.1302-1, *Installed Systems and Equipment for Use by the Flightcrew*, etc.
- After determining display requirements, the display and prioritization of chart data **should** be guided by SAE ARP 5621[4], display of chart symbology **should** be guided by SAE ARP 5289A, *Electronic Aeronautical Symbols,* and ARP 5430, *Human Interface Criteria for Vertical Situation Awareness Displays,* **should** be used in part for the presentation of chart data on the VSD. General attributes of chart data **should** conform to RTCA DO-257A, *Minimum Operational Performance Standards for the Depiction of Navigational Information on Electronic Maps,* invoked by TSO-C165, and the chart database **should** comply with DO-200A, *Standards for Processing Aeronautical Data* and DO-201A, *Standards for Aeronautical Information*.
- The following human factors topics **should** be considered for data driven chart certification approval scrutiny **[HON SME]**:
  - Display of chart data on the VSD.
  - Integration of chart data with FMS flight plan data on the navigation display.
  - Use of Level C software assurance requirements.
  - Correspondence between aircraft altitude on the VSD and altitude on the PFD. The altitude source should be the same, and relative position of the aircraft to the altitude should not be ambiguous.
  - Relative position of aircraft on glidepath between VSD and vertical deviation on the PFD.
  - Assurance that chart data on the front displays is 100% accurate with digital chart data supplied by vendor.
  - Assurance that the system provides salient feedback to the pilot for appropriate chart selection.
  - Availability of chart data during reversionary modes.
  - Crew advisories when a fault or database out of date event occurs.
  - Quick access (e.g., single button press) for toggling between the DDC layer and electronic fixed chart viewer.
  - Provision for concurrent viewing of the electronic fixed chart viewer and the DDC layer.

[4] SAE ARP 5621 was developed prior to the revision of SAE ARP 5289A which specifies symbols for electronic displays. SAE ARP 5621 was not coordinated with the FAA, and its guidance may conflict with FAA regulatory and guidance material.

- **Procedure ID block [HON SME]:** A data-driven chart system **must** display a procedure header ID block on the DDC layer to identify which IFR procedure chart has been called up from the data-driven charts database and shown on the NAV or moving map display. The procedure header block validates whether the system has called up the correct chart procedure, based on FMS procedure and transition selections.
- The procedure ID block, although necessary, can add clutter to a moving map display that should display high priority safety critical information (e.g., TERR and TRAFFIC). Its use **should** be evaluated case-by-case to make sure the ID block is not covering up other critical map information.

> *IFR chart procedure data can be displayed with courses, altitudes, and waypoints and then overlaid on the NAV display where conflicts with the FMS drawn flight plan may occur. The FMS draws the lateral flight plan based on 'FMS rules' and the chart data can be drawn by totally separate rules. Trouble spots may occur with 'curves' in the lateral flight plan and/or the way FMS versus chart courses are calculated.*

- **Concurrent display of chart data and FMS data [HON SME]:** IFR chart procedure data can be displayed with courses, altitudes, and waypoints and then overlaid on the NAV display where conflicts with the FMS drawn flight plan may occur. The FMS draws the lateral flight plan based on FMS rules, and the chart data can be drawn using totally separate rules. Trouble spots may occur with 'curves' in the lateral flight plan and/or the way FMS versus chart courses are calculated. In paper charts, it is common to see 1 or 2 degree variations in the course bearing between the FMS leg course and the charted course. Pilots are aware of this variation and compensate. However, when the deviation is shown on a moving map display, it becomes a point of confusion. The applicant **should** demonstrate intended function for showing the full charted course concurrently with the course information.
- **Toggle [HON SME]**: A quick (single toggle action) method **may** be used for switching between the electronic information chart and the NAV or moving map display.
- When toggling between the moving map display and the electronic fixed chart viewer, the moving map display settings **should** be preserved (e.g., range, selected layers, TCAS, or TERR selections).
- **Charts notes and data formats [HON SME]:** Pilots are used to Jeppesen, Lido, or government chart formats for IFR procedures. They have trained, used, and developed SOPs using these formats for decades. Deviating from these layouts has the potential to cause pilot confusion. The applicant or vendor **should** justify through analysis and HITL evaluations that deviations from standard formats do not cause undue confusion, ambiguity, or additional pilot workload.
- **Charts advisory messages [HON SME]:** An electronic information chart system **must** provide a system output of its database status with the minimum status information as follows:
  - DDC database effective period (valid or outdated)
  - DDC database configuration status (validation of data file configuration)

> *A data-driven chart system must display a procedure header ID block on the DDC layer to identify which IFR procedure chart has been called up from the data-driven charts database and shown on the NAV or moving map display.*

- **Charts display reversion [HON SME]:** The applicant **should** demonstrate, through analysis, design and evaluation how electronic information chart systems can be displayed under various failure modes such as display unit (DU) failure. The applicant may have to demonstrate this with various screen configurations such as a three DU flightdeck or a four DU flight deck.

6. Need for additional regulatory guidance for map symbology to support RNAV RNP operations [HON SME]

- **Levels of service.** Multiple RNP level-of-service requirements exist for the same approach type to the same runway end. Level of service covers the approach constraints for RNP, Minima, etc. and is expressed as an RNP value, CAT 1, CAT II, or CAT III. Although RTCA SC-227 *Standards of Navigation Performance* is currently working on developing them, no industry standards are yet available to specify what should be displayed (approach type and level of service) and where such information should be displayed.

- **Consistent alerting with aircraft estimated position uncertainty (EPU) in relationship to established leg RNP.** No industry standards specify how to display this concept graphically or whether it should even be required to be displayed graphically (although there is a numerical annunciation of ANP/RNP).
- **Early FMS output for FMS approach mode.** The industry does not have regulatory guidance that directs OEMs to indicate when the aircraft is in the RNP approach mode. Usually, this approach "proper" area is very near the FAF (2 to 5 miles). Therefore, the pilot receives no RNP indications until very near the FAF.
- **Curved path on RNP or RNP AR procedure**: When flying a curved path on an RNP or RNP AR procedure with an HSI, it is recommended that a pointer or some other graphical icon be provided to show the roll-out heading.
- **RNP Sensor State Output:** We recommend that once an approach selection is made by the pilot, the FMS **should** output a new parameter showing whether the state for RNP approach is available. This will allow enough reaction time for the pilot to decide to change the approach type.

When appropriate IFR procedures and transitions are selected through the FMS, all other transitions for electronic information charts should be automatically deselected in the FMS and suppressed on the displays.

7. Chart usability [LRA; HON SME]

- **Procedure notes customization**: Pilot customizable features **should** allow pilots to filter notes. Such filtering would make accessing the notes more intuitive for the pilot and ensure a way to place a few important notes directly on the navigation display or in a pre-defined display area.
- **Flightcrew interaction:** When appropriate IFR procedures and transitions are selected through the FMS, all other transitions for electronic information charts **should** be automatically deselected in the FMS and suppressed on the displays.
- **Off-screen display**: Off-screen transition chart elements **should** be displayed and easily identified by the pilot.
- If the pilot is operating at lower map ranges and the NEXT waypoint, turn, altitude, etc. are off-screen, these data **should** be parked at the display edge.
- **Compatibility with flight deck systems**: Electronic information chart display elements **should** be consistent with other systems for color, menu design, and symbology. Symbology in the chart data (e.g., NAVAIDS) and symbology produced by the navigation system **should** be the same.
- **Potential for error**: The presentation of chart data **should** not conflict with the presentation of FMS route data. For instance, differences may occur in how the FMS calculates route course and distance. The FMS calculation of course and distance may differ from the chart data. This difference should be visually clear to the flightcrew. Although pilots are generally aware of these differences, their presentation in the display system may carry more 'weight' and bias the crew into thinking the differences are due to display calculations. Also, chart data should not conflict with other data presented on the PFD or MFD. That is, the chart data should not render some other higher priority object unreadable (e.g., aircraft position).

CONTRIBUTION TO NEXTGEN OPERATIONAL AND CERTIFICATION APPROVAL GUIDANCE

The study results contribute to the development of operational and certification approval guidance in the future Next Generation Air Transportation System (NextGen) airspace environment. Our considerations for these two areas are summarized below.

1. Operational approval for electronic information charts:

- The electronic information chart display clutter and flight deck integration issues identified through literature review, human factors analysis, and pilot evaluations will be helpful for developing operational guidelines for electronic information charts in the NextGen environment. They are likely to have significant impact on flight deck design and flightcrew interaction with electronic information chart displays.
- We developed conceptual examples of solutions to electronic information chart display clutter and flight deck integration issues. In designing the concepts, we accounted for information/display elements (e.g., weather, traffic) and concepts of operations (e.g., CPDLC, D-NOTAMS) that will be operational in the NextGen environment. Pilots may have to obtain these information elements from a number of different sources and mentally combine them. The workload and situation awareness impacts on the flightcrew will become even more difficult to cope with in the NextGen environment because information automation will trigger dynamic changes in displays and more frequent updates. With these factors in mind, we developed concepts for categorizing and prioritizing chart information so that the most relevant and task-appropriate information can be presented at any time through one application.
- We made recommendations for developing usable and acceptable electronic information charts. The information categorization and prioritization approach and results can become a template for NextGen flightdeck displays that present appropriate information at the right time to the crew. The design concepts could also help improve electronic information chart displays and their integration with other flight deck systems.
- The recommendations and concepts introduced here will help ameliorate complexity, density and clutter of RNAV/RNP chart data.

The recommendations and concepts introduced will help ameliorate complexity, density and clutter of RNAV/RNP chart data.

2. **Certification for electronic information charts:**

- The utility of electronic information charts will increase as the FAA transitions to future operations envisioned for the NextGen system, such as performance-based navigation (PBN) airspace, that involve more complex and precise operations (for example IFR procedures). FAA Aircraft Certification will be increasingly involved in scrutinizing electronic information charts software products as they are implemented on installed avionics equipment. The FAA could use our recommendations to determine electronic information chart criteria to help evaluators identify operationally unsuitable versions.
- Advisory circular AC 25.1302-1, which provides guidance for design and compliance methods for equipment that flightcrew use on transport airplanes, is applicable to electronic information charts software as implemented on installed avionics equipment. The guidance provided by this AC is intended to minimize design-related errors and to enable the flightcrew to detect and manage errors that do occur. It is relevant to the design and development of electronic information charts because, as their complexity increases, the level of scrutiny, rigor and thoroughness of means of compliance with the regulation is expected to increase. Two main issues expand on the implications of 25.1302 for electronic information charts.

Advisory circular AC 25.1302 provides guidance for the design and methods of compliance for installed equipment on transport airplanes. It is also applicable to electronic information charts software as implemented on installed avionics equipment. Its guidance is intended to minimize design-related errors and enable the flightcrew to detect and manage errors that do occur. As complexity increases, the level of scrutiny, rigor and thoroughness of compliance with the regulation will also increase.

- Complexity: Electronic information charts will be highly complex due the number of interconnections with other systems and functions, the amount of information the pilot needs to process in using the system, and the variety of input/display methods. For example, a DDC chart database, having its own cycle, interacts with the FMS and displays chart data on the NAV display and is collocated on the display with other map layers such as WX, TERR, TCAS, FMS, etc.
- Level of systems integration: Integration generally goes hand-in-hand with the level of complexity, and the issues and implications are similar. Electronic information charts, which are highly integrated with other flight deck systems, are likely to have multiple sources of information, each with potential inaccuracies and synchronization problems. The multiple information dependencies require a high level of assessment for compliance, including issues such as consistency of symbology. Electronic information charts have two specific issues of concern that relate to this aspect of 25.1302. One issue is the symbology used in chart data and NAV data symbology that already exists on OEM platforms or NAV displays. The second area of concern is that the overlay of chart database data (courses, altitudes, distances, etc.) may be conflict with FMS calculated data that is also displayed adjacent to the chart data.

- Electronic information chart applications are likely to include novel features and interactions, introducing new human factors issues that should be evaluated. When this is the case, several means of compliance (MOC) should be considered. For many human factors issues and requirements, such as showing acceptable workload and situation awareness, there is no good substitute for the rigor of results from human-in-the-loop (HITL) studies designed to evaluate integrated, full-mission crew performance under normal and off-nominal situations. On the other hand, the ability to analyze a wide breadth of issues and manipulate a variety of parameters becomes more difficult with HITL evaluations. Therefore, the FAA should consider a combination of appropriate MOCs to support electronic information chart certification approval. The display concepts we have developed as part of this study, if fully developed, could be suitable as a test bed. As such a test bed tool, it could be used to generate certification approval checklists and guidelines for finding compliance to regulations/requirements relating to generalizable applicable issues relevant to electronic information charts, such as: display clutter, database validity and information quality, complexity of displayed information and prioritization of information for layering.

FUTURE RESEARCH NEEDS

Simulator Evaluations: We recommend full software, high-fidelity implementations of the data-driven chart concepts, declutter concepts and presentation of procedural notes described in this study in order to access MOCs, develop checklists, guidelines, and requirements to help certification approval evaluators of electronic information charts. Simulation will also support a full mission study in a Part 25 airframe configuration to identify human factors, operational, and certification issues associated with electronic information charts. Using representative scenarios and manipulation of electronic information chart experimental conditions, an HITL study will help to generate data that supports the development of generalizable electronic information chart certification checklists, requirements and guidelines relating to:

- Categorizing levels of electronic information chart display clutter
- Specific range-related requirements for declutter
- Impact of electronic information chart complexity on pilot performance
- Validation of levels of criticality of electronic information layers
- Information automation issues relating to electronic information charts: distraction, information quality, skill degradation and trust
- Identification of potential for error in using electronic information charts

Our recommended information categorization and prioritization approach and results can become a template for NextGen flightdeck displays that present appropriate information at the right time. The design concepts could also help improve electronic information chart displays and their integration with other flight deck systems.

- Access and usability of procedural notes

The evaluations will also validate and iterate the recommendations and guidelines we developed in this study.

Integration with Portable Electronic Devices: Many, if not all, of the data-driven chart concepts described in this paper can be exported to EFB applications. Because EFBs are often side mounted, however, electronic information chart access, presentation, ergonomics, and crew procedures for EFBs may differ from front displays of chart data as described in this paper. We recommend future research on these differences so that display and control concepts can be used consistently across the flight deck. We also recommend conducting research to compare flightcrew performance with data-driven charts in either the EFB or installed front flight deck displays.

Evaluate HF issues with the flight deck implementation of D-NOTAMS: The presentation of digital notices to airmen (NOTAM) on the flight deck raises some of the same issues as the presentation of chart notes. Considerations should include filtering and integration of digital NOTAM information about facilities that are closed or out-of-service with other displayed information, as well as the integration of digital NOTAM information with chart notes and automatic terminal information service (ATIS) information. These information sources are all highly correlated, and although flightcrews deal with them independently, digital cockpits allow merging and integration of information sources. Research is needed to verify the anticipated benefits of such integration on flightcrew workload, situation awareness, and potential for error.

Survey OEM philosophy on integration of chart data with map layers: Although different original equipment manufacturers (OEMs) have different schemes for layering information on navigation displays, creating a new layer for chart data increases the complexity and potential for clutter. While this project addressed the issue of clutter, the issue of information prioritization should be suitably explored in a part task HITL study under realistic scenario conditions. Such a study should address certification approval guidance, operational approval guidance, and HF design recommendations related to MOC with FAA regulation 25.1302.

Database synchronization and accuracy: The chart data presented on the front displays from the chart database is highly correlated with the data presented by the FMS from the FMS navigation database. Industry trends suggest that these two databases could be merged in the near future. This merger would have obvious cost savings for database subscription and reduced maintenance down time for database loading. However, we recommend exploring issues around the validation and verification of data necessary for the IFR procedures. Also, not all chart data is used for navigation; notes, expect altitudes, expect speeds, condition based minima, etc. will make the merger of the two databases complex. There is the potential for compatibility issues between the two databases. Currently, DDC is based on IFR procedures only (arrivals, approaches, and departures) and not IFR high and low enroute.

Chart complexity: Chart complexity includes display characteristics such as the quantity of information (number of elements), the variety of elements (diversity in the types of information presented), and display dynamics. The concepts presented in this paper (for example decluttering schemes) are ways and means of reducing chart complexity. More formal and operational studies, including information theoretic approaches with techniques and metrics for determining complexity of display, should define the categorization of different levels of complexity of electronic information charts and their impact on pilot performance, including potential for inducing pilot error. This research will help certification evaluators determine appropriate levels of scrutiny and MOCs for requirements.

Develop recommendations for inspector guidance: Conduct studies to develop specific evaluation guidance for aviation safety inspectors who will operationally approve use of DDC and who will conduct safety oversight surveillance of operators who are approved for use of DDC.

Develop government/industry standards for DDC standardized functions: establish meetings to achieve government/industry consensus, including specific guidance for research to identify flightcrew performance and workload effects of alternatives under consideration.

Incorporate DDC operational guidance into AC 120-64 (Operational Use & Modification of Electronic Checklists). Further develop AC 120-64 to incorporate DDC operational guidance to guide applicants and inspectors who will make the operational approval decisions and to use material developed under this contract in the operational guidance section to develop a new OPSPEC for DDC.

Add DDC line check and route check operational guidance to FSIMS Order 8900.1 [Cockpit Enroute Inspection Vol 6: Chap 2, Section 9]. The DDC operational guidance is summarized as follows: DDC Operating experience, line checks, and route checks. Check airmen should routinely incorporate proper data-driven charts use as discussion, demonstration, or evaluation factors to satisfy requirements of 14 CFR Part 121, when aircraft equipped with data-driven charts are used for line checks, route checks, or in conducting operating experience.

Declutter menus for DDC chart data should be intuitive and easily manipulated. The pilot must be able to comprehend the textual or symbolic meaning of the chart data that is being selected and/or deselected. Future research, conducted with empirical pilot in the loop simulations should be performed to address the categorization, menu hierarchy, menu navigation and naming conventions so that updates to AC 25-11A (electronic flight deck displays) can be made. Declutter menus for data-driven charts have the potential of grouping and categorizing hundreds of individual chart elements. Thus, simplicity and intuitiveness are necessary to prevent undue pilot workload and confusion.

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1. INTRODUCTION

1.1. ELECTRONIC INFORMATION CHARTS

Flight deck design has been evolving, integrating more new technology into forward display systems. Although the form, fit, and function of legacy aircraft initially drove new functionality to peripheral auxiliary displays (i.e., electronic flight bag (EFB)), new production aircraft generally incorporate new functions such as electronic chart displays and controls within the modular architecture of the front display units.

The utility of electronic information charts will increase as the Federal Aviation Administration (FAA) transitions to operations envisioned in the Next Generation Air Transportation System (NextGen), such as performance-based navigation (PBN) airspace, involving more complex and precise operations (for example IFR procedures), more highly automated and complex systems, and increased flightcrew tasks and responsibilities (Chandra, Grayhem, & Butchibabu, 2012).

Instrument flight rule (IFR) charts can be very detailed, having large quantities of symbols, lines, text, and notes. Chart information must be easily accessible, easily verified against the chart database, and presented in a manner that allows the pilot to use the information as intended (e.g., strategically, tactically, or in a briefing mode).

This project investigated how to integrate IFR chart data into an avionics suite using a concept called "Data Driven Charts." The integrated chart data will be available on the flight deck forward displays such as the primary flight display (PFD), multi-functional display (MFD), and vertical situation display (VSD). Integration should be such that the pilot could fly a procedure without referring to a paper chart or electronic fixed chart viewer. The advantage and power of data-driven charts is that the chart symbology can be mission-specific, making it possible to show only chart data relevant to the mission, conditions, and procedure. Designs can use powerful, pilot-customizable decluttering methodologies. Data in electronic information charts can be layered with other map information such as terrain, weather, traffic, and/or FMS flight plan data.

This project investigated how to integrate IFR chart data into an avionics suite, making it available on the flight deck forward displays such as PFD, MFD, and VSD. The integration should be such that the pilot could fly a procedure without referring to a paper chart or electronic fixed chart viewer.

The advantage and power of data-driven charts is that the chart symbology can be mission-specific, making it possible to show only chart data relevant to the mission, conditions, and procedure.

As with other new flight deck technology, human factors research helps us to better understand, assess, and improve electronic information charts. The human factors issues relate to current and future electronic information chart functionality including pilot interaction and customization, integration into/with flight deck systems, and information display (amount, format and layering). Other issues include display design, declutter, certification, and operational usage of such systems. Based on AC 25.1302-1 - Installed Systems and Equipment for Use by the Flightcrew, we expect the level of certification scrutiny to increase as electronic information charts become more integrated into conventional flight deck systems (installed avionics equipment) and as their complexity increases.

Little human factors research discusses the depiction of advanced PBN procedures; however, a report by Butchibabu and Hansman (2012) attempts to answer questions and make recommendations related to the development and usage of electronic information charts. The research team implemented conceptual designs for evaluating flightcrew acceptability and for identifying potential issues early in chart development.

Most flight deck charts today (2013) are presented on paper or in an electronic fixed chart viewer (on a portable electronic display (PED) — for example, EFBs, iPad, or display unit window). A full electronic information chart can replace a paper chart (Chandra & Herschler, 2012). However, the evolutionary trend for flight decks has been toward integrating IFR procedural chart data with the flight deck forward displays such as the PFD, MFD and VSD. To achieve such integration, graphic modules access an on-board chart database to present IFR procedural data on the front displays of the flight deck. The onboard chart database can contain all departures, arrivals, and instrument approach procedures for all airports worldwide. Within the chart database, all chart symbols and text are stored as digital chart elements. These chart elements can then be manipulated and shown on the front displays. The chart data can be customized by the pilot or by onboard automation using available data on aircraft position relative to the stored active flight plan and other such status information. These types of integrated charts are known as data-driven or electronic information charts and are currently in development within the industry. The major advantage of data-driven charts is that the chart symbology can be layered with other navigation displays such as terrain, weather, traffic, and/or FMS flight plan data.

1.2. OBJECTIVES AND SCOPE

The purpose of the study was to develop recommendations for managing display complexity with electronic chart information on NextGen flight deck information displays. To develop these recommendations, the study team investigated the following objectives, in line with FAA NextGen Human Factors Division R&D planning for support of NextGen Instrument Procedures (Chandra & Herschler, 2012).

- Electronic information chart usability:
  - Procedural notes
  - Clutter management
  - Seamless transition to between continuous electronic information charts
  - Compatibility with flight deck systems
  - Allocation of chart data across flight deck
  - Integration with map layers, FMS Data
  - Requirements for new MFD symbology
- Recommended human factors guidance for operational approval
- Recommended human factors guidance for certification approval of flight deck systems

The study involved both analytical and empirical methods to answer the research objectives including:

- Reviewing related literature, industry and regulatory standards
- Conducting a card sorting exercise to gain subject matter expert opinions for information organization/grouping
- Developing declutter mechanisms
- Developing display prototypes for procedure notes depiction based on HF design principles
- Conducting a heuristic evaluation with pilots to assess the electronic information chart design concepts

The scope of the study was limited to the development of low-fidelity prototypes of design concepts to demonstrate usability and to help identify potential human factors issues. We made the following design assumptions:

- Dual pilot operations, although we considered and discussed issues that could be associated with single pilot operations.
- Conventional flight deck display and control hardware and software configuration: PFD, MFD, keyboard, and CCD.
- EFB equipage is not considered for the electronic information charts.
- Certified on-board chart database is available.
- Electronic fixed chart viewer is available.
- Dual flight management system is in use.

The following subsections provide background information and context to study objectives.

1.2.1. Electronic Information Chart Usability

ISO 9241- Ergonomics of human-system interaction - defines usability as the effectiveness, efficiency, and satisfaction with which specified users achieve specified goals in particular environments. Based on this definition, measures of effectiveness include task completion and achievement of intended tasks. Metrics for efficiency measure how much effort users require to complete tasks, while satisfaction is mainly measured through subjective feedback. Specific metrics for chart usability along these dimensions include: task times, task completion, workload, errors and pilot acceptability ratings.

The usability of electronic information charts is affected by many different design decisions that are made by chart designers (e.g., how to name and access the charts, how to zoom/pan, how to configure the data, how to change scales, declutter methodology, integration with FMS data and other map layers such as terrain, weather, traffic, etc.).

1.2.2. Procedural Notes

Depiction of procedural notes affects several human factors considerations including perception, readability, situation awareness, and decision making. As a result, it impacts the effectiveness of electronic information charts. For example a Volpe study by Butchibabu, Midkiff, Kendra, Hansman, and Chandra (2010) reported that in many Aviation Safety Reporting System (ASRS) voluntary pilot reports, pilots stated that they were confused by the text descriptions of procedures that accompany the visual depiction.

1.2.3. Clutter Management

We expect that in an integrated flight deck, electronic information charts would increase the number of layers and amount of information available for display on the limited display space that is available. Reducing the workload in accessing the extensive, layered information on flight decks will require decluttering methods that can remove unimportant information from displays. To declutter displays appropriately, we considered the criticality of information so that information required to perform tasks is always available. We derived recommendations for decluttering displays by evaluating what works well in existing integrated flight deck displays. By reducing workload, DDC helps address "Finding #10" of Abbott, McKenney and Railsback (2013). Finding #10 states that flight deck task/workload management continues to be an important factor affecting flight path management.

> *Decluttering techniques for removing unimportant information from displays will reduce the workload involved in accessing the extensive, layered information on flight decks.*

1.2.4. Transition to Continuous Electronic Information Charts

The *Human Factors Research Plan for Instrument Procedures* (Chandra & Herschler, 2012) states that many types of paper charts (e.g., high and low altitude instrument-flight-rules charts, airport diagrams, approach charts, arrival charts, and departure charts) focus on specific types of operations. Electronic information chart data can be used to transition seamlessly between the data contained on different types of charts as the flight progresses through the applicable airspace and procedure for that chart data. It is important to understand how current uses of different chart types can inform the development of recommendations for displaying electronic

Figure 2. Example of digitized paper charts displayed on a tablet computer

information chart data. In this study, we sought and analyzed data to determine:

- Do pilots mentally separate chart types and if so, does that separation impact workflow?
- Do pilots expect specific types of data, based on chart type or phase of flight?

1.2.5. Compatibility with Flight Deck Systems

We analyzed the compatibility of chart information with other flight deck information. For example, chart data will have its own on-board databases. The flightcrew must verify database currency and accuracy in the same way as they access and check other on-board databases.

Chart data presentation should not conflict with the presentation of FMS route data. For instance, the FMS may calculate route course and distance differently, resulting in calculations that differ from the chart data. This difference should be visually clear to the flightcrew.

In considering the presentation of chart data, we concluded that it should not conflict with the presentation of FMS route data. For instance, the FMS may calculate route course and distance differently, resulting in calculations that differ from the chart data. This difference should be visually clear to the flightcrew. Within the rendering of chart data on the display, the pilot should be able to visually distinguish electronic chart information from FMS-generated chart information.

Flight deck compatibility also calls for consideration of reversionary modes if the display unit (DU) on which chart data is presented should fail. Reversionary modes typically collapse information into available display areas when there is a partial or full failure of the DU. Reversionary display modes are based on a design philosophy for the entire flight deck display suite. What information is displayed and how it is displayed is determined by criticality of the information. Criticality is determined by aircraft design regulations and guidance, and industry guidance documents. For a paperless cockpit, charts must always be accessible to the flight crew by some means such as data driven charts on the front display, fixed chart viewer, EFB, portable electronic device [14CFR 91.503: Flying equipment and operating information].

1.2.6. Allocation of Chart Data across the Flight Deck

We used pilot structured walkthroughs, card sort techniques, and other expert opinions and analytical methods to determine if some of the chart information can or should be allocated to other display areas such as the VSD and PFD. For instance, it may make sense to allocate MDA/DH, altitude restrictions and missed approach information to the PFD. This may improve pilot situation awareness and reduce instrument scan workload for the final approach segment for the flying pilot. Recommendations in this regard are included in Section 5.2, Chart Declutter.

1.2.7. Operational Guidance

We reviewed existing advisory circulars (e.g., AC 120.70B: Operational Authorization Process for use of Data Link Communication System; AC 120.74B: Parts 91, 121, 125, and 135 Flightcrew Procedures During Taxi Operations; 120.76B: Guidelines for the Certification, Airworthiness, and Operational Use of Electronic Flight Bags; AC 120.64B: Operational Use & Modification of Electronic Checklists), industry guidance, and lessons learned from related internal programs (e.g., Honeywell Data-driven Charts program) to examine operational issues and solutions for electronic information charts in integrated cockpits. Topics reviewed included:

- Defining operational issues such as chart database identification and verification
- Verification of displayed chart against the selected FMS procedure
- Crew actions with electronic information chart annunciations
- Normal and non-normal operations
- Areas of operation (phase of flight)
- Limitations (with chart data display of procedures)
- Crew qualification
- Intended function of chart features
- Operational concept
- Crew procedures (standard operating procedures (SOP)

1.2.8. Certification

We reviewed regulatory and industry requirements, standards and guidelines that might impact recommended guidance for design approval of electronic information chart displays, which included:

- RTCA minimum operation performance specifications (MOPS)
- SAE (Aerospace Recommended Practices) ARPs
- Title 14 Code of Federal Regulations, Aeronautics and Space and Advisory Circulars
- Technical papers (NASA, Boeing, NASA, MIT, VOLPE)
- Lessons learned from Honeywell's Data-driven Charts (DDC, internal R&D) development program and certification efforts
- Human factors certification plan for Honeywell's DDC program

1.2.9. Contribution to NextGen Operational and Certification Guidance

The study results contribute to the development of recommendations for operational approval and certification approval guidance in the NextGen National Airspace System (NAS) environment. Our considerations for these two areas are summarized below.

1. Operational approval for electronic information charts:

   - The electronic information chart display clutter and flight deck integration issues identified through literature review, human factors analysis, and pilot evaluations will be helpful for developing operational guidelines for electronic information charts in the NextGen environment. They are likely to have significant impact on flight deck design and flightcrew interaction with electronic information chart displays.
   - We developed conceptual examples of solutions to electronic information chart display clutter and flight deck integration issues. In designing the concepts, we accounted for information/display elements (e.g., weather, traffic) and concepts of operations (e.g., CPDLC, D-NOTAMS) that will be operational in the NextGen environment. Pilots may have to obtain these information elements from a number of different sources and mentally combine them. The workload and situation awareness impacts on the flightcrew will become even more difficult in the NextGen environment because information automation will trigger dynamic changes in displays and more frequent updates. With these factors in mind, we developed concepts for categorizing and prioritizing information layers in electronic information charts so that the most relevant and task-appropriate information can be presented at any time through one application.
   - We made recommendations for developing usable and acceptable electronic information charts. The information categorization and prioritization approach and results can become a template for NextGen flightdeck displays that present appropriate information at the right time to the crew. The design concepts could also help improve electronic information chart displays and their integration with other flight deck systems.
   - The recommendations and concepts will help ameliorate complexity, density and clutter of RNAV/RNP chart data.

Our recommended information categorization and prioritization approach and results can become a template for NextGen flightdeck displays that present appropriate information at the right time. The design concepts could also help improve electronic information chart displays and their integration with other flight deck systems.

2. Certification approval for electronic information charts:

   - The utility of electronic information charts will increase as the FAA transitions to future operations envisioned for the NextGen system, such as performance-based navigation (PBN) airspace, that involve more complex and precise operations (for example IFR procedures). FAA Aircraft Certification will be increasingly involved in scrutinizing electronic information charts software products as they are implemented on installed avionics equipment. The FAA could use our recommendations to determine electronic information chart criteria to help evaluators make certification approval determinations.

- Advisory circular AC 25.1302-1, which provides guidance for design and compliance methods for equipment that flightcrew use on transport airplanes, is applicable to electronic information charts software as implemented on installed avionics equipment. The guidance provided by this AC is intended to minimize design-related errors and to enable the flightcrew to detect and manage errors that do occur. It is relevant to the design and development of electronic information charts because, as their complexity increases, the level of scrutiny, rigor and thoroughness of means of compliance with the regulation is expected to increase. Two main issues expand on the implications of AC 25.1302-1 for electronic information charts.

Advisory circular AC 25.1302 guides the design and methods of compliance for installed equipment on transport airplanes. It is also applicable to electronic information chart software as implemented on installed avionics equipment. Following its guidance should minimize design-related errors and enable the flightcrew to detect and manage errors that do occur. As complexity increases, the level of scrutiny, rigor and thoroughness of compliance with the regulation will increase.

  - Complexity: Electronic information charts will be highly complex because of the number of connections with other systems and functions, the amount of information the pilot needs to process in using the system, and the variety of input/display methods. For example, a DDC chart database, having its own cycle, interacts with the FMS and displays chart data on the NAV display and is collocated on the display with other map layers such as WX, TERR, TCAS, FMS, etc.
  - Level of systems integration: Integration generally goes hand-in-hand with the level of complexity, and the issues and implications are similar. Electronic information charts, which are highly integrated with other flight deck systems, are likely to have multiple sources of information, each with potential inaccuracies and synchronization problems. The multiple information dependencies require a high level of assessment for compliance, including issues such as consistency of symbology. Electronic information charts have two specific issues of concern that relate to this aspect of 25.1302. One issue is the symbology used in chart data and NAV data symbology that already exists on OEM platforms or NAV displays. The second area of concern is that the overlay of chart database data (courses, altitudes, distances, etc.) may be conflict with FMS calculated data that is also displayed adjacent to the chart data.

- Electronic information chart applications are likely to include novel features and interactions, introducing new human factors issues that should be evaluated. When this is the case, several means of compliance (MOC) should be considered. For many human factors issues and requirements, such as showing acceptable workload and situation awareness, there is no good substitute for the rigor of results from human-in-the-loop (HITL) studies designed to evaluate integrated, full-mission crew performance under normal and off-normal situations. On the other hand, the ability to analyze a wide breadth of issues and manipulate a variety of parameters becomes more difficult with HITL evaluations. Therefore, the FAA should consider a combination of appropriate MOCs to support electronic information chart certification. The display concepts we have developed as part of this study, if fully developed, could be a test bed. Future research could generate recommendations for certification checklists and guidelines for finding compliance with regulations and regulatory guidance. The recommendations could address generalizable issues relevant to electronic information charts such as: display clutter, database validity and information quality, complexity of displayed information and prioritization of information for layering.

2. LITERATURE REVIEW AND STATE OF THE ART

The section describes our review of applicable Title 14 CFRs, Advisory Circulars, published scientific literature, industry and academic research regarding the integration of procedural chart data with aircraft displays (primarily moving map displays). In the review, we sought information on the state of the art in each research area, implications of existing work that might have implications for the development of recommended guidance for certification approval of electronic information chart data, and gaps and/or areas for future research. The results are summarized in the following subsections.

2.1. TYPES OF ELECTRONIC INFORMATION CHARTS, INTENDED FUNCTION AND BENEFITS

An early research program studying the development of electronic information charts was conducted by the Volpe National Transportation Systems Center (Hannon & Huntley, 1995). A key finding of this early research suggests that electronic map displays may best benefit pilots by providing information that improves situation awareness. This information provides an early indication of the intended function or benefits of electronic information charts on the flight deck. In their study documenting a user-centered survey and interviews that analyzed the information content of (then) current instrument procedures (IP), Hansman and Mykityshyn (1995) identified benefits of electronic information charts for both precision and non-precision IP formats. The vast majority of the respondent group (70%) favored electronic replication (pdf-type paper replica) of current IP formats.

Apart from the IP format, electronic information charts come in a variety of forms, and Chandra and Grayhem (2012) described the differences between the categories of electronic information charts. The first category they covered was scanned copies of paper charts that are "pre-composed" (i.e., not interactive, other than in that they can be zoomed and panned). The second category of electronic information charts was data-driven. These charts were highly customizable and could be created and modified in real-time.

We found that data-driven charts have a specific advantage for the flightcrew. They can be customized to correspond to the planned route of flight in the FMS, whereas digitized images of paper charts cannot. Chart data that are unrelated to the route of flight can be suppressed to reduce display clutter. We found that data-driven charts will support a number of significant changes, such as the integration of different chart types (en route, arrival, and departure) into a single electronic product that allows selective display of data based on the location of the aircraft.

The third category is the integration of more chart information onto installed flight deck displays such as the moving map display. This last category was the focus of the present study.

The operational goal of electronic charts is to improve the efficiency and safety of flight operations (Yeh & Gabree, 2010).

The operational goal of electronic information charts is to improve the efficiency and safety of flight operations (Yeh & Gabree, 2010). Although one electronic information chart function is to provide information required for navigation, it is not intended to supplant the aircraft's primary navigation display (SAE ARP5621[5]). The definition of intended functions is important because it is the basis for showing or finding compliance with regulations and standards (e.g., 14 CFR 25.1301, 25.1302). Some anticipated benefits of using electronic information charts listed in Yeh and Gabree (2010) include:

- Increased position awareness.
- Reduction in pilot deviations.
- Increased ability to detect data entry and flight planning errors.
- Reduction of runway incursions and collisions at controlled airports.

[5] SAE ARP 5621 was developed prior to the revision of SAE ARP 5289A, which specifies symbols for electronic displays. SAE ARP 5621 was not coordinated with the FAA, and its guidance may conflict with FAA regulatory and guidance material.

Data-driven charts are described in an industry article by Ellerbrock and Haffner (2012) as improving safety margins, reducing pilot workload, and providing greater operating efficiency. It also lists other advantages of electronic information charts, including:

- Data-driven charts enable information readability and usability across a broad range of map scales.
- Data-driven charting requires significantly less storage capacity than pre-composed images.
- Digitally enhanced full-color, high-quality, vector-based data with zoom and pan features allow greater detail to be rendered on the EFB display.
- Search functionality allows immediate access and display of a needed chart feature, such as an airport, navigational aids, or waypoint.
- Flightcrew members can more easily collaborate and share information.
- Pilots can choose what flight data is displayed, including airports, airways, waypoints, navigational aids, airspace, and terrain information, allowing for an individualized, dynamically rendered on-screen presentation that best supports the task at hand.

The anticipated benefits related to these advantages include:

- Safety. Data-driven charts support safety objectives by improving situational awareness through the availability of more complete and timely information about the airplane's navigation, weather, terrain, and traffic situation—including during ground operations.
- Reduced workload. By providing flightcrews with charting and other relevant flight information in one place, the electronic information charts eliminate the need to carry and sort through large amounts of unlinked printed information.
- Operational efficiency. By replacing paper charts, electronic information charts provide operators with real-time route planning capabilities, and deliver intelligent information when and where it is needed to streamline onboard operations, reduce fuel burn, reduce delays, and improve on-time performance.

Despite the potential benefits, electronic information charts have potential human factors challenges to overcome. A substantial number (93%) of pilots surveyed in a study felt specific kinds of flightcrew error might be attributed to charting considerations (Hansman & Mykityshyn, 1995). Yeh and Gabree (2010) corroborate the potential for flightcrew error and suggest that the presentation of electronic information charts on the flight deck raises a number of human factors issues that must be addressed:

- Clarity of the information.
- Hierarchy of information.
- (Automatic) ranging.
- Symbology.
- Layering and searching information.

2.2. ELECTRONIC INFORMATION CHART USABILITY

A human factors issue which needs to be brought to the forefront in the study of electronic information charts is the prioritization of information on a shared display (i.e., one that supports additional applications). As more chart and procedural data are integrated into the flight deck, the placement of that information, potentially across more than one display, must be explored so that information is easily accessible and integrated when necessary (Chandra & Grayhem, 2012).

As more chart and procedural data are integrated into the flight deck, the placement of that information, potentially across more than one display, must be explored so that information is easily accessible and integrated when necessary (Chandra & Grayhem, 2012).

Other electronic information chart research areas include decluttering of moving map displays and integration of chart and procedure information onto moving map displays (Chandra & Grayhem, 2012). It is also important to understand the impacts of transitioning continuously between different charts and scales (e.g., from departure to en route operations), to ensure that the appropriate information is displayed during each phase of flight.

Procedural notes (text descriptions of the routes, restrictions, or contingency procedures included in charts) present unique human factors challenges. The concern about notes is that they can be lengthy and repetitive. According to Chandra et al. (2012), previous research shows that many notes contain information that is perceived as unusual and unimportant, but, based on FAA standards for procedure designers (see the FAA 8260 series Orders), they are required to be included in the instrument procedure. Nonetheless, some notes contain critical information that the pilot may need to execute the procedure or to inform decisions involving flight safety.

Another concern with notes is that their sheer volume may make it more difficult for the flightcrew to quickly find those that are of immediate concern. An example of low priority notes cited in the report are departure procedure notes that convey information that is already depicted graphically. Another example is notes that inform the pilot of nearby obstacles relevant to a takeoff procedure (e.g., tall trees or structures that affect minimum climb gradients). However, in our opinion, this last example may not always be low priority, since departure-obstacle notes may have a high priority in the planning for a missed approach.

Also related to usability, some studies discuss design recommendations to improve the design of charts so that there is a reduced likelihood of errors by the flightcrew. For example Navtech and Lufthansa Systems/Lido (Chandra et al., 2012) are two chart systems that optimize the actual text of the notes on arrivals and departures using brief descriptions with minimal words to improve usability. The Jeppesen method arranges and places the notes within the graphic page, numbering notes clearly so that their location corresponds to the correct portion of the path. We did not find a study comparing either Navtech or Lufthansa to FAA's North American National Aeronautical Charting Office (NACO) charts.

DDC should enable flight crew awareness at all levels of situation awareness (SA) as described in SA taxonomy to minimize potential for errors. Three levels of situation awareness are generally described in SA taxonomy: perception, comprehension, and projection. Perception is the basic level (1) of situation awareness and is achieved if operators are able to perceive information that is needed to perform intended or required tasks. Comprehension, which is the next level (2) of awareness, involves combining different information elements, interpreting information correctly, storing and retaining information. The third level (3) of awareness, projection, is the ability to forecast future situation events and dynamics based on the current situation. A study by Jones and Endsley (1996) reported that observed errors were predominantly Level 1 situational awareness errors. Consistent with the perceptual requirements of this level of SA, these errors occurred when relevant data was not available, when data was hard to discriminate or detect, when a failure to monitor or observe data occurred, when presented information was misperceived, or when memory loss occurred. We believe that digital chart data could mitigate these sorts of errors, if appropriately integrated with other displayed navigation information for the flightcrew. Information should be easy to find and easy to read. Information critical to the flightcrew tasks should also be salient. This information should be provided when pilots need it; and the pilot should not have to memorize any information, especially flight-critical elements.

The potential for error and human factors issues calls for electronic information chart design that can improve flightcrew error avoidance, detection, and management. An initial design step is to analyze, categorize, and prioritize information that is typically available during flight. In a study reported by Jonsson and Ricks (1995), fifty-two commercial airline pilots participated in tasks that required them to provide similarity ratings for pairs of flight-deck information and then prioritize this information under two separate contexts (without regard to any specific phase of flight and in the context of the takeoff condition of a flight mission). The results suggest three cognitive dimensions that pilots use in categorizing flight-deck information:

1. The flight function that the information is designed to support.
2. The strategic or tactical nature of the information.
3. The frequency of information referral.

The study also identified four high-level categories that pilots use in categorizing flight-deck information. These categories are consistent with the general flight deck function allocation: aviation, navigation, communication, and systems administration.

Another design related study (Butchibabu & Hansman, 2012) investigated human factors issues related to the design and depiction of RNAV and RNP procedures, including highly complex characteristics of procedures, high levels of visual clutter, and increased numbers of paths per chart. It investigated whether depicting procedures across multiple pages improves access to information by reducing clutter. To mitigate increased information density and visual clutter on the RNAV and RNP procedure depiction, the method reduced the number of flight paths shown on a single page by separating the depicted paths onto multiple pages. The study evaluated whether the modified charts would impact information retrieval time and accuracy compared to the charts in current use. Pilots were asked information retrieval questions associated with each chart. Researchers recorded the response time and accuracy with which pilots answered the information retrieval questions. The task was completed for both approaches and departures. Overall question response accuracy for 47 participants was 99.5%. The study found no statistically significant differences in response accuracy between modified and current chart use.

Butchibabu and Hansman (2012) also conducted an extensive literature review of instrument procedure charts in general. In particular, the review looked at what types of information are required and how the information types should be depicted to augment pilot performance. It used examples of metrics and measures for assessing electronic information charts usability and clutter. They implemented and evaluated a paradigm for decluttering electronic information charts. The potential for extending the study includes considerations of representative flight deck tasks for assessment of workload and situation awareness. The study is consistent with the difficulty of finding objective measures for assessing issues relating to electronic information charts such as clutter.

The following human factors for information integration should be considered when developing electronic information charts (Yeh & Gabree, 2010):

- Criticality: charts contain information necessary to conduct flight operations, and their operational use has a direct impact on air safety.
- Consistency: consistent appearance and access to information from one chart to another allows pilots to transition from one chart system to another one.
- Adherence to standards: chart providers must adhere to charting standards (contents and symbology) to maintain consistency across product offerings.
- Clarity: because charts are used in the cockpits under high workload, they should he as clear while providing the required information to accommodate the needs of the pilot.
- Decluttering: to reduce clutter, the amount of information on the charts shall be limited whenever possible.
- Maintenance: charts shall be updated according to the Aeronautical Information Regulation and Control (AIRAC) cycle in order to make sure that the information is up to date.

Tuccio (2012) presents an overview of the chart creation process and regulatory framework along with an examination of the process used to create charted depictions of aviation instrument approach procedures in the United States. The overview highlights the following possible innovations enabled by object-oriented chart rendering:

- Decluttering charts by displaying only the category-related minimums and information of the aircraft (i.e., A, B, C, D, E) being operated rather than all information and excluding the display of ultra- high frequency (UHF) or tactical air navigation system (TACAN) channels for operators who do not need such information.
- Highlighting key features through the use of flashing icons, such as the highest obstacle on the chart or exceptional, key features such as mandatory crossing altitudes.
- Guided approach briefings through timer-based highlighting of information blocks on the chart.
- Interactive display of alternate missed approach procedures, when such information exists in the Form 8260 record.

- Automated update of approach minimums when airport and navigational components are out of service through interoperability with NOTAMS.
- Interactive frequency selection, i.e., touch on a frequency on the mobile device and the frequency is selected on a communication or navigation device.

Pschierer, et al. (2011) describe a conceptual example of a solution to electronic information chart declutter and integration issues. They discuss issues in the Next Generation Air Transportation System (NextGen) information environment. NextGen will engage technologies and associated concepts of operation such as automatic dependent surveillance-broadcast (ADS-B) and performance-based navigation (PBN). These technologies increase flight deck information and the need for information automation. In relation to electronic information charts, the study suggests that pilots now must obtain required information from a number of different chart information sources and mentally integrate the information. The authors suggest that changes in the flight path, more frequent updates of weather, NOTAMs and other information will all combine to require a higher degree of information automation and better information display presentation approaches. To address these considerations, the study authors proposed a concept where all required information could be provided through one flight deck display application. Depending on the phase of flight (taxi- in/taxi-out, departure, enroute, arrival, approach), the display application would select the appropriate information for display, and then seamlessly package it for optimal use. The challenge for the designer and regulator is to determine what information management and display characteristics are necessary to provide just the right amount and kind of information at the right time to the flightcrew.

The authors attribute the increase in number of EFB-based applications to the easier and faster certification process of EFB applications compared to front panel displays and the ease of retrofitting existing cockpits via Class 1 or Class 2 electronic flight bags. The authors also suggest that the trend will continue in the future so that new applications will be introduced on EFBs first, and then become integrated into installed flight deck displays later.

2.3. DECLUTTER APPROACHES USED IN RELATED PLATFORMS AND DOMAINS

We reviewed the scientific literature for other platforms and domains that employ electronic information declutter techniques which might be applied to the flight deck of fixed-wing transport category aircraft.. One example is a study that investigated the effectiveness and usability of a simulated Boeing CH-47 Chinook helicopter's horizontal situation display hover (HSDH) pilot visual interface (Sapp, Jessee, Crutcher, King, & Morris, 2012). It is a permanent flight deck decluttering mechanism and also an electronic information chart usability evaluation. The study compared three HSDH display configurations: (1) the existing CH-47F baseline HSDH, (2) a proposed HSDH redesign, and (3) a default decluttered configuration of the proposed HSDH redesign. Eight career pilots evaluated the HSDH usability under simulated brownout visual conditions for six different hover and landing tasks. Usability was assessed along four dimensions including cockpit visual gaze, aircraft control, pilot workload, and pilot vehicle interface preference for ease of use and effectiveness of information presentation.

Declutter was achieved through the removal of information. The decluttered HSDH removes the torque tape and replaces it with the torque digital readout. The decluttered HSDH also removes the air speed tape. Both of these tapes are still available to the pilot on the vertical situation display (VSD), located on the upper half of the multi-function display (MFD). The ground speed is moved from the bottom of the vertical speed tape to the left side of the center horizontal line to bring it closer to the other important gauges used when hovering or landing.

Crew gaze analyses indicate that the proposed and decluttered HSDH reduced pilots' visual workload compared to the baseline. Aircraft control analyses indicated that pilots overall aviating effectiveness while flying with the proposed and decluttered HSDH. Crews reported that workload demands were at acceptable levels while using the new displays during all mission tasks included in the study. Pilot feedback indicated that the readability of the new display interface was effectively designed and presented. Pilots highly recommended the overall design of the proposed HSDH and voted unanimously for its immediate implementation.

We identified one example in the maritime domain with a novel declutter approach that could be applied in the aviation context (Pfautz, Schurr, Ganberg, Bauer, & Scerri, 2011). Pfautz et al. describe model-driven visualization (MDV) as a novel framework that supports more effective, intelligent user interfaces to improve decision making in complex environments by coupling cognitive and perceptual theories of information processing with advanced artificial intelligence methods. The framework embeds empirical and theory driven approaches for identifying and prioritizing data based on the information requirements and needs of the human decision maker within intelligent agents. The agents automatically deliver and present information based on its likely value using visualizations that best convey that information to the system users. Agents also reason about the user context and constraints, environment, and display to enable a higher degree of personalization within an interactive user interface (e.g., by drawing a user's attention to interesting aspects of the data such as trends, anomalies, and patterns). The study cites examples of objective measures that define clutter based on physical display characteristics, including the size of the display region, target size, local and global density, feature occlusion, number of objects, target background contrast, and the number of active pixels. References to several subjective dimensions of measuring clutter are also identified. Unlike subjective measures that require operator evaluation, the computational approach to determining visual clutter can be integrated into information automation systems to automatically declutter displays. The initially identified groups of objective measures that provide a reliable approximation of clutter under various contexts are the number of tracks, display density, and feature occlusion.

We identified another relevant domain in electronic battlefield maps, which contain information similar to flight deck electronic information charts. Participants in a study (Yeh & Wickens, 2000) viewed electronic battlefield maps containing five classes of information discriminable by three declutter methods. The three methods were compared to assess their potential benefits for accessing information from electronic map displays. The methods were the use of color-coding, intensity coding (i.e., foreground-background contrast in which different domains of information are presented at varying levels of brightness), and decluttering (removal of one domain of information that is not relevant to the current task at hand). The results suggested that the benefits of color and intensity coding appear to be in segregating the visual field rather than calling attention to the objects presented at a certain color or intensity. Decluttering was identified as a disadvantage because the cost of information retrieval outweighed the benefits of presenting less information on the display or even allowing map users to customize their displays. Declutter was implemented by presenting information in the same color and intensity level but with capability for the user to "erase" or display information elements at the user's discretion.

Potential applications of this research include a cost-benefit analysis for the use of three attention filtering techniques and an attempt to quantitatively measure map complexity.

2.4. INDUSTRY EXAMPLES OF ELECTRONIC CHART INFORMATION APPLICATIONS

Our review of the state of the art in electronic information charts investigated current examples of applications. Rockwell Collins' Integrated Flight Information system (IFIS) (Rockwell Collins IFIS, 2007) is intended to replace heavy, bulky printed charts with large-format, high-resolution data-driven electronic information charts. Critical departure, arrival, approach, and airport information are instantly available electronically to the flightcrew. The electronic information charts are described as easy to read and interpret. They also provide the ability to range in or out (unlike paper charts). Other features include display of geo-referenced approach charts and airport charts which embed aircraft position.

Jeppesen's EFB electronic information chart application is a data-driven, enroute charting application. It is notionally identified as not only eliminating the need for cumbersome paper en route charts but also providing operators with real-time route planning capabilities and global positioning system (GPS)-based positional awareness in-flight (Ellerbrock & Haffner, 2012). Jeppesen claims that data-driven charting offers more flexibility and intelligence than pre-composed chart images. Electronic information charts also allow the user to activate or deactivate certain functions and apply filters to control presentation. Within predetermined parameters, users can also manipulate what is displayed on the chart.

Other related applications identified in the review were:

- The Garmin Aera 796 and Aera 795 (Garmin, 2011), are a series of portable aviation navigation devices that include a touchscreen user interface, pilot-selectable screen orientation, and 3D Vision. The Aera 796 also takes the pilot closer to a paperless cockpit with a digital document viewer, scratch pad, and pre-loaded geo-referenced AeroNav IFR and VFR enroute charts.
- iPad applications: Four iPad navigation apps with relevance to electronic information charts were identified:
  - ForeFlight
  - WingX Pro7
  - Garmin Pilot
  - Jeppesen Mobile FliteDeck.

The applications have functionality for electronic IFR charts, VFR charts, and data-driven enroute charts. Even though these applications are hosted on an iPad and take advantage of the touch screen capabilities, we reviewed them to identify potential HF issues that could help in our analysis and concept designs.

2.5. SUMMARY OF LITERATURE REVIEW

The electronic information chart studies identify the potential benefits and intended functions of electronic information charts. The operational goal of electronic information charts is to improve the efficiency and safety of flight operations. Other benefits include reduced workload and improved situational awareness. Despite the suggested benefits of electronic information charts, their human factors issues must be addressed.

> *Based on the review, we conclude that the research objectives of this study can answer significant questions and address the need for recommendations for operational and certification approval guidance for data-driven electronic chart information displays.*

Electronic information chart usability is affected by the organization and presentation of data in the charts. We observed a proportionally high number of studies on clutter management compared to the other research objectives of this study (Section 1.2, Objectives and Scope), notably information prioritization and categorization. In most cases, the studies show user selection/de-selection as the most prevalent method of decluttering. Examples of concepts for decluttering in different environments are also presented.

Based on the review, we conclude that the research objectives of this study can answer significant research questions and address the need for recommendations for operational and certification approval guidance for data-driven electronic chart information displays.

For example, we found only one direct reference related to procedural notes. Use of these notes, however, is a key problem in developing electronic information charts for integrated displays that lack the display qualities and touch screen capabilities of mobile platforms.

In sum, the literature that we reviewed suggests that additional regulatory guidance for manufacturers and FAA flight standards and aircraft certification specialists concerning the recommended minimum characteristics of electronic information charts could be beneficial.

3. DESIGN OBJECTIVES AND METHODS

3.1. DESIGN OBJECTIVES

In this section, we describe the design objectives and methodology used to develop a conceptual electronic information chart prototype for this study. The underlying philosophy for displaying electronic information charts involved high-level human factors considerations guided by design philosophy items in various human factors, industry, and regulatory standards:

The authority philosophy for the application is a fully manual approach, such that the pilot is always in charge and can override any automatic changes.

- **Authority and automation**: The authority to make changes on the display is an important feature, since the intended function of electronic information charts includes the dynamic presentation and modification of information. The authority to make changes can range from fully-automated to fully-manual design. Between the two extremes, is a flexible mode where both the flightcrew and automation can make changes. The authority philosophy that we selected for the application is a fully manual approach, such that the pilot is always in charge and can override any automatic changes. The main rationale for this approach is to make the behavior of the electronic information chart application predictable rather than appear non-deterministic or random. Our approach is consistent with the flightcrew declutter discussion in Yeh, Jo, Donovan, and Gabree, (2013).
- **Symbols and colors:** All electronic information chart symbology should present information quickly to the pilot and minimize head-down time and cognitive workload required to interpret or understand symbols. The color philosophy used in electronic information charts should comply with FAA AC 25-11A Electronic Flight Deck Displays. The symbols and colors were selected to be consistent with existing flight deck conventions and industry recommendations, minimizing potential for conflict.
- **Ease of learning:** To minimize training cost and encourage flightcrew trust in the electronic information charts, the system should support learning by exploration. The menu titles, labels, and prompts (selection options) should be intuitive, easy to learn, and support procedural task performance. With basic knowledge about electronic information charts and computer interaction, the pilot should be able to effectively interact with the display. The ease of learning and using the electronic information chart system should support accessing information on the chart more quickly than when using an equivalent paper chart.
- **Error checking and feedback:** The electronic information chart system should be designed to prevent user errors during the process of selecting information for display. Accordingly, the display should not allow the removal of any critical information which must be presented on the flight deck at all times.
- **Grouping information:** Information layers in electronic information charts should be organized based on SAE ARP5621[6] (2004-11) Electronic Display of Aeronautical Information (Charts) and subject-matter-expert guidance from a policy-capturing exercise. The logical grouping of information should support the flightcrew, as they must build an accurate mental model of the relationships and criticality of electronic information chart electronic elements.

[6] SAE ARP 5621 was developed prior to the revision of SAE ARP 5289A, which specifies symbols for electronic displays. SAE ARP 5621 was not coordinated with the FAA, and its guidance may conflict with FAA regulatory and guidance material.

3.2. PROTOTYPE DESCRIPTION

3.2.1. Clutter Management

The electronic information chart design concept is intended to reduce the time flightcrew members require to identify and interpret electronic information charts by presenting information in a simple and organized way. However, display clutter can work against this objective. The electronic information chart display should allow the flightcrew to use discretion to limit the amount of information presented at any time without losing critical information. It should allow the flightcrew to program (for example during pre-flight) the system to display the most important information all the time and less important information on request.

The electronic information chart design concept is intended to reduce the time required to identify and interpret chart information using a simple and organized presentation. Display clutter can work against this objective.

AC 25-11A defines a cluttered display as one that presents an excessive number or variety of symbols, colors, and/or other unnecessary information and, depending on the situation, in a way that may interfere with the flight task or operation. Title 14 CFR 25.1302 Installed Systems and Equipment for Use by the Flightcrew defines clutter as the presentation of information in a way that distracts flightcrew members from primary tasks. AC 25-11A suggests that a cluttered display causes increased flightcrew processing time for display interpretation and may make it difficult to interpret information necessary to navigate and fly the airplane. Similarly, AC 25.1302-1 Installed Systems and Equipment for Use by the Flightcrew indicates that layering information on a display should not add to confusion and clutter as a result of the color standards and symbols used. AC 25.1302-1 also identifies potential human factors issues with display clutter mitigations. It suggests that display options that automatically hide information to reduce visual clutter may inadvertently hide needed information from the flightcrew. An example of such an approach is the potential use of automatic de-selection of chart data. In these cases, the display system must provide all of the information that the flightcrew needs.

We considered how to provide the necessary information in the display while minimizing clutter. Honeywell Aerospace flight deck user interface design experts brainstormed ideas for a decluttered electronic information chart interface. Declutter methods such as manual ranging were developed to minimize clutter on the electronic information chart display. For example, lower criticality chart information is removed at certain ranges while higher criticality chart information, such as that required for the flightcrew to fly the airplane, is retained. In developing clutter management techniques, we obtained guidance from subject-matter experts in a card sorting task for grouping and organizing information elements. The results of the task guided information prioritization to support decluttering. We used auto and manual ranging mainly to remove or display electronic information chart elements to support decluttering based on information criticality. However, the prototype was designed so that the pilot is always in control and can configure the display as desired.

The notes design concept is intended to ensure that specific notes are placed in an exact area on the moving map or linked to the appropriate areas on the map.

3.2.2. Procedural Notes

SAE ARP 5621[7] differentiates between general notes that apply to the entire procedure and other notes that are specific to a certain area on a chart. The notes design concept for the electronic information charts procedure is intended to ensure that specific notes are placed in an exact area on the moving map or linked to the appropriate areas on the map. We organized and presented notes logically for quick and easy access and

[7] SAE ARP 5621 was developed prior to the revision of SAE ARP 5289A, which specifies symbols for electronic displays. SAE ARP 5621 was not coordinated with the FAA, and its guidance may conflict with FAA regulatory and guidance material.

interpretation of information. A major challenge with the use of color is that colors used in displaying procedure notes must not violate the flight deck color philosophy. Similar to concepts used in displaying CPDLC messages, important components of notes are highlighted (for example using reverse video) to reduce search time for visual elements.

Since notes are textual, the major human factors issue was readability. We used AC 25-11A to guide development of the electronic information charts notes. The main guidance we derived is that, regardless of the font type, size, color, and background used, the foreground text should be readable in all foreseeable lighting and operating conditions from the flightcrew station. Specific guidelines on readability were gleaned from:

- SAE ARP 1093A Numeral, Letter and Symbol Dimensions for Aircraft Instrument Displays
- SAE ARP 4102-7 Appendix B Electronic Display Symbology for EHSI/ND

3.2.3. Continuous Charts

Continuous charts are a key element of an integrated flight deck that features an electronic chart display capability. We used an integrated avionics suite with common displays for FMS, PFD, and MFD. The flight deck configuration did not include peripheral devices for the display of charts, such as EFBs and iPads, which are considered to be portable electronic devices (PEDs). However, the flight deck assumptions included the presence of an electronic fixed chart viewer on the front displays.

The electronic fixed chart viewer is intended for selecting the appropriate chart for the procedure or phase of flight, viewing the charts, briefing, and cross-checking the chart data with FMS entry and display. MFD and PFD presentation of chart data is intended for tactical "go fly" the procedure only. Between the chart data and the FMS programmed procedure, we expect to have adequate navigation data to fly the procedure without reference to the electronic fixed chart viewer. We envision that the requirement for having an electronic fixed chart viewer could eventually be eliminated and that the pilots could brief and fly each procedure using only the data driven charts on the PFD and MFD.

The conceptual boundary between the presentation of chart data and FMS data is blurring.

Chart data presented on the front displays supplements the FMS and other navigation data contained in the ARINC 424 NAV Database. With some exceptions, data on IFR charts resides in the FMS ARINC 424. Those exceptions such as notes, EXPECT ALTITUDES, short range navigation (radials and NAVAIDS, etc.) are the types of chart data that should be used to supplement FMS data, so that all of the information needed to fly the procedure is visible and readable.

The conceptual boundary between the presentation of chart data and FMS data is blurring. For example, when the pilot selects procedures through the FMS to comply with an ATC clearance, the procedure selection is presented as a continuous active flight plan on the navigation display. If the pilot selects [DEP RUNWAY] + [DEPARTURE/SID] + [JET AIRWAY] + ARRIVAL in the FMS, the active flight plan is strung together in a continuous line. There are some exceptions of course when, because of ATC needs, a discontinuity may occur. For instance ATC may assign a different arrival procedure that does not have a transition fix to the enroute flight plan thus causing a discontinuity. When the DDC layer is selected on, DDC will still overlay the chart information on the new assigned FMS arrival procedure (assuming the new arrival procedure is programmed into the FMS). In another case, if ATC directs the aircraft off of the cleared airway, then the electronic presentation of airway chart data, although still displayed if the airway layer is selected to ON, becomes supplemental to navigation awareness since the aircraft is either on vectors for an airway or procedure intercept. Thus, if the aircraft is being vectored for an airway intercept then displaying the airway chart data would be necessary for navigation situational awareness so the pilot can view aircraft position and track relative to the airway to be intercepted. The point here is that ATC clearances may deviate from the charted information. However as long as the ATC deviations from the original clearance includes new procedures

Since notes are textual, the major human factors issue was readability.

that can be programmed into the FMS, then those new procedures (e.g. arrivals, departures and approaches) will be faithfully represented by chart data when the DDC layer is on.

After the flight plan is entered, the pilot can select the chart layer to ON. Selecting the chart layer to ON will add chart data to the existing FMS flight plan. The challenge is to present the chart data so that the pilot can distinguish chart data from FMS data. This distinction is important for a number of reasons, but the most common and salient reasons are the difference between charted course and FMS-computed flight path and also between chart distance between waypoints and FMS-computed distance between waypoints. Chart courses and distances can differ from FMS-calculated values, so it is very important for the pilot to distinguish the two types of data (FMS versus chart data). We even question the worth of putting the chart values on the display. When a pilot sees a 1 or 2 degree difference on the paper or electronic paper chart, it is usually of no human factors concern. But when that difference is presented on the front display, it assumes a greater weight, since the pilot sees the system as producing the value and not just replicating the value from a chart database.

The point we want to emphasize is that the integration of chart data with the front displays is a new paradigm and a blended solution. In this paradigm, there is no such thing as a continuous chart as it is commonly conceived. Rather, it is a continuous path that is supplemented by chart data.

To further the example, it is now possible to show airport moving maps supplemented with chart data such as signage, paint on the taxiways and runways, and airport lighting. These airport moving maps can be presented in either 2D on the navigation display or 3D on the PFD. Airport moving maps make it possible to fly "gate to gate" with the front displays supplemented by airport and procedural chart data, in lieu of referencing paper chart products—including the airport diagram (aerodrome sketch) that is typically needed during taxi operations.

Some issues can arise with this scheme. The chart data for airport moving maps may reside in a separate database (also true for IFR procedural chart data and FMS navigation data). Thus, the pilot must confirm the time period applicability of the chart databases prior to departure. Another concern is the conformity of airport moving map displays with the outside visual scene. The position of taxiway and runway centerlines, widths, signage, paint, etc. should conform to the outside view.

Pilots use various IFR charts (terminal, departure, en-route high/low, arrival, and IAP charts) in training and practice (61.65 Subpart b Aeronautical Knowledge subpart (5) use of IFR charts for en-route, approach and terminal area. And subpart D Aeronautical Experience). Practice with IFR chart types is constantly reinforced through initial, recurrent, checking, and line flying. As a result, pilots know which type of chart to use to program, check, and fly to comply with IFR clearances. In the blended paradigm, where chart data supplements on board NAV and FMS data, the pilot merely needs to turn ON the chart database map layer to blend the chart data with the FMS procedure selections, which should correspond to the ATC IFR clearance. However, flightcrews will require additional training to correctly verify the chart database information prior to flight. Figures 3 through 6 show examples of how a pilot could use front displays supplemented with chart data.

Figure 3. Airport moving map on navigation display

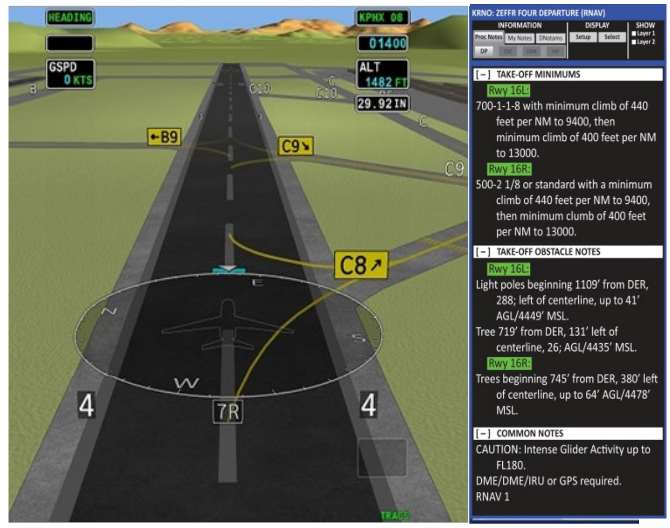

Figure 4. AMM on PFD in 3D perspective with notes.

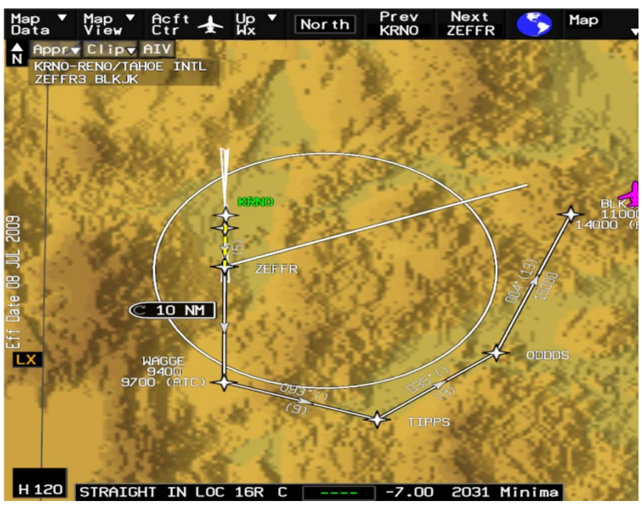

Figure 5. FMS flight plan supplemented by chart data

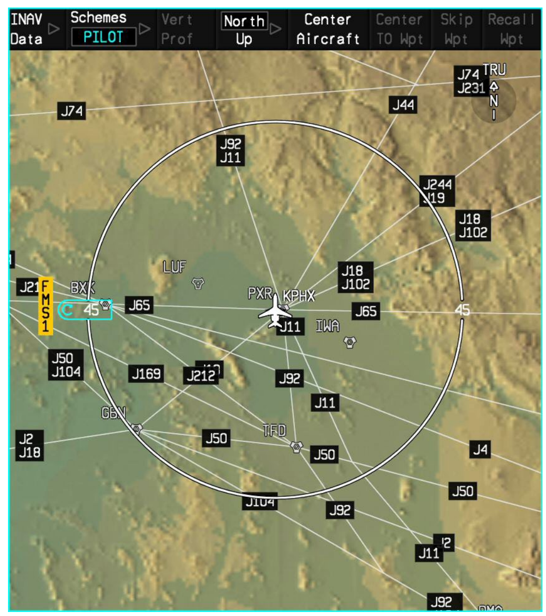

Figure 6. High/low airways on navigation display

1. During pre-flight, the pilots must check the validity period for the airport chart database, IFR chart database, fixed chart viewer database, and the ARINC 424 database (FMS). Prior to push back, the pilot turns the chart layer ON so that chart data can supplement the front displays.
2. At the gate, the pilot calls up the airport moving map (AMM) on the navigation display. The AMM is a 2D representation of the airport surface with all taxiways, runways, gate areas, paint, and signage faithfully represented. See example in Figure 3.
3. The pilot could also call up the AMM on the PFD in a 3D perspective display, as illustrated in Figure 4 .
4. The taxi clearance is represented on these displays as a magenta line (example not shown). The pilot can use these displays for pre-departure briefing, supplemented with information in the chart notes and data manager.
5. During flight, the pilot uses the navigation display (Figure 5) to follow the FMS flight path programmed during the departure and does not have to refer back to the electronic fixed chart viewer.

6. Enroute, the pilot can add the High/Low airways layer to monitor aircraft position relative to the FMS flight path (see example in Figure 6).
7. As the flight joins the arrival, the FMS flight plan, supplemented by chart data comes into view.
8. Finally, when the flight lands the PFD or MFD will show the airport surface with taxiway clearance information.

3.3. PILOT REVIEWS

3.3.1. Card Sort Analysis

We used card sort analysis to identify common themes in the placement of IFR chart data on the PFD, MFD, or VSD. We conducted a card sorting exercise to develop a pilot-centered taxonomy of structured information relating to paper instrument procedural charting elements. This taxonomy drove the flight deck information architecture associated with the functional allocation and presentation of the electronic charting information that is normally associated with paper charts. This method addresses the complexity and variety of the items to be organized. We were aware of no existing taxonomy for organizing the items into a useable presentation suitable for replication on the moving map navigation display.

The current practice of presenting paper or digital representations of paper charts in their entirety poses difficulties for pilots who need to quickly find critical information. The challenge for the pilot is even more difficult with complex procedures, as the amount of depicted information increases and the resulting density of information increases the pilots' search times. Ultimately, the card sort evaluation, in conjunction with ARP 5621[8] guidance and a separate engineering analysis provided the basis for the concepts and methods we used for organizing and depicting the chart data.

The card sort was administered through a commercial card sorting web-site, which allowed pilots from Honeywell's internal pilot pool in several Honeywell locations to participate. They sorted the cards independently on their own computers. Each pilot was given specific instructions prior to participating in the evaluation (Appendix A). The instructions summarized the objectives of the study, the assumed platform configurations, and definitions of the levels of criticality.

3.3.2. Results of Card Sorting

In Appendix A, we show the results of the card sort analysis collapsed across cockpit location. Additionally, Table A-1 of the appendix presents the criterion determined by ARP 5621 and an internal Honeywell engineering analysis. We did not include any Criterion 3 items from the original ARP 5621 classification in the card sort analysis; therefore, they are not included in the presentation of the results in Table A-1.

Table 2A of Appendix A shows the results of the card sort analysis by cockpit allocation. The results also include the current cockpit allocation of aircraft with the following equipment setup: full glass (4 or 5 display units such as dual PFDs, Dual or Triple MFDs) with or without EFB/side display, electronic fixed chart viewer, and an FMS with integrated (versus federated) data-bus systems. Fields formatted in bold font indicate where we observed differences between the card sort results and the categorization from ARP 5621.

3.3.3. Pilot Evaluation of Design

Internal Honeywell flight test pilots evaluated the conceptual electronic information chart described in Section 3.2 in a web-based review. Eight of the ten pilots who were contacted participated in the evaluation. All the pilots had an ATP rating. The average number of flight hours was 8,256 hours. with a range of 650 to 20,000 hours. See Table B-1 Appendix B for details of pilot demographics.

We used card sort analysis to identify common themes in the placement of IFR chart data on the PFD, MFD, or VSD.

[8] SAE ARP 5621 was developed prior to the revision of SAE ARP 5289A, which specifies symbols for electronic displays. SAE ARP 5621 was not coordinated with the FAA, and its guidance may conflict with FAA regulatory and guidance material.

During the evaluation, we presented to the pilots a general overview of the background and basic functionality of the display concepts. Once the initial orientation was completed, we conducted a formal walk through of the prototype and demonstrated the design features of the concept. Two researchers recorded the pilot comments and feedback from each session. Lastly, each pilot completed a usability questionnaire. Appendix B.1 gives details of the evaluation procedure.

3.3.4. Results of Pilot Evaluation of Concepts

The evaluation resulted in mixed opinions; however, the majority of pilots reported strong acceptability of the electronic information charts concept. Pilots said that they thought it was an operationally valuable feature and that they wished it were currently available in the cockpit.

Pilots responded to 20 questions related to human factors of electronic information charts using a seven point scale (1-Strongly Disagree to 7- Strongly Agree). The ratings varied from minimum of 3.3 to a maximum of 5.8 with an average rating of 4.9, indicating slightly favorable judgments overall. Average responses to all the evaluation questions are shown in Table B-2 of Appendix B. Appendix B.2 reports the detailed pilot comments in response to each question.

Pilots strongly agreed that the moving map provided a means to manage the visual clutter associated with complicated procedures. However, pilots weakly disagreed that mental workload due to electronic information charts would be similar to that of using a paper charts or electronic fixed chart viewers. We did not investigate the valence (higher or lower) of electronic information chart workload compared to paper charts. This is a potential research question to be addressed in future studies.

Some pilots reported that setting up multiple options could take a lot of work and could create the potential for error. However, the intent or design philosophy for pilot customization is for the pilot to set some pre-determined defaults before pre-flight activities (e.g., the night before flight). Customization could also be done through preset company defaults. Thus, the pilot could load his or her profile or the company profile during setup and not worry about further setup or major manipulation of the interface during critical phases of flight. Pilots also were concerned that they could forget an important procedural element in the setup and only realize it later. If this were noted during a high workload segment, it could be challenging for the flightcrew to make the appropriate change to display settings. This is another potential area for research that could be addressed in future studies and that could help to refine the design and operating requirements for the preflight system functions. However, the design philosophy of the conceptual electronic information chart ensures that all of the elements that are defined according to SAE ARP5621's[9] Criticality 1 definition will always be available on the map; thus, no critical elements will be turned off intentionally or accidently.

[9] SAE ARP 5621 was developed prior to the revision of SAE ARP 5289A, which specifies symbols for electronic displays. SAE ARP 5621 was not coordinated with the FAA, and its guidance may conflict with FAA regulatory and guidance material.

4. DESIGN CONCEPTS

This chapter describes the actual display concepts developed by the Honeywell Aerospace research team and includes screen captures of prototype concepts. We used these prototypes to investigate electronic information chart human factors issues and to develop recommendations for operational and certification approval guidance. The fidelity of the graphical illustrations differs for each concept, as appropriate to depict the human factors issue under consideration.

4.1. DIGITAL CHART DISPLAYS: DECLUTTER CONCEPTS FOR INSTRUMENT PROCEDURES

This section of our report gives a high-level categorization of information, reviewing a variety of techniques that organize the vast amount of information provided to pilots on paper charts. Our ultimate goal is to present a system design that will let pilots manage the chart information content to appropriately monitor the procedure as performed by the FMS. Paper charts can be quite complex, having a large amount of information compressed into a small package. As instrument procedures have become more complex, information depicted on instrument procedure charts has increased commensurately. This greater information density has resulted in a cluttered presentation that challenges the pilot's ability to use the chart for navigation tasks in flight. Additionally, the text is small and difficult to read because the information has been compressed into a relatively small piece of paper.

> *Charts appear to have excessive clutter because the information density is so great.*

Digital instrument charts provide a solution to many common human factors issues associated with the paper representation of instrument procedures. To provide pilots with the information necessary to execute an instrument procedure, the information must convey the procedure effectively. More intuitive and readable organization of the data can provide aesthetically and functionally effective information. Ultimately, the digital chart display system design must deliver on its main purpose of providing the information that the pilot needs to execute the procedure.

> *To provide pilots with the information necessary to execute an instrument procedure, the information must convey the procedure effectively—aesthetically and functionally—by organizing the data more intuitively.*

Charts provide all of the information to the pilot at once. When pilots use paper charts to fly procedures, they first use the chart to brief the procedure and then put the chart away until it is needed to execute the procedure. Upon the execution of the procedure, many pilots will clip the chart to the yoke or set it out for reference. With electronic fixed chart viewers, the pilot must flip back and forth between the chart viewer and the navigation display. In larger cockpit layouts, the pilot can put the electronic fixed chart viewer on a separate display, but this still requires the pilot to look at and interpret information on both displays and then mentally integrate the information between the two displays to execute the procedure.

Having the charting information readily available on a single integrated display allows the pilot to easily look at and interpret chart information on the display as needed, while it also allows the pilot to focus attention on flying the procedure without referring to the electronic fixed chart viewer. Digital chart data, when coupled with the display of navigation information, provides a single source display that allows the pilot to acquire all the needed information to monitor procedure compliance.

A major advantage of providing digital chart data on a navigation display is that pilots require less effort to acquire and integrate chart information, as compared to existing paper and digital charts. When using published charts, accessing just the charted flight information for the assigned procedure takes a lot of effort. In contrast, a data-driven chart application is more pilot-centered, providing only the information that is specific to the procedure assigned by ATC or specific to the mission to be flown. If the system could limit the display of information to that needed to fly a specific procedure, much extraneous information found on paper charts could be avoided. As a result of better information management, we believe that a tailored system of data-driven chart data displays will lead to better readability and access to the charting elements necessary for pilots' to successfully monitor flight progress and conformity to the procedure.

4.1.1. Hierarchy of Information

As a means to better manage the large volume of information that charts provide, we developed a hierarchy of the procedural data presented on charts. It was based on the card sort results and ARP5621[10] organization of data elements. Figure 7 shows our system's declutter logic.

The hierarchical organization can further categorize and suppress data from display procedural elements that are not associated with the specific procedure that the pilot is currently flying. Initially, pilots can declutter procedural information using the procedure selection menu (setting up and loading a profile). The next level lets the pilot declutter the display by turning on or off the layers on the various displays (PFD, MFD, VSD). Ranging in or out provides the next level of declutter management. Hot spots or stick pins that encapsulate detailed chart data provide the final level of declutter management for the pilots.

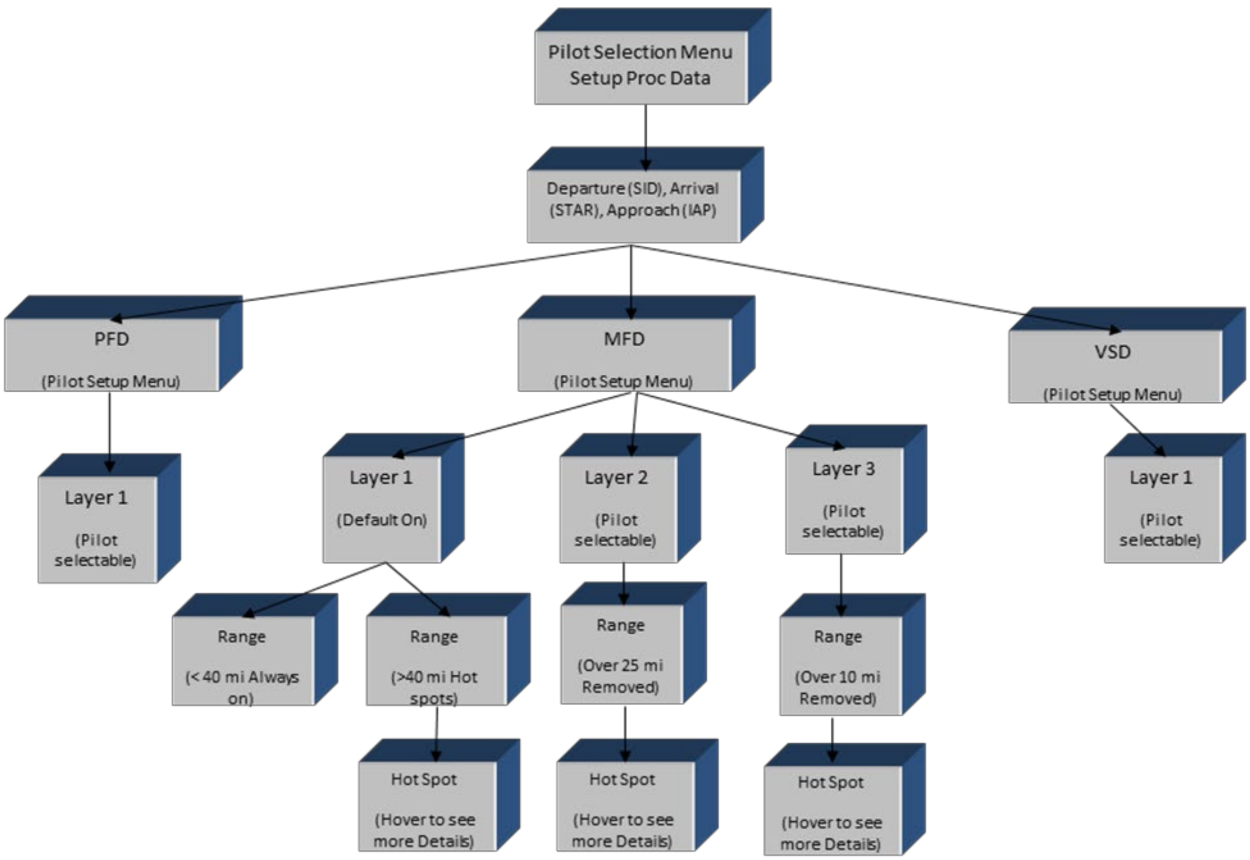

Figure 7. Hierarchy of procedure data selection across the cockpit by layer and range

4.1.2. Procedure Menu Selection Layer and Criticality of Information

We developed a menu for chart information display based on the hierarchy of procedural data. The menu selection logic allows pilots to select procedural data for display based on their own judgment and preference for monitoring flight conformity to an ATC-assigned procedure or mission. Criticality 1 items cannot be suppressed from display at any time. The logic allows pilots to place particular Criticality 2 and 3 information into a specific display layer that can be turned on and off at the pilot's discretion. Additionally, the pilot can

[10] SAE ARP 5621 was developed prior to the revision of SAE ARP 5289A, which specifies symbols for electronic displays. SAE ARP 5621 was not coordinated with the FAA, and its guidance may conflict with FAA regulatory and guidance material.

add specific additional elements to the PFD, MFD, or VSD. These elements would then be controlled through an on/off toggle button from the main navigation page.

This information display logic will let pilots declutter each layer quickly and independently on a separate map control button that will reside on the base menu structure of each display: PFD, MFD, and VSD.

4.1.3. Procedure-specific FMS Programming

We assumed the aircraft will be fitted with an FMS, and initially declutter will occur when the pilot enters departure and destination airports into the FMS. This process immediately declutters all procedures except the selected procedures, subject to the pilot's selections for decluttering. See Appendix C.1 (Figures C1.1 and C1.2) for example.

4.1.4. Removing Notes

The display can be further decluttered by removing procedure notes. Once the procedure notes are removed from the map, the readability and access to information are further improved. See Appendix C.2 (Figure C2.1) for example.

4.1.5. Radial Positioning of Labels

Radial positioning of labels provides a way to maintain the readability of chart data. As the aircraft turns, the label rotates, maintaining the proper orientation and distance of the text from a symbol or midpoint on a segment. The angle or distance can be changed dynamically from what is stored in the database, so as to not obscure adjacent labels and symbols.

In heading up mode, the labels and notes appear to rotate about the center of the text as the course changes which minimizes the chance of obscuring other notes in heading up mode. Such text rotation is a major change from typical paper or digital charts that are north up and text orientation is fixed. See Appendix C.3 (Figure C3.1) for example.

4.1.6. Ranging In and Out

We used the display range in/out function to reduce the number of lines of information, thus reducing the clutter while still maintaining sufficient information coherence for the flightcrew. In addition to just removing lines of information, the range function can remove entries based on criticality. A pilot can range out to declutter the display or can range in to see more details associated with each procedural element, but again, this is subject to the pilot's selections for decluttering. See Appendix C.4 (Figures C4.1) for example.

4.1.7. Point without Arrowheads

Arrows are drawn on charts to indicate where data belongs. These arrows can contribute to the visual clutter. To help reduce the visual clutter, the arrow head could be left off. Directionality can still be maintained by providing a line that uses a gradual transparency change towards the procedural data elements. Drawing the transparent segment under the note and gradually increasing the opacity as it gets closer to the associated data gives a sense of directionality and pointing without the need to add an arrowhead (See Appendix C.5, Figure C5.1 for example). An additional benefit of removing the arrowheads is that it eliminates any visual clutter or confusion between competing arrowheads that indicate directionality of courses or radials.

4.1.8. Offset Display of Information

As the distance between waypoints becomes insufficient to display the necessary data, the system can generate a pointer to indicate an area of interest where the information would normally be presented. The course, elevation and distance are offset to the left and a pointer indicates where it would have normally been displayed on the course segment line.

As the distance between waypoints increases, the system can revert the data, bearing, course, and distance to its normal orientation along the segment as shown on the right side of Figure 8.

Figure 8. Benefits of an offset pointer drawn to the area where the data belongs

4.1.9. Font Size Reduction

As the pilot ranges out on the navigation display, the data can become cluttered and hard to read. Reducing the font size of the text symbols can make it possible to show the entire procedure at once, without labels and symbols overlapping and making the information unreadable.

Some pilots may find information in reduced fonts hard to read. One method of improving readability is to provide a means for the pilot to call attention to the information independently from all the other textual items on the display. In this mode, the text may become *symbolic*. By moving the cursor near the text or when the aircraft approaches the text, the font returns to its normal size and any information that was removed can also be restored.

4.1.10. Off Screen Transitions

To show the procedure in sufficient detail, it is often necessary to range in, which may push transitions off the display (Figure 9). One successfully implemented method uses a dashed line to indicate an off screen element; it allows the pilot to anticipate and react to upcoming events more quickly. Critical flight information that would not be on the display can be shown with the broken line technique. This mechanism should increase procedural awareness by allowing pilots to plan for future events.

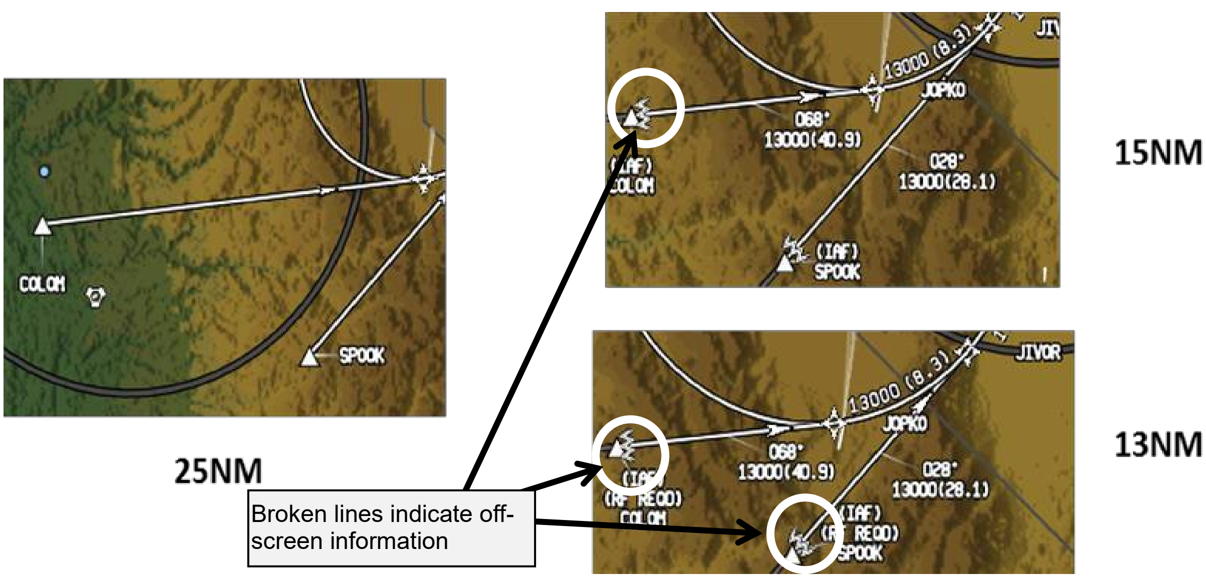

Figure 9. Critical procedure elements off of the display range can be shown with a broke line segment

4.1.11. Off Screen Procedures

Off screen procedures can be shown on the display as an inset similar to a box inserted on printed charts. With data-driven procedure elements, using an inset can show dynamic relationship with the Ownship, increasing the pilot's awareness of the relationship between the procedure and the pilot's current state. See Figure 10.

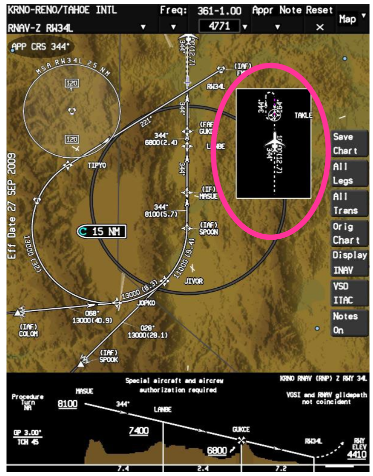

Figure 10. Inset showing ownship in relationship to the missed approach procedure

4.1.12. Phase of Flight/Aircraft Altitude

The phase of flight and aircraft performance is another way we drive decluttering logic. As the pilot completes each phase of the flight, information about elements that have been passed no longer needs to be shown on the display. Once the aircraft altitude has reached some pre-defined separation minimum from the enroute altitude, the segment information can be removed until the pilot descends back below that separation minimum. Figure 11 illustrates an example of information removal and display logic, which is further described below.

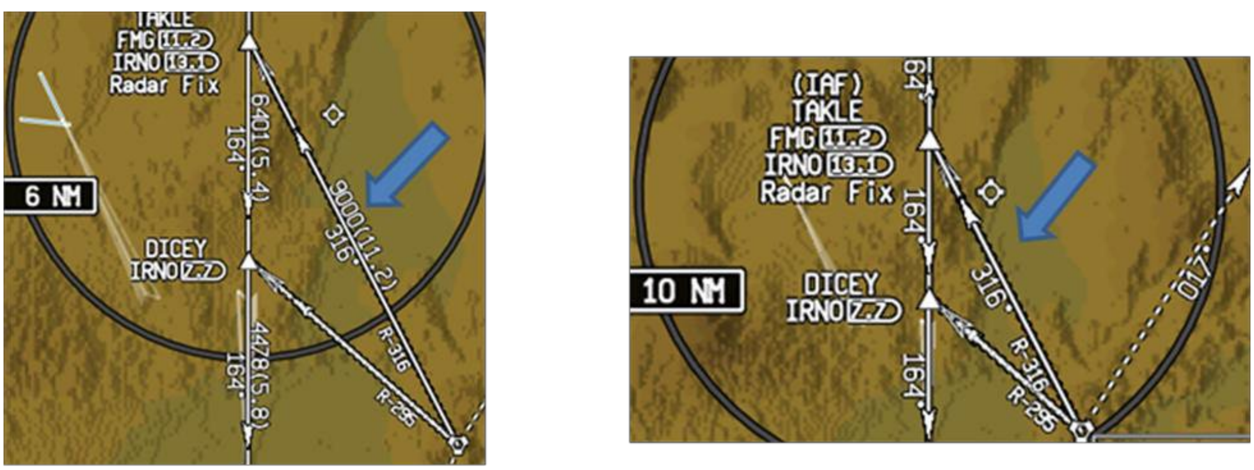

Figure 11. Example of segment altitude information removed

- Remove segment altitude information when:
  - Aircraft altitude is greater than segment altitude by 1000' and climbing (e.g. 10,000')
- Information can be added back in when:
  - Aircraft altitude is at a defined separation (1000')
  - Aircraft descent rate is closing on the altitude at some pre-defined rate

The parameters associated with phase of flight/aircraft altitude could be defined by the vendor during design, development, validation and certification.

4.1.13. Hot Spots with Pop-up Hovering

Once the charting information has been decluttered, stick pins or hot spots can be used to allow the pilots to quickly recall important pieces of information. By hovering the cursor over hot spot data, a pilot can quickly pull up information as needed. (See Appendix C.7, Figure C7.1 for an example of how a chart can be decluttered while allowing quick access to individual pieces of information associated with the procedure.) The hot spot information is temporary and is removed from the display when the pilot moves the cursor to another display location.

4.1.14. Information Pop-ups Based on Relative Position to the Procedural Element

Another mechanism for managing clutter is for the system to pop up information based on the relative position of the aircraft in relationship to the location of a critical procedure element. As the aircraft flies close to a location, the critical information can be automatically displayed, then removed as the aircraft passes over the data. In Appendix C.8, Figure C8.1, an example illustrates the concept of automatically displaying critical information as the aircraft closes in on a pre-defined range from the information. This process ensures that critical elements are always displayed.

4.2. NOTES MANAGEMENT

Paper charts provide a great deal of textual information to the pilot. This information is divided into general notes, specific procedures, alerts, aircraft performance limits, restrictions, transition information, obstacle locations, etc. Adding procedural notes increases information density on paper charts and contributes greatly to the visual clutter. The density of textual information shown on paper charts would render a moving map navigation display unusable. This section describes a pilot-centered approach to the managing procedure notes and other textual information.

Our design concept provides a dialog window to house all procedural notes. The dialog window can be resized for a 1/6, 1/3, 2/3, or full screen layout. It provides a centralized location for all textual information associated with the depicted procedure. Using a dialog window with separate tabs for high-level organization, we provide separate categories for Procedure Notes, pilot preferences labeled "My Notes," and D-NOTAMs. As information content increases, other high-level categories might be added. Information presented within each tab is arranged by phase of flight. Procedure-specific information, such as runway assignment, is used to select what information is displayed. When the pilot has loaded a specific procedure into the FMS, only the notes associated with that procedure are immediately visible. The other procedural information will be collapsed into an intuitive heading label. A "+" symbol by the header indicates that more information is available upon expansion. The pilot can easily view the collapsed information by expanding the header. The notes are further organized within the dialog window using the order of precedence shown inTable 1. Table 1 was derived through engineering analyses, pilot focus groups, and pilot in the loop scenario walkthroughs with the software prototype on a PC.

The next level of organization is based on chunking information, which further helps pilots quickly and efficiently locate the correct information for each segment of the procedure. Chunking, or grouping similar elements together, is a natural way to improve recognition and recollection of data elements.

Chunking, or grouping similar elements together, is a natural way to improve recognition and recollection of data elements.

Researchers (Dallal & Meck, 1990; Egan & Schwartz, 1979; Sakai, Kitaguchi, & Hikosaka, 2003) have shown that chunking can improve information recall. In the chunking process, the grouping must have a meaningful association. This modular layout also creates a consistent display arrangement that is lacking in paper charts. The display should incorporate smaller chunks that do not require the pilot to scroll down numerous levels to find what they need. Using smaller chunks of information also reduces the chance that pilots will miss information it is collapsed and not currently displayed.

In this pilot-centered design, we expect that the pilot can quickly and efficiently access and read all the applicable chart notes associated with the assigned procedure.

Table 1. Dialog View menu organization and order of menu control label

Order	Notes Organization by Specific Type		
	DP	STAR	IAP
1	Notes (General Notes)	Notes (General Notes)	Notes (General Notes)
2	Obstacles	Restrictions	Restrictions
3	Restrictions	Transition Text	Transition Text
4	Takeoff Min	Routing	Missed Appr
5	Climb Grad	Landing	Frequency
6	Initial Climb	Lost Comm	
7	Routing	Frequency	
8	Transition Text		
9	Lost Comm		
10	Frequency		

5. HUMAN FACTORS RECOMMENDATIONS

Our human factors recommendations are based on the broad analytical methods used in our study; however, we believe that further research will make it possible to better specify and support the recommendations before they are incorporated into regulatory guidance.

The title of each recommendation is followed by initials in square brackets that indicate the sources of the recommendation. These sources are:

- LRA – Literature Review and Analysis
- CS – Card Sorting
- PE – Pilot Evaluation
- HON SME – Honeywell Subject Matter Expertise (Human Factors, flight test pilots, certification and internal flight deck engineering display developers).

5.1. HUMAN-CENTERED CHART DESIGN [HON SME; CS, PE]

Each IFR chart can be decomposed into individual chart elements and stored in a chart database. Chart elements should be integrated so that displayed information is intuitive—easy to understand and interpret. The integrated chart database elements should form a more intuitive whole than that represented on paper charts or an electronic fixed chart viewer. Figure 12 illustrates this recommendation for a terminal area arrival (TAA) chart. Integrating chart information electronically assures minimizing confusion and errors.

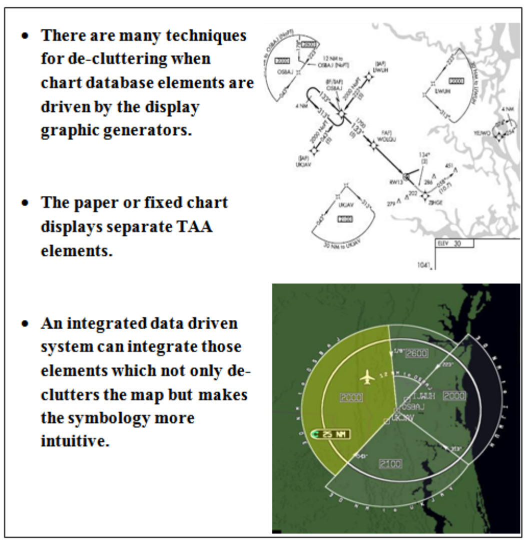

Figure 12. TAA paper chart reconfigured to be more intuitive as an electronic data driven chart display

5.2. CHART DECLUTTER [HON SME; CS, PE, LRA]

- **Phase of flight and declutter [HON SME; PE, LRA]:** The applicant may use phase of flight as a trigger mechanism to declutter electronic information charts by using aircraft altitude, position, speed, and other contextual variables to change chart information on the moving map display. This technique can give the pilot "the right information at the right time." For instance, showing airway MEA or MOCA when the aircraft is on an airway at FL 360 may not add any operational value.

Phase of flight can be a trigger mechanism to declutter electronic information charts by using aircraft altitude, position, speed, and other contextual variables to change chart information on the moving map display. This technique can give the pilot "the right information at the right time."

- **Allocation of chart data across displays [HON SME; CS, PE, LRA]:** The applicant may allocate chart data across the front displays (PFD, MFD) to declutter the navigation display and logically assign data to displays, congregating data specific to a pilot task. For approach tasks, collocating some chart information with the PFD will improve pilot scan for the approach task while decluttering the moving map display. For instance, our card sort analysis indicated a strong pilot preference for presenting final approach and missed approach information on the PFD to avoid splitting the scan between the MFD and PFD. As another example, presenting chart data on the moving airport display (diagram), lets the pilot see all information on one display (e.g., aircraft position, ADS-B traffic, and airport chart data), eliminating the need to flipping between the airport moving map and the airport diagram on the electronic fixed chart viewer or paper. Presenting chart data on the front displays will also make it possible for the pilot to taxi or fly a clearance without referring back to the airport diagram or IFR procedure on the electronic fixed chart viewer. Thus, all necessary information for taxi and the IFR procedure to be flown needs to be tactically displayed on the moving map. Analysis, pilot focus groups, and demonstrations will enable electronic information chart designers to select the right information to be displayed.
- **Procedure notes [HON SME; PE]:** Some charts have extensive pages of notes for the pilot to read. The applicant should consider these design guidelines to address clutter due to chart notes:

  Some charts have extensive pages of notes. Our design objectives address the potential for clutter due to chart notes.

  - Display only notes that are relevant to the mission.
  - Allow the pilot to customize the notes into a briefing format.
  - Allow the pilot to insert additional (free text) notes for display, as relevant to the mission.
  - Allow the pilot to place a note, designated by a unique icon, on the moving map display. This capability will make it possible to tie the notes to the appropriate phase of flight or segment of the flight plan. The benefit is that it creates memory prompts for important notes and mitigates the need to refer back to mission-relevant notes in the notes display box.
- **Chart data layers and declutter [HON SME; CS, PE, LRA]:** One decluttering technique is to allow the pilot to define or customize chart data relevant to the mission. Chart data, as differentiated from chart notes; it contains symbols, lines, courses, and altitudes. The applicant should allow the pilot to customize the layers so that only chart data relevant to the mission is displayed. All other chart data is suppressed but can be turned on again with a simple action.

  One decluttering technique is to allow the pilot to define or customize chart data relevant to the mission.

  The applicant must not suppress chart data defined as Category 1 data by ARP 5621[11]. Category 1 data is the highest priority or criticality level assigned by ARP 5621. This data is necessary for flight safety and to properly fly a procedure and must be displayed when the chart layer is ON.

5.3. INTEGRATION OF CHART DATA WITH OTHER NAVIGATION DISPLAY SYMBOLOGY [HON SME; CS, PE]

- IFR chart data rendering should integrate within the overall priority drawing level philosophy of the target OEM (original equipment manufacturer).

[11] SAE ARP 5621 was developed prior to the revision of SAE ARP 5289A, which specifies symbols for electronic displays. SAE ARP 5621 was not coordinated with the FAA, and its guidance may conflict with FAA regulatory and guidance material.

- FMS and data-driven charts data should be clearly distinguishable as separate entities. Chart course-lines, bearings, distances, waypoints and EXPECT altitudes should be clearly distinguishable from FMS flight plan data.

FMS and data-driven charts data should be clearly distinguishable as separate entities. Chart course-lines, bearings, distances, waypoints and EXPECT altitudes should be clearly distinguishable from FMS flight plan data.

- The applicant should show only data-driven chart data that supplements FMS data. That is, once a procedure is loaded into the FMS, the FMS will pull all waypoints, courses, bearings, altitudes, etc. from the NAV Procedure database. In a tactical mode (versus a briefing mode), the application should suppress data-driven chart data that conflicts with FMS computed data.

- The applicant should not display chart data that replicates altitudes, waypoints, courses, and bearings in the FMS on the moving map. Avoiding replication reduces clutter and prevents confusion over chart distances and course bearings that may disagree with the FMS calculations. There are however no changes to paper charts and the fixed chart viewer will remain the primary source for ATC communications, briefing, and setting up NAV equipment.

- OEM data and chart data should use the same symbology. OEM moving-map displays have a certified symbol set for displaying NAVAIDS, runways, airports, and the like. Pilots should not have to learn and remember different symbology sets that represent the same entity.

5.4. OPERATIONAL APPROVAL [HON SME]

- Our generalizable guidelines flow from an operational philosophy grounded in the intended function of a data-driven charts system (analogous to paper charts or electronic fixed chart viewers). The data-driven chart system should support crew tasks such as:

Our generalizable guidelines flow from an operational philosophy grounded in the intended function of a data-driven charts system.

  - Finding the relevant chart through an indexing system.
  - Changing charts as ATC clearances or flight conditions change.
  - Checking chart validity.
  - Using chart data to configure the navigational systems and cross check.
  - Using the chart data to fly the procedure tactically. That is, the chart data should be available for review of forgotten items or to refresh the pilot on the procedure.

The pilot should always have quick access to the electronic fixed chart viewer. The electronic fixed chart viewer contains all notes, procedures applicable to a given procedure that a pilot may need to review. Initial implementations of the DDC layer would contain adequate information to fly a procedure under nominal conditions but not for all unforeseen conditions. For instance, with approach minimums, an unexpected landing system component out-of-service situation (e.g., centerline lights INOP) may require the pilot to quickly find, review, and adjust the aircraft flight path to comply with higher approach minimums associated with a loss of centerline lights.

- Since data-driven charts are comprised of several components that add complexity compared to paper charts, each component in a DDC system should be traceable to a crew task so that crew procedures can be defined. Although electronic information charts have multiple components, their design should be flexible so that the crew can set-up, fly, and then change the procedure, all from the same interface on the MFD. Currently, the intended function of the electronic fixed chart viewer is to brief the crew on a procedure since it contains 100% of all information related to any given procedure, including off-nominal events such as component out minimums. Once the pilots are briefed, they can fly the procedure with the DDC layer, which contains adequate procedure information under normal or nominal conditions.

5.5. CHART USABILITY [LRA; HON SME]

- **Procedure notes customization**: Pilot-customizable features should allow pilots to filter notes. Such filtering would make accessing the notes more intuitive for the pilot and ensure a way to place a few important notes directly on the navigation display or in a pre-defined display area.
- **Flightcrew interaction:** When appropriate IFR procedures and transitions are selected through the FMS, all other transitions for electronic information charts should be automatically deselected in the FMS and suppressed on the displays.
- **Off-screen display**: Off-screen transition chart elements should be displayed and easily identified by the pilot. If the pilot is operating at lower map ranges and the NEXT waypoint, turn, altitude, etc. are off-screen, these data should be parked at the display edge.
- **Compatibility with flight deck systems**: Electronic information chart display elements should be consistent with other systems for color, menu design, and symbology. Symbology in the chart data (e.g., Navaids) and symbology produced by the navigation system should be the same.
- **Potential for error**: The presentation of chart data should not conflict with the presentation of FMS route data. For instance, differences may occur in how the FMS calculates route course and distance. The FMS calculation of course and distance may differ from the chart data. This difference should be visually clear to the flightcrew. Although pilots are generally aware of these differences, their presentation in the display system may carry more weight and can bias the crew to believe the differences are due to display calculations. Also, chart data should not conflict with other data presented on the PFD or MFD. That is, the chart data should not render some other higher priority object unreadable (e.g., aircraft position).

6. CERTIFICATION AND OPERATIONAL APPROVAL CONSIDERATIONS AND INITIAL RECOMMENDATIONS

Our certification approval recommendations cover the intended functions of data-driven charts, general certification basis, and special certification considerations approving data-driven charts.

6.1. INTENDED FUNCTIONS OF DATA-DRIVEN CHARTS

Data-driven charts are designed to work with an electronic fixed chart viewer. The intended function of the electronic fixed chart viewer is to be used as a briefing tool and cross check device with FMS and flight guidance set-up. The electronic fixed chart viewer chart database has been verified to contain 100% of needed information for any given IFR procedure.

Once pilots have briefed the procedure from the electronic fixed chart viewer, they can fly the entire RNAV/RNP procedure using the data-driven chart overlay on the moving map or navigation display without referring to the electronic fixed chart viewer.

The graphics generator draws the data-driven chart layer on the navigation display using individual chart elements stored in an avionics chart database. The data-driven chart layer is superimposed on the navigation or moving map display along with other navigation display layers such as TERR, WX, TRAFFIC, FMS flight plan, etc. The moving map data-driven chart overlay contains the critical information as defined in SAE ARP5621[12] to execute an IFR procedure. The example implementation in Figure 13 shows chart data such as the chart identification or ID block, MSA, minimums, courses and altitudes, all of which are geographically referenced to the navigation display.

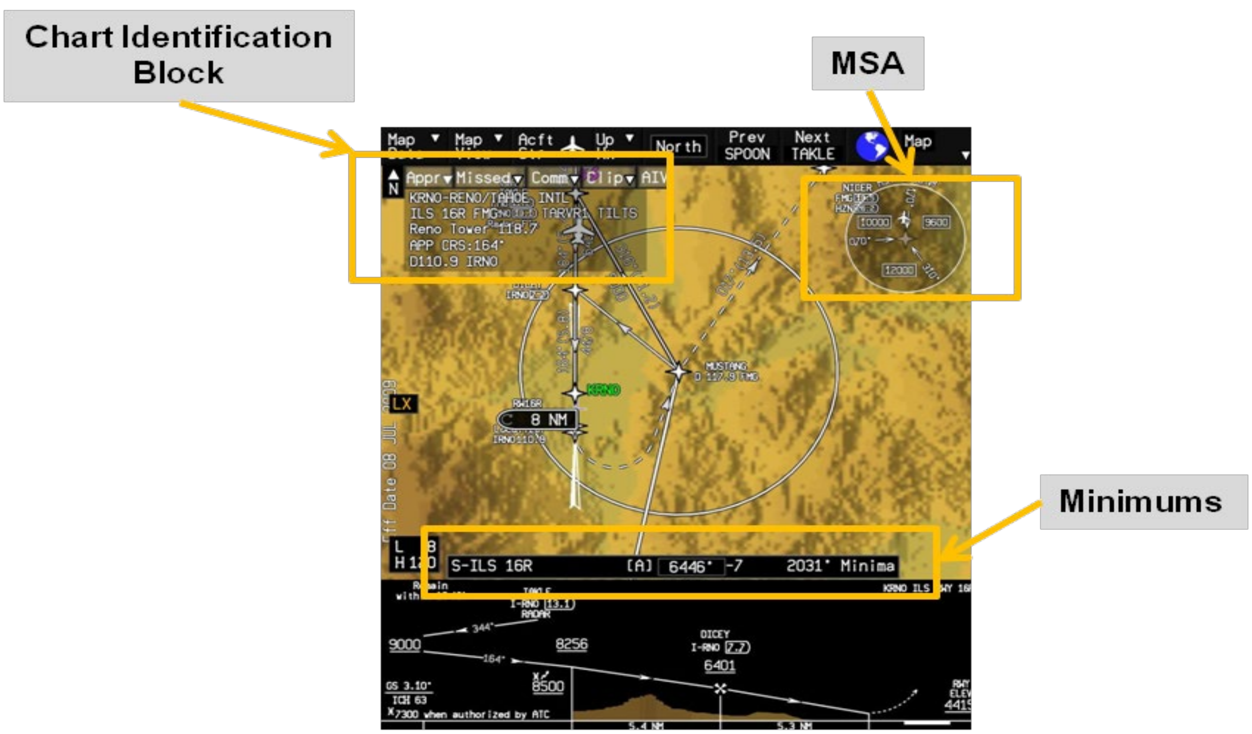

Figure 13. **Data-driven chart displayed on a moving map or navigation display.**

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[12] SAE ARP 5621 was developed prior to the revision of SAE ARP 5289A, which specifies symbols for electronic displays. SAE ARP 5621 was not coordinated with the FAA, and its guidance may conflict with FAA regulatory and guidance material.

6.2. INTENDED FUNCTION OF DDC MISSED APPROACH DATA

The missed approach information shown in Figure 14 is presented on the navigation or moving map display. This information contains graphical and textual descriptions of the initial heading/course, initial altitude, and holding. The missed approach information should either be automatically displayed based on go-around activation or by pilot manual control.

Prior to executing the missed approach, the missed approach information must be in view. The DDC missed approach information can be called up with a single button press or displayed automatically via flight phase logic. Automatic or single-button press display of missed approach information allows the pilot to maintain the primary view on the forward displays without diverting attention to get missed approach information from a paper chart, chart viewer, or other cockpit equipment (e.g., the MCDU).

The missed approach information on the lateral moving map can also be used to validate the FMS missed approach course contained on the FMS route or LEGS page against the chart navigation database.

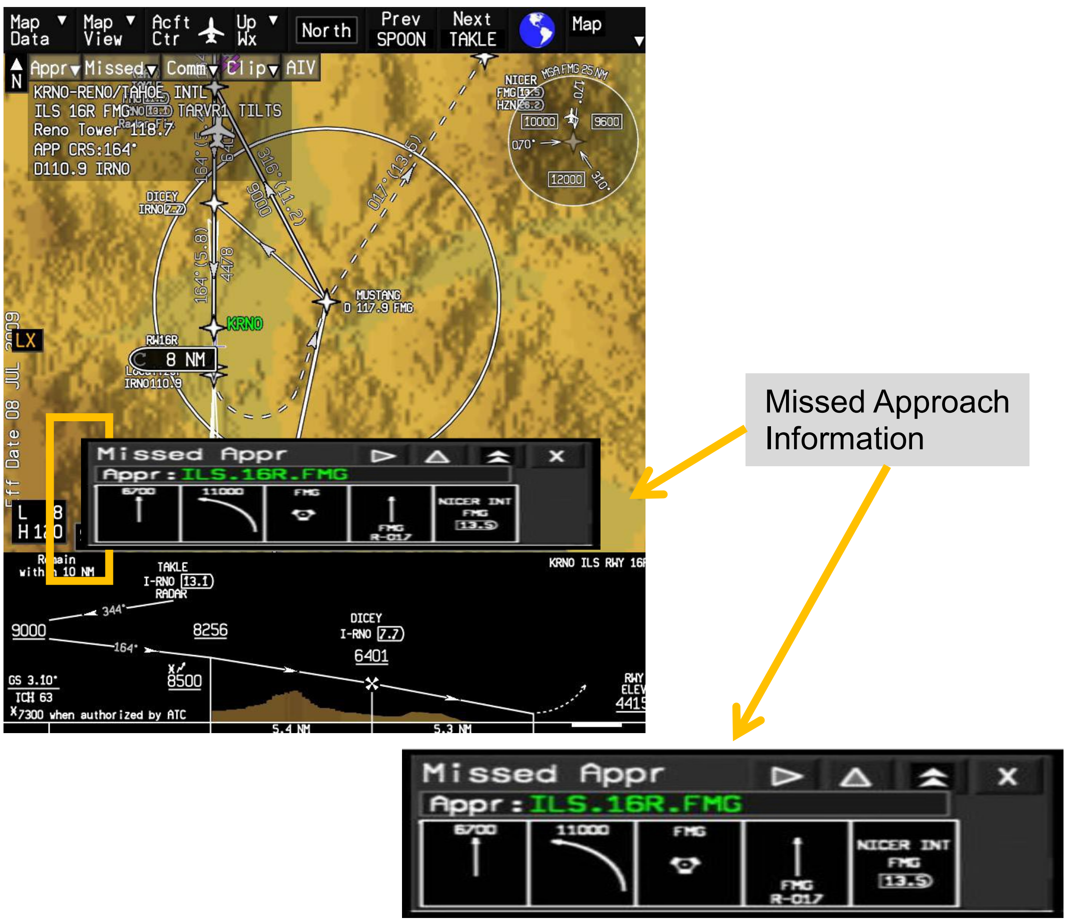

Figure 14. Data-driven chart missed approach information on the navigation display

6.3. INTENDED FUNCTION OF DDC CHART DATA ON THE VSD

The data-driven charts overlay on the vertical situation display (VSD) facilitates the pilot's awareness with respect to the following:

- Reference IFR chart information relevant to the vertical profile such as G/S intercept altitude, distance to go (DTG), threshold crossing height (TCH), touchdown zone elevation (TDZE), and other charted information on the vertical profile.

- Aircraft energy management awareness (e.g., knowledge of speed vs. vertical descent—to reach speed stabilization by a target waypoint).
- Position of the aircraft relative to glide-path and terrain.

6.4. CERTIFICATION APPROVAL RECOMMENDATIONS

6.4.1. Certification Approval of Data-driven Charts

The general approval basis for the electronic information chart system will be TSO 165, *Electronic Map Display Equipment for Graphical Depiction of Aircraft Position*. This is compliant with Title 14 Code of Federal Regulations (CFR). All regulations for Title 14 CFR Part 25, Airworthiness Standards: Transport Category Aircraft must be met. The basis of this recommendation comes from Honeywell's Airworthiness/Organization Designation Authorization (ODA) experts and Product Certification Group during a series of initial meetings with the FAA LA Aircraft Certification Office.

Display and prioritization of chart data should be guided by SAE ARP 5621[13]. SAE ARP 5621 breaks chart data down into three criticalities or categories. Category 1 chart data is determined to be safety critical to the execution of a procedure and must always be displayed when the chart layer is on. Category 2 and 3 chart data, although considered important, depending on mission, can be decluttered.

Chart symbology should conform (very similar in shape and color and have identical meaning) to other navigation symbology on the navigation display (i.e., waypoints, NAVAIDs, etc.). The design of chart symbology should be guided by SAE ARP 5289A *Electronic Aeronautical Symbols,* as a general reference. Avionic OEMS often design and certify their own symbology sets based on system performance constraints and their customers' own flight deck philosophies and standards.

Chart data presentation on the VSD should follow ARP 5430, *Human Interface Criteria for Vertical Situation Awareness Displays*. ARP 5430 is a general reference for the design of VSDs. Pilots build up habit patterns when scanning the vertical chart profiles (paper or electronic). These habit patterns are reinforced through thousands of hours of flying IFR. Therefore, we recommend creating similarity when superimposing chart data onto a VSD display. The chart data should not be so dissimilar to paper or electronic information charts as to create confusion or ambiguity.

General attributes of chart data should conform to RTCA DO-257A, Minimum Operational Performance Standards for the Depiction of Navigational Information on Electronic Maps.

The chart database should comply with DO-200A, *Standards for Processing Aeronautical Data* and DO-201A, *Standards for Aeronautical Information*. When specifying the chart elements in the chart database, the applicant should demonstrate traceability from each displayed chart element to the Data Quality Requirements that define the accuracy and resolution of each chart element.

> *A data-driven chart system must display a chart identification block on the DDC layer to identify which IFR procedure chart has been called up from the data-driven charts database and shown on the navigation or moving map display.*

The data-driven charts layer must display a chart identification block. The chart identification block allows the pilot to confirm that the right chart data is being presented on the navigation or moving map display based on FMS procedure and transition selections. At minimum, the chart identification block should contain airport ICAO ID, airport name and geographical reference (e.g., city), and procedure type (e.g. ILS 25R). This recommendation is based on several Honeywell pilot focus groups and two human factors evaluations. The HF evaluations were scenario-based, pilot-in-the-loop simulations with real hardware and software in a part-task simulator. General human factors principles and guidelines concerning situation awareness also apply to the need for a

[13] SAE ARP 5621 was developed prior to the revision of SAE ARP 5289A, which specifies symbols for electronic displays. SAE ARP 5621 was not coordinated with the FAA, and its guidance may conflict with FAA regulatory and guidance material.

chart identification block. Both paper and electronic charting have a standard indexing system for identifying the chart. This same standard should also apply to data-driven charts.

Case-by-case evaluation of the chart identification block display should ensure that the ID block is not covering up other critical map information. Although the design can include semi-transparency, this feature may not be adequate given the criticality of other map functions. The chart identification block, although necessary, can add clutter to a moving map display that may also be displaying high-priority, safety-critical information (e.g., TERR and TRAFFIC). Optionally, the crew can minimize the chart identification block after it is viewed.

6.4.2. Concurrent Display of Chart Data and FMS Data

We recommend making the display of chart course data (course lines, crossing restrictions, course bearings, etc.) a declutter item. That is, after the pilot views the chart course data, the pilot should be allowed to declutter chart course data. This recommendation is based on two human factors pilot-in-the-loop simulations and several pilot focus groups with air-transport-qualified pilots. IFR chart course data can be displayed with courses, altitudes, and waypoints and then overlaid on a navigation or moving map display where conflicts with the FMS-drawn flight plan may occur. The FMS draws the lateral flight plan based on FMS rules, and the chart data can be drawn using totally separate rules. Trouble spots may occur with 'curves' in the lateral flight plan or the way FMS versus chart courses are calculated. In paper charts, pilots commonly see 1 or 2 degree variations in the course bearing between the FMS leg course and the charted course and compensate. However, when such deviations are shown on a moving map display, it can become a point of confusion.

IFR chart procedure data can be displayed with courses, altitudes, and waypoints and then overlaid on the NAV display where conflicts with the FMS drawn flight plan may occur. The FMS draws the lateral flight plan based on 'FMS rules' and the chart data can be drawn by totally separate rules. Trouble spots may occur with 'curves' in the lateral flight plan and/or the way FMS versus chart courses are calculated. In the paper chart world it is common to see 1 or 2 degree variations in the course bearing between the FMS leg course and the charted course. Pilots are aware of this and compensate. However, when the deviation is shown on a moving map display it becomes a point of confusion. The applicant should demonstrate intended function for showing the full charted course with the course information concurrently.

We recommend making a single-press, quick-action toggle available for switching between the navigation or moving map display and the electronic fixed chart viewer. This recommendation is based on several pilot focus groups that affirmed a strong preference for a quick way to toggle between the data-driven chart layer and the electronic fixed chart viewer.

We recommend preserving display settings (e.g., range, selected layers, TCAS, or TERR selections) when toggling between the moving map display and the electronic fixed chart viewer. This recommendation is based on several pilot focus groups and two pilot-in-the-loop evaluations of data-driven charts.

Quick and intuitive access to DDC chart data set-up menu. Access to the DDC chart data set-up menu should be accessible in flight (air/ground logic should not prevent DDC menu access in-flight). In addition, the pilot should be able to access the menu with an easily locatable single-button press. The pilot may encounter changing flight conditions such as ATC clearances that deviate from the previous clearance, changing airfield conditions (such as component outage, closed runway, visibility changes, etc.). If the pilot encounters changing conditions the pilot may elect to change the DDC data that is being displayed on the NAV displays.

Ensure that Criticality 1 chart data as defined by ARP 5621[14] is always displayed when the DDC chart layer is turned ON with the NAV display. Criticality 1 information is chart information that is considered to be safety critical in performing the charted procedure (arrival, departure, or instrument approach). To further mitigate the possibility that the pilot may not select all procedure attributes or information required for the DDC layer to fly the procedure, it is important that the crew brief the procedure prior to procedure execution when all available information for the procedure has been obtained by the crew via ATIS, ATC, NOTAMS and company. This operating practice is further explained in the operational guidance section of this paper.

Chart Format Conventions. The applicant or vendor should justify, through analysis and HITL evaluations, that deviations from standard chart formats do not cause undue confusion, ambiguity, or additional pilot workload. Pilots are used to Jeppesen, Lido, or government chart formats for IFR procedures. They have trained, used, and developed SOPs using these formats for decades. General human factors principles suggest that deviating from these layouts can cause pilot confusion. For example, Yeh et al. (2013) discuss extensively display layouts and consistency of display formats.

Failure Modes. The applicant must demonstrate, through analysis, design, and evaluation how electronic information chart systems can be displayed under various failure modes such as display unit (DU) failure. The applicant must demonstrate display redundancy for the display of an electronic fixed chart viewer in the event of one or two DU failure condition. Display failure modes can be caused by individual display unit failures, graphics generator failures, or some other display system component. If the OEM has certification approval for the flight deck to be paperless with regard to IFR charts, then the applicant must demonstrate display system redundancy so that electronic information charts can always be available to the crew. Figure 15 is an example of a two-screen failure in a four-DU cockpit and the windows that would be available under those conditions to display DDC or electronic fixed chart viewer.

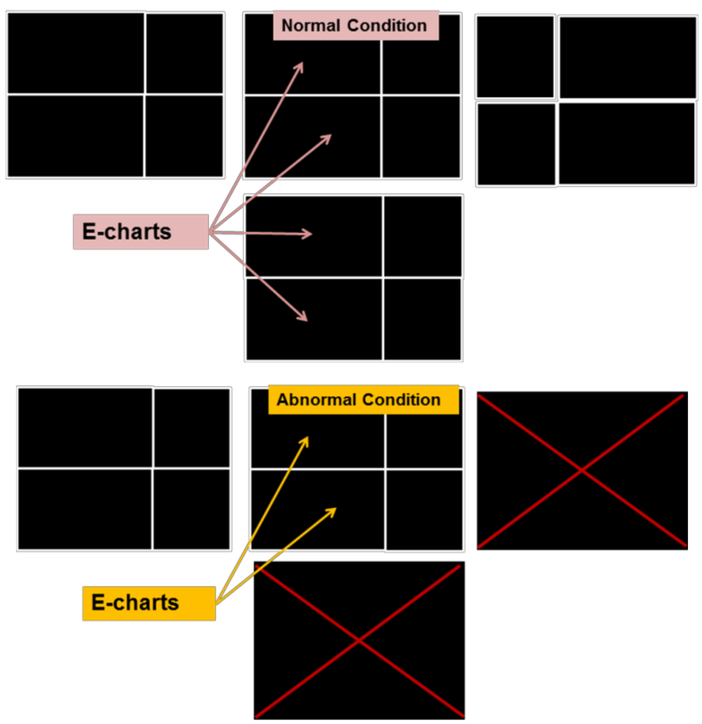

Figure 15. Two-screen failure in a four-DU cockpit

[14] SAE ARP 5621 was developed prior to the revision of SAE ARP 5289A, which specifies symbols for electronic displays. SAE ARP 5621 was not coordinated with the FAA, and its guidance may conflict with FAA regulatory and guidance material.

An electronic information chart systems must provide a system output (advisory messages) of its database status with the minimum status information as follows:

- DDC database effective period (valid or outdated)
- DDC database configuration status (validation of data file configuration)

The applicant should demonstrate, through analysis and HITL evaluations, the intended function of using range control to declutter the chart so that the displayed chart data meets the intended function for flying an IFR procedure at different map ranges without reverting to the electronic fixed chart viewer. Specific issues with map ranging and declutter are discussed in Section 4.1.6. Range control and the presentation of chart data present some operational and human factors issues. For example, pilots typically fly lower ranges on departure and when approaching the runway. We used task analysis, focus groups, and HF evaluations to develop a matrix of displayed chart data versus map range.

Table 2 is an example of an analysis data sheet showing departure procedure symbols that should be displayed at various ranges. The display of chart data at various map ranges was derived through engineering analysis, SME and pilot focus groups. The concept was then flown with pilot-in-the-loop simulations in a full scenario to validate the map ranges and data presentation during internal Honeywell studies.

Table 2. Matrix of map range declutter vs. departure procedure symbols

Departure Procedure	Map Range Declutter					
	< = 5	10	25	50	100	> 100
Orig Airport Symbol				X	X	
Orig Runway Symbol	X	X	X			
On-Course Fix Symbol	X	X	X	X	X	
On-Course Fix ID	X	X	X	X	X	
Crossing Altitude	X	X				
MEA	X	X	X			
MOCA	X	X	X			
Segment Distance	X	X	X			
Segment Course	X	X	X			
Transition Computer Code	X	X	X			
Fix Formation Radials	X	X	X			
Fix Formation Distance	X	X	X			
Navaid Label - Navaid ID	X	X	X			
Navaid Label - Navaid Freq	X	X	X			
Fix Formation Navaid Symbol	X	X	X			
Fix Formation Localizer Symbol	X	X	X			
Holding Patterns	X	X	X			
Holding Pattern Annotations	X	X	X			

6.5. RECOMMENDATIONS FOR RNAV/RNP SYMBOLOGY

6.5.1. RNAV RNP Symbology

Our recommendations in this area are preliminary; they are based on several discussions internally within the Honeywell Navigation Display Applications group. To investigate potential display issues with RNAV/RNP navigation, the project team interviewed several avionics application groups within Honeywell that are responsible for the specification and development of navigation displays associated with RNAV/RNP flight. These application groups are also the external 'face' to the customer airframe OEMs. The airframe OEMs reported several issues with regard to RNP and/or RNAV navigation displays. We discuss these issues and recommendations below.

Levels of Service: The display of RNP levels of service should be standardized. "Levels of service" refers to multiple RNP level-of-service requirements for the same approach type to the same runway end. Level of service is defined as the approach constraints for RNP, approach minima, etc. and is expressed as an RNP value such as CAT 1, CAT II, or CAT III. No industry standards describe what should be displayed (approach type and level of service) or where it should be displayed on the front displays. Some OEMs display the approach information and others do not. Some OEMs also display the information but exclude level of service. Some OEMs display the information on the PFD and others on the MFD. The approach to this problem could be a structured survey to gather initial SME opinions and then validation in a pilot in the loop experiment to collect data. See example picture in Figure 16:

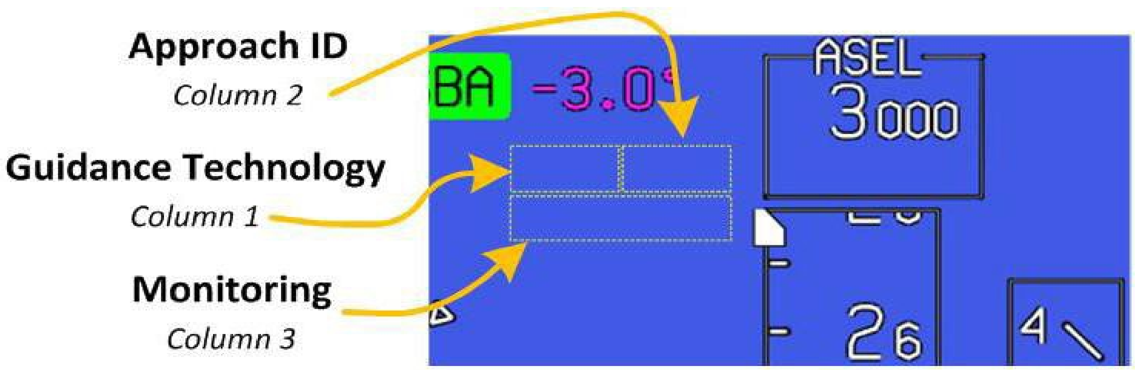

Figure 16. Approach annunciations with level of service on the PFD

Positive rollout guidance: The applicant should provide positive rollout guidance on HSI displays when flying RF legs on RNAV RNP procedures. This issue refers only to flying RNP RF legs and HSI CDI indications. As the aircraft flies the RF leg on the curved path, the HSI 'ratchets' one degree at a time, which is an annoying distraction to pilots. Additionally, no 'tick mark' or other display feature shows roll-out heading for the TF leg. This feature could provide anticipatory roll-out guidance or cueing for the pilot where the RF leg transects the TF leg (see Figure 17 and Figure 18).

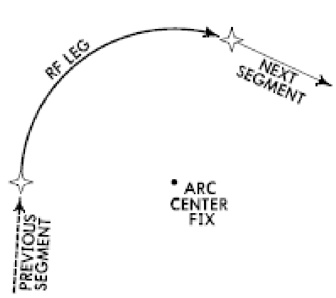

Figure 17. RF leg terminating at a TF leg

Figure 18. HSI with 'ghost' pointer roll out guidance when flying an RF leg

6.6. OPERATIONAL APPROVAL GUIDANCE INCLUDING MINIMUM EQUIPMENT LIST CONSIDERATIONS

The recommendations for operational guidance are derived from AC 120.74B, FAA Order 8900.1, 14 CFR 91.503, an analysis of flightcrew tasks per flight phase, several pilot focus groups, and two pilot-in-the-loop human factors simulations.

The applicant should use the electronic fixed chart viewer to brief all IFR procedures (departures, arrivals and approaches) and use the data-driven chart layer tactically to fly the procedure.

Figure 19. Shows IFR chart data integrated within a navigation display

We assume that the configuration will include an electronic fixed chart viewer to brief (review) a procedure, provide data for flight deck configuration set-up, and to validate FMS or NAV system inputs. The data-driven chart layer on the navigation display is used to fly the procedure safely without reference to a paper chart or electronic fixed chart viewer. The following subsections describe a crew's data-driven chart tasks, beginning with pre-flight.

6.6.1. DDC Preflight Checks and Set-up

The electronic charting function should permit flightcrew interactions and provide minimum status information as follows:

1. Flightcrew receives ATC voice clearance and programs the FMS procedures appropriate to the clearance.
2. The FMS communicates with the DDC or electronic information chart function so that the appropriate chart data is displayed when the chart layer has been turned on.
3. Flightcrew turns data-driven chart layer to ON.
4. Flightcrew checks for any advisory messages generated by the electronic information chart function.
5. Data-driven charts display advisory and status messages, which, at minimum, should include:
   - DDC database effective period (valid or outdated)
   - DDC database configuration status (validation of data file configuration)
6. Flightcrew validates that the chart index information (ICAO, airport and city name, procedure name) corresponds to the FMS flight plan procedures.
7. The pilot displays a chart set-up menu and, based on intended flight path, customizes the chart notes and data for the specific mission or flight. Through a chart notes and data interface, the pilot selects the notes and data to be displayed on the moving map or navigation display
8. The crew briefs the takeoff and departure by reviewing information on the electronic fixed chart viewer. This requirement is supported by 14 CFR 91.503, which states that all information relative to the flight must be available and reviewed.

6.6.2. Ground Operation of Data-driven Charts during Taxi

Once the airplane is under its own power, crew should brief all IFR procedures, beginning with push-back and prior to taxi, and complete the data-driven chart setup. If changes to the data-driven chart system become necessary (e.g., change of ATC departure clearance), the crew must ensure that changes to the DDC system are accomplished without jeopardizing taxi safety. All changes to the DDC system should be verbalized and cross-checked by both pilots. All changes to the DDC system should be complete prior to entering the active runway for takeoff.

6.6.3. Minimum Equipment List (MEL)

Operators should formulate necessary MEL revisions to accommodate electronic information charts before activating the electronic information chart system for each particular fleet. MEL revisions must be consistent with the MEL established for each aircraft type. The MEL should include the following items:

- Model XYZ I and date: 31-xX
- Number of DDC systems installed
- Number of electronic fixed chart viewers installed
- Number required for dispatch (most likely zero)
- May be inoperative provided approved paper charts are available and used
- May be inoperative or deactivated provided approved paper charts are available and used
- Current chart database for DDC and electronic fixed chart viewer
- Electronic fixed chart viewer operating system version and serial number

6.6.4. Flightcrew Operating Manual (FCOM)

The operator flightcrew operating manual (FCOM) should, at minimum, include the following:

- Features and functions of the electronic fixed chart viewer
- Features and functions of the data-driven charts system
- Normal operations for an electronic fixed chart viewer
- Non-normal operations for electronic fixed chart viewer
- Normal operations for data-driven charts system
- Non-normal operations for data-driven charts system
- Crew actions with advisories or alerts related to an electronic fixed chart viewer and for data-driven charts
- Crew actions with reversionary display modes for data-driven charts
- Crew actions with reversionary display modes for electronic fixed chart viewer
- Maintenance requirements for chart database loading and verification should be described.

6.7. TRAINING AND FLIGHTCREW QUALIFICATION

AC 120-64B for electronic checklists (ECL) can be used as an analogous advisory circular for data-driven charts since no guidance yet exists for this new technology. Some commonalities exist between ECLs and DDC systems: both have databases that require updating and checking; both systems require crew training; and both systems must define dispatch requirements, including paper backup in the event of an INOP system. Applicant should evaluate individual crewmember knowledge and use of data-driven charts before operational use. Acceptable means of initial assessment include:

- Evaluation by an authorized representative of the operator using a simulator or training device capable of modeling electronic fixed chart viewers and data-driven chart systems in both normal and non-normal states. Alternate methods may be approved by the operator's principal operations inspector (POI).
- Instructors and check airmen who have received initial or differences training on data-driven charts equipment may conduct initial data-driven charts evaluations of crewmember as authorized by the operator and POI.
  - **Recurrent data-driven charts training**. Recurrent training on electronic information chart operation should be integrated into or conducted in conjunction with established recurrent

training programs. Recurrent data-driven charts training should address significant issues identified by line operation, system, or checklist changes.

- **Data-driven charts recurrent checking.** Recurrent checking should be an element of routine proficiency training or proficiency check programs.
- **Data-driven charts currency.** Crews who have operated aircraft equipped with data-driven charts and attend recurrent training do not need to train for specific data-driven charts currency requirements. Crews who have been trained in data-driven charts operation but have not flown a data-driven charts equipped aircraft within one year of initial training or who have not taken recurrent training, must complete data-driven charts requalification training.
- **Data-driven charts re-qualification.** Applicant is not required to offer dedicated requalification training for data-driven charts. Crew members re-qualifying on an aircraft for the same crew position or who are upgraded to a different crew position should meet requirements as specified in FAA Order 8900.1, Volume 3, Chapter 19, Section 11, as applicable to data-driven charts proficiency.
- **Initial ground training.** At minimum, the applicant should address the following topics in initial ground training:
  - General concepts and assumptions relating to data-driven charts. The general overview should cover all data-driven chart functions, alerts and advisories.
  - System components and operation as appropriate to the design of the specific data-driven charts system, including controls and displays, flightcrew pre-flight checks, and menu structure.
  - Data-driven charts failure indications.
  - Applicable limitations.
  - The air carrier's maintenance logbook or other reporting procedures for data-driven charts failures or checklist errors, if not otherwise addressed by routine maintenance or operational reporting procedures.

6.8. METHODS OF USE FOR DATA-DRIVEN CHARTS

Standard Practices. To fully benefit from the advantages of data-driven charts technology, OEMs and operators should establish standard practices and methods for flight deck use of data-driven charts. At minimum, the standards should specifically address crew coordination methods for data-driven charts, callouts, use of the electronic fixed chart viewer, briefing the procedure, and validating the data-driven chart layer against the fixed chart and FMS flight plan.

6.9. OTHER OPERATIONAL ISSUES

Database identification. Applicant should provide a way for the the flightcrew to uniquely identify the data-driven charts database installed on the airplane for the purpose of confirming compatibility between the data-driven charts database and the paper or electronic backup, or to otherwise confirm the validity of the database.

Manuals and other publications. Applicant should amend AFMs, operating manuals, maintenance manuals, general policy manuals, or other manuals, publications, or written materials (e.g., operating bulletins) that relate to data-driven chart operation to describe data-driven charts equipment, procedures, and policies.

Operating experience, line checks, and route checks. Check airmen should routinely incorporate proper data-driven charts use as a discussion, demonstration, or evaluation factors to satisfy requirements of 14 CFR part 121, when aircraft equipped with data-driven charts are used for line checks, route checks, or in conducting operating experience.

Aircraft with data-driven chart system differences. Operators whose aircraft is equipped with data-driven charts systems that show differences in displays, controls, or procedures, or who are involved with interchange operations, must account for system differences. Applicant should offer an approved differences training program in accordance with FAA Order 8900.1, Volume 3, Chapter 19, Section 11, 14 CFR parts

121 and 135, initial and recurrent pilot testing requirements in accordance with 14 CFR part 125, or as otherwise specified in applicable FSB reports concerning crew qualification pertaining to a particular aircraft type.

7. RECOMMENDATIONS FOR FUTURE STUDIES

Simulator Evaluations: To assess MOCs, develop checklists, guidelines, and requirements to help certification evaluators of electronic information charts we recommend using full software, high-fidelity implementations of the data-driven chart concepts, declutter concepts, and presentation of procedural notes described in this study. Simulation will support a full mission study in a Part 25 airframe configuration to identify human factors, operational, and certification issues associated with electronic information charts. Using representative scenarios and manipulation of experimental conditions for electronic information chart, a human-in-the-loop (HITL) study will help generate data to support the development of generalizable electronic information chart certification checklists, requirements, and guidelines relating to:

- Categorizing levels of electronic information chart display clutter.
- Specific range-related requirements for declutter.
- Impact of electronic information chart complexity on pilot performance.
- Validation of levels of criticality of electronic information layers.
- Information automation issues relating to electronic information charts: distraction, information quality, skill degradation, and trust.
- Identification of potential for error in using electronic information charts.
- Access and usability of procedural notes.

The evaluations will validate and iterate the recommendations and guidelines we developed in this study. The output of this study also includes a certification and operational guidance checklist that can be used in the certification and operational approval of data-driven chart systems.

Integration with portable electronic devices: Many, if not all, of the data-driven charts concepts described in this paper can be exported to EFB applications. Because EFBs are often side-mounted, electronic information chart access, presentation, ergonomics, and crew procedures for EFBs may differ from front displays of chart data as described in this paper. We recommend future research on these differences so that display and control concepts can be used consistently across the flight deck. We recommend future research on these differences so that display and control concepts can be used consistently across the flight deck. We also recommend conducting research to compare flightcrew performance with data-driven charts in either the EFB or installed front flight deck displays.

Evaluate HF issues with the flight deck implementation of D-NOTAMS. The presentation of digital notices to airmen (NOTAM) on the flight deck raises some of the same issues as the presentation of chart notes. Considerations should include filtering and integration of digital NOTAM information about facilities that are closed or out-of-service with other displayed information, as well as the integration of digital NOTAM information with chart notes and automatic terminal information service (ATIS) information. These information sources are all highly correlated, and although flightcrews deal with them independently, digital cockpits allow merging and integration of information sources. Further research must verify the anticipated benefits of such integration on flightcrew workload, situation awareness, and potential for error.

Survey OEM philosophy on integration of chart data with map layers: Although different original equipment manufacturers (OEMs) have different schemes for layering information on navigation displays, creating a new layer for chart data increases the complexity and potential for clutter. While this project addressed the issue of clutter, the issue of information prioritization should be suitably explored in a part task HITL study under realistic scenario conditions. Such a study should address certification approval guidance, operational approval guidance, and HF design recommendations related to MOC with FAA regulation 25.1302.

Database synchronization and accuracy: The chart data presented on the front displays from the chart database is highly correlated with the data presented by the FMS from the FMS navigation database. Industry trends suggest that these two databases could be merged in the near future. This merger would have obvious cost savings for database subscription and reduced maintenance down time for database loading. However, we recommend exploring issues around the validation and verification of data necessary for the IFR procedures. Also, not all chart data is used for navigation; notes, expect altitudes, expect speeds, condition based minima, etc. will make the merger of the two databases complex. There is the potential for compatibility issues between the two databases. Currently DDC is based on IFR procedures only (arrivals, approaches, and departures) and not IFR high and low enroute.

Chart complexity: Chart complexity includes display characteristics such as the quantity of information (number of elements), the variety of elements (diversity in the types of information presented), and display dynamics. This paper presented concepts presented (for example decluttering schemes) that provide ways and means of reducing chart complexity. We recommend conducting more formal and operational studies, including information theoretic approach techniques and metrics for determining complexity of display, to categorize different levels of complexity of electronic information charts and their impact on pilot performance, including potential for error. This research will help certification evaluators determine appropriate levels of scrutiny and MOCs to requirements.

Develop recommendations for inspector guidance: Conduct studies to develop specific evaluation guidance for aviation safety inspectors who will operationally approve use of DDC and who will conduct safety oversight surveillance of operators who are approved for use of DDC.

Develop government/industry standards for DDC standardized functions: establish meetings to achieve government/industry consensus, including specific guidance for research to identify flightcrew performance and workload effects of alternatives under consideration.

Incorporate DDC operational guidance into AC 120-64 (Operational Use & Modification of Electronic Checklists). Further develop AC 120-64 to incorporate DDC operational guidance to guide applicants and inspectors who will make the operational approval decisions and to use material developed under this contract in the operational guidance section to develop a new OPSPEC for DDC.

Add DDC line check and route check operational guidance to FSIMS Order 8900.1 [Cockpit Enroute Inspection Vol 6: Chap 2, Section 9]. The DDC operational guidance is summarized as follows: DDC Operating experience, line checks, and route checks. Check airmen should routinely incorporate proper data-driven charts use as discussion, demonstration, or evaluation factors to satisfy requirements of 14 CFR part 121, when aircraft equipped with data-driven charts are used for line checks, route checks, or in conducting operating experience.

Declutter menus for DDC chart data should be intuitive and easily manipulated. The pilot must be able to comprehend the textual or symbolic meaning of the chart data that is being selected and/or deselected. Future research, conducted with empirical pilot in the loop simulations should be performed to address the categorization, menu hierarchy, menu navigation and naming conventions so that updates to AC 25-11A (Electronic Flight Deck Displays) can be made. Declutter menus for data driven charts have the potential of grouping and categorizing hundreds of individual chart elements. Thus, simplicity and intuitiveness are necessary to prevent undue pilot workload and confusion.

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9. APPLICABLE REFERENCE DOCUMENTS

The following documents, of the exact issue shown with the latest amendments and notes, form a part of this document to the extent specified herein.

Order of Precedence

In the event of a conflict between the contents of this document and the documents referenced herein, this document takes precedence. However, nothing in this document supersedes applicable laws and regulations.

GOVERNMENT & REGULATORY PUBLICATION REFERENCES

Federal Aviation Administration (FAA)

1. AC 23.1311-1C Installations of Electronic Displays
2. AC 25.1302-1 Installed Systems and Equipment for Use by the Flightcrew
3. AC 25-11A Electronic Flight Deck Displays
4. AC 120.70B Operational Authorization Process for use of Data Link Communication System;
5. AC 120.74B Parts 91, 121, 125, and 135 Flightcrew Procedures During Taxi Operations
6. AC 120.76B Guidelines for the Certification, Airworthiness, and Operational Use of Electronic Flight Bags
7. AC 120.64B Operational Use & Modification of Electronic Checklists
8. FAA Order 8400.10 Flight Standards Handbook Bulletin for Air Transportation
9. FAA Order 8900.1 Flight Standards Information Management
10. Title 14 CFR Part 121 Operating Requirements: Domestic, Flag, and Supplemental Operations
11. Title 14 CFR Part 125 Certification and Operations: Airplanes having a seating capacity of 20 or more passengers or a maximum payload capacity of 6,000 pounds or more; and rules governing persons on board such aircraft
12. Title 14 CFR Part 135 Operating Requirements: Commuter and On-Demand Operations and Rules Governing Persons On Board Such Aircraft
13. Title 14 CFR Part 135.83 Operating information required
14. Title 14 CFR Part 25 Airworthiness Standards: Transport Category Airplanes
15. Title 14 CFR Part 25.1301 Airworthiness Standards: Equipment Function and Installation
16. Title 14 CFR Part 25.1501 Airworthiness Standards: General Operating Limitations and Information
17. Title 14 CFR Part 91 General Operating Flight Rules
18. Title 14 CFR Part 91.189 Category II and III operations: General operating rules.
19. Title 14 CFR Part 91.503 Flying equipment and operating information
20. Title 14 CFR Part 91.505 Familiarity with operating limitations and emergency equipment
21. TSO 165 Electronic Map Display Equipment for Graphical Depiction of Aircraft Position
22. PS-ANM111-1999-99-2 Guidance for Reviewing Certification Plans to Address Human Factors for Certification of Transport Airplane Flight Decks.

Radio Technical Commission for Aeronautics (RTCA)

23. DO-178C Level C Software Considerations in Airborne Systems and Equipment Certification
24. DO-200A Standards for Processing Aeronautical Data
25. DO-201A Standards for Aeronautical Information
26. SC-227 Standards of Navigation Performance
27. DO-257A Minimum Operational Performance Standards for the Depiction of Navigational Information on Electronic Maps

Society of Automotive Engineering (SAE)

28. SAE ARP 5621[15] Electronic Display of Aeronautical Information
29. SAE ARP 5289A Electronic Aeronautical Symbols
30. SAE AIR 1093A Numeral, Letter, and Symbol Dimensions for Aircraft Instrument Display
31. SAE ARP 1068A Flight Deck Instrumentation, Display Criteria and Associated Controls for Transport Aircraft
32. SAE ARP 5430 Human Interface Criteria for Vertical Situation Awareness Displays
33. SAE ARP 4102-7 Appendix B Electronic Display Symbology

[15] SAE ARP 5621 was developed prior to the revision of SAE ARP 5289A, which specifies symbols for electronic displays. SAE ARP 5621 was not coordinated with the FAA, and its guidance may conflict with FAA regulatory and guidance material.

APPENDIX A: RESULTS OF CARD SORTING EXERCISE

The Honeywell research team conducted a card sort analysis to identify common themes in the placement of IFR chart data on the PFD, MFD, or VSD. Card sorting addresses the complexity and variety of items to be organized. The card sort was administered through a commercial card sorting web-site, which allowed pilots from Honeywell's internal pilot pool in several Honeywell locations to participate. They sorted the cards independently on their own computers. Each pilot was given specific instructions prior to participating in the evaluation as follows:

> *We are conducting research that will help us gain a better understanding of how instrument procedure data should be presented and categorized for each phase of flight across the flight deck.*
>
> *We would like you to focus on the following platform: full glass (4 or 5 display units such as dual PFDs, Dual or Triple MFDs) with or without EFB/side display would be the norm for Next Gen. Also, you will have a fixed chart viewer to brief all procedures. Finally, we would like you to assume FMS and integrated (versus federated) data-bus systems.*
>
> *So, as you think about the items: think about where you would like to see the information and think about how critical each element is to flying that procedure. We are defining criticality as the level at which you need access to that item for that phase of flight. Criticality 1 items would be required to be visible in order to successfully fly the procedure without having to reference the fixed chart source. Criticality 2 items are items that are required initially to be visible on the display but you would like to be able to quickly and easily remove them. They are good reminders of procedure elements but ultimately not needed to execute the procedure safely and efficiently. Criticality 3 items are elements that are not required to be up in order to execute the procedure, but can be brought up manually for reference at any time. Pre-flight elements are required during the preflight planning phase of a procedure but are not necessary to execute the procedure.*

Table A-1: Pilot Card Sort Results Collapsed by Criteria

Percent of Items in Each Group	Criteria 1	Criteria 2	Criteria 3	Briefing Only	Card Sort	ARP 5621 [16]	Engineer
IAP-Landing Minimums Height above Airport (HAA) (2)	50	45	5		1	2	
IAP-Landing Minimums CAT 2 Decision Altitude (DA) (2)	70	20	5	5	1	2	
IAP-Landing Minimums CAT 2 Radio Altimeter (RA) (1)	75	20	5		1	1	
IAP-Landing Minimums Minimum Descent Height (MDH) (2)	85	15			1	2	
IAP-Landing Minimums Decision Height (DH) (2)	80	15		5	1	2	
IAP-Landing Minimums Minimum Descent Altitude (MDA) (1)	85	15			1	1	
IAP-Landing Minimums CAT 1 Decision Altitude (DA) (1)	90	5		5	1	1	
SIDs-Textual Information-Climb Gradient – Obstacle (1)	15	15	25	45	4	1	
STAR-Transition Courses notes (2)	10	25	35	30	3	2	

[16] SAE ARP 5621 was developed prior to the revision of SAE ARP 5289A, which specifies symbols for electronic displays. SAE ARP 5621 was not coordinated with the FAA, and its guidance may conflict with FAA regulatory and guidance material.

Percent of Items in Each Group	Criteria 1	Criteria 2	Criteria 3	Briefing Only	Card Sort	ARP 5621 [16]	Engineer
STAR-Textual Information Performance limitations (2)	5	25	45	25	3	2	
STAR-Textual Information General Notes (2)		25	35	40	4	2	
SIDs-Textual Information-Procedural Data Notes (2)	10	10	50	30	3	2	
STAR-Textual Information Notes (2)	10	25	25	40	4	2	
SIDs-Transition Text (1)	15	30	30	25	2,3	1	
SIDs-Textual Information-Performance limitations (2)	15	25	20	40	4	2	
SIDs-Textual Information-Climb Gradient- ATC (1)	5	30	25	40	4	1	
SIDs-Textual Information-Notes (2)	5	20	35	40	4	2	
IAP Obstacle Heights and Related Datum (2)	20	25	35	20	3	2	
IAP-Navigation Procedural Data Notes (2)	10	40	25	25	2	2	
STAR-Textual Information Text Only Procedures (1)	20	25	25	30	4	1	
SIDs-Textual Information-Text Only Procedures (1)	25	10	40	25	3	1	
IAP-Navigation General Notes (2)	10	20	35	35	3,4	2	
STAR-Textual Information Procedural Data Notes (2)		30	35	35	3,4	2	
SIDs-Textual Information-Runway departure text (1)	5	30	25	40	4	1	
STAR-Transition Text (1)	10	20	35	35	3,4	1	
STAR-Textual Information Noise Abatement (2)	5	20	40	35	3	2	
SIDs-Textual Information-Noise Abatement (2)	10	20	25	45	4	2	
SIDs-Textual Information-General Notes (2)	5	20	30	45	4	2	
STAR-Textual Information Crossing Altitude Restrictions (1)	40	35	15	10	1	1	
STAR-Textual Information Runway Arrival Text (1)	10	45	25	20	2	1	
SIDs-Transition Courses Notes (2)	20	30	30	20	2,3	2	
SIDs-Textual Information-Speed Restrictions (1)	25	30	30	15	2,3	1	
STAR-Communications-Transponder Setting, where appropriate (2)	10	50	15	25	2	2	
IAP City Location and Name	20	30	20	30	2,4		
IAP-Geography Visual Landmarks (not required for navigation) (2)	15	20	30	35	4	2	
IAP-Geography International Boundaries (2)	20	35	25	20	2	2	
IAP-Communications Helicopter Freq (1)	25	15	30	30	3,4	1	
IAP-Navigation Aids Localizer Morse Code	5	35	35	25	2,3		
SIDs-Geography-International Boundaries (2)	10	10	50	30	3	2	
SIDs-Navaids for Legs-Morse code (2)	15		55	30	3	2	
STAR-Navaids for Legs-Morse code (2)		25	45	30	3	2	
STAR-Navaids for Fixes-Morse code (2)		15	50	35	3	2	
SIDs-Navaids for Fixes-Morse code (2)	5	20	45	30	3	2	
IAP-Navigation Prohibited, Restricted, and Danger Airspace Graphic (1)	20	30	50		3	1	

Percent of Items in Each Group	Criteria 1	Criteria 2	Criteria 3	Briefing Only	Card Sort	ARP 5621 [16]	Engineer
STARS-Prohibited, Restricted and Danger Airspace Graphic (1)	20	30	45	5	3	1	
IAP-Navigation Special Use Airspace-Other (2)	5	25	40	30	3	2	
IAP-Secondary Airports Source Doc-Runway Layouts and Name	5	20	40	35	3		
STAR-Other Airport Names (2)	5	10	45	40	3	2	
IAP-Secondary Airports IFR Airports in Plan View	15	10	45	30	3		
IAP-Secondary Airports VFR Airports within Spec Dist. App Track	5	30	40	25	3		
SIDs-Other Airport Names (2)		20	45	35	3	2	
STARS-MSA Reference Point/Center (2)	15	35	25	25	2	2	
STARS-MSA Distance when other than 25nm (2)	5	45	35	15	2	2	
SIDS-MSA Sector Radials. (2)	5	30	40	25	3	2	
IAP-Navaids in the vicinity of the procedure Frequency (2)	10	35	40	15	3	2	
IAP-Navaids in the vicinity of the procedure Names (2)	5	25	50	20	3	2	
IAP-Navaids in the vicinity of the procedure Identifier (1)	10	35	45	10	3	1	
SIDs-Communications-Communications boundaries (2)	5	35	40	20	3	2	
IAP-Navaids in the vicinity of the procedure Symbol (2)	10	35	40	15	3	2	
SIDS-MSA Reference Point/Center (2)	15	30	30	25	2,3	2	
IAP MSA Distance when other than 25nm (2)	10	35	30	25	2	2	
SIDS-MSA Distance when other than 25nm (2)	5	30	45	20	3	2	
SIDs-Other Airport Elevations (2)		20	30	50	4	2	
IAP-Geography Range (1)	10	25	30	35	4	1	
STARS Range	10	25	50	15	3		
SIDs-Geography-Parallels and Meridians with AMAs, OROCAs, MORAs (2)		20	45	35	3	2	
STARS-AMA, OROCA or Grid MORA where est. (2)		25	55	20	3	2	
SIDS-AMA, OROCA or Grid MORA where est. (2)		25	45	30	3	2	
SIDs-Geography- Range (1)	5	35	30	30	2	1	
STAR-Other Airport Symbols (2)	5	35	40	20	3	2	
SIDs-Communications-Transponder setting where appropriate (2)	5	35	35	25	2,3	2	
STARS Terrain Contours (2)	10	40	20	30	2	2	
STARS Contour Interval Legend (2)	5	35	25	35	2,4	2	
IAP-Geography Visual Landmarks Label (not required for navigation) (2)	5	50	25	20	2	2	
SIDs-Geography-Terrain Contours (2)	10	50	20	20	2	2	
STARS Geography	10	35	25	30	2		
STARS Terrain Contour Elevations (2)	10	50	25	15	2	2	
SIDs-Course Definition-MEA/MOCA (1)	10	35	40	15	3	1	
IAP-Geography Spot Elevations (2)	5	40	35	20	2	2	

Percent of Items in Each Group	Criteria 1	Criteria 2	Criteria 3	Briefing Only	Card Sort	ARP 5621 [16]	Engineer
STAR-Communications-Lost Comm Procedure Outline Lines (2)	5	25	40	30	3	2	
SIDs-Other Airport Symbols (2)	10	20	55	15	3	2	
SIDs-Transition Course-MEAs, MOCAs (2)	5	40	40	15	2,3	2	
STAR-Communications-Communications Boundaries (2)		25	60	15	3	2	
SIDs-Communications-Lost Comm Procedure (2)		30	25	45	4	2	
STAR-Communications- Lost Comm Procedure (2)		35	35	30	2,3	2	
SIDs-Communications-Lost Comm Procedure Outline Lines (2)	5	30	35	30	3	2	
STAR-Course Definition-MEA/MOCA (2)	20	30	35	15	3	2	
STAR-Transition Course-MEAs, MOCAs (2)	20	30	35	15	3	2	
STARS-Special Use Airspace-Other (2)	5	40	35	20	2	2	
SIDs-Geography-Spot Elevations (2)	15	35	25	25	2	2	
IAP-Geography Terrain Contours (2)	25	25	30	20	3	2	
IAP-Geography Terrain Contour Elevations (2)	10	50	20	20	2	2	
SIDs-Geography-Terrain Contour Elevations (2)	5	45	30	20	2	2	
STAR- Primary Airport Shaded Area (2)	10	40	40	10	2,3	2	
SIDs-Geography-Highest Reference Point (2)	20	20	35	25	3	2	
IAP-Navigation Terminal Arrival Area (TAA) (2)	35	20	30	15	1	2	
IAP All appropriate Navaid Symbols (1)	50	25	10	15	1	1	
IAP MSA Reference Point/Center (2)	5	45	35	15	2	2	
IAP Minimum Area/Sector Altitudes	20	30	30	20	2,3		
IAP MSA Sector Radials. (2)	10	35	35	20	2,3	2	
IAP MSA Minimum Altitudes (2)	30	55	5	10	2	2	
SIDS-MSA Minimum Altitudes (2)	20	45	15	20	2	2	
IAP-Navigation Aids Marker Beacon Symbols (1)	35	40	15	10	2	1	
IAP-Geography Highest Reference Point (2)	25	40	20	15	2	2	
IAP-Navigation Aids Simultaneous Parallel Loc Symbol	30	40	25	5	2		
IAP Rate of Descent (feet per minute) (2)	25	45	20	10	2	2	
IAP Threshold Crossing Height (2)	25	60	5	10	2	2	
IAP-Navigation Aids Localizer Frequency (1)	60	30	10		1	1	
IAP-Navigation Aids WAAS/SVAS-LAAS/GBAS Channel (1)	35	45	15	5	2	1	
IAP-Procedure Navaid 0 Identifier (1)	35	45	15	5	2	1	
IAP-Navigation Aids Localizer Front Course for Back Crs Apprchs (1)	70	20	10		1	1	
IAP VNAV Intercept Altitude (Above Arpt) (QFE) (1)	45	45	10		1,2	1	
IAP Localizer Magnetic Course (1)	75	20		5	1	1	
IAP VNAV Intercept Altitude (MSL) (1)	60	35		5	1	1	

Percent of Items in Each Group	**Criteria 1**	**Criteria 2**	**Criteria 3**	**Briefing Only**	**Card Sort**	**ARP 5621[16]**	**Engineer**
IAP GS Intercept Altitude (MSL) (1)	60	40			1	1	
IAP GS Intercept Altitude (Above Arpt) (QFE) (1)	70	20	5	5	1	1	
IAP-Landing Minimums Visibility Requirement (1)	50	30	15	5	1	1	
IAP TDZE/Threshold Elevation for Landing Runway (1)	50	30	10	10	1	1	
IAP-Missed Approach Time from FAF to MAP (1)	45	35	15	5	1	1	
IAP Airport Elevation (1)	55	25	5	15	1	1	
IAP Landing Runway Number (1)	60	25	15		1	1	
IAP Glide Slope Angle (2)	50	35		15	1	2	
IAP-Procedure Navaid Names (2)	50	35	15		1	2	
IAP VNAV Angle (2)	50	45		5	1	2	
IAP Fix Name/Identifier (1)	65	25		10	1	1	
IAP Step-Down Fix Formation (1)	60	40			1	1	
IAP Procedure Turn Altitude (1)	45	50	5		2	1	
IAP Procedure Name (1)	50	25	10	15	1	1	
IAP Procedure Mag. Course (1)	70	25		5	1	1	
IAP Step-Down Fix Altitude (1)	65	30		5	1	1	
IAP FAF Crossing Altitude (MSL) (HAT) (1)	65	25	5	5	1	1	
IAP Fix Altitude (1)	75	20		5	1	1	
IAP-Missed Approach Location of MAP (1)	65	35			1	1	
IAP FAF (Maltese Cross) (1)	70	25		5	1	1	
IAP Runway Location in Profile View (1)	75	20	5		1	1	
IAP-Missed Approach Fix Name/Identifier at MAP (1)	65	30		5	1	1	
IAP Procedure Turn Outbound Course (1)	55	40	5		1	1	
IAP-Navigation Aids Localizer Identifier	60	30	5	5	1		
IAP Lead Radial (1)	50	40	10		1	1	
IAP-Missed Approach Distance from FAF to MAP (1)	45	35	10	10	1	1	
SIDs-DP Type (2)	25	25	25	25	1,2, 3,4	2	
IAP Transition Level (2)	20	45	20	15	2	2	
IAP Transition Altitude (2)	30	50	15	5	2	2	
STARS-Transition Level (2)	25	45	20	10	2	2	
STAR-Transition Courses Computer Codes (2)	20	15	35	30	3	2	
SIDs-Transition Courses Computer Codes (2)	30	25	20	25	1	2	
IAP-Holding Pattern Holding Pattern Leg Length (2)	25	45	20	10	2	2	
SIDs-Holding Pattern-Holding Pattern Time (2)	20	35	35	10	2,3	2	

Percent of Items in Each Group	Criteria 1	Criteria 2	Criteria 3	Briefing Only	Card Sort	ARP 5621 [16]	Engineer
IAP-Holding Pattern Holding Pattern Time (2)	35	30	25	10	1	2	
SIDs-Holding Pattern-Holding Pattern Leg Length (2)	20	50	20	10	2	2	
STAR-Holding Pattern Time (2)	20	35	35	10	2,3	2	
STAR-Holding Pattern Altitude (1)	30	25	35	10	3	1	
SIDs-Holding Pattern-Holding Pattern Altitude (1)	40	15	35	10	1	1	
SIDs-Holding Pattern-Holding Pattern Depiction (1)	30	35	25	10	2	1	
STAR-Holding Pattern Leg Length (2)	25	20	45	10	3	2	
IAP-Holding Pattern Holding Pattern Depiction (1)	40	30	20	10	1	1	
IAP-Holding Pattern Holding Pattern Courses (2)	45	15	30	10	1	2	
IAP-Holding Pattern Holding Pattern Speed (2)	25	50	10	15	2	2	
IAP-Holding Pattern Holding Pattern Altitude (1)	35	35	15	15	1.2	1	
STAR-Holding Pattern Speed (2)	25	35	30	10	2	2	
IAP-Navigation Aids Localizer for Intersection Formations (1)	45	35	15	5	1	1	
SIDs-Intersection/Fixes on Procedures-Symbol (1)	40	45	10	5	2	1	
IAP Fix Information (1)	50	45	5		1	1	
IAP-Holding Pattern	45	45	5	5	1,2		
STAR-Holding Pattern Depiction (1)	45	35	15	5	1	1	
SIDs-Holding Pattern-Holding pattern courses (2)	30	35	25	10	2	2	
STAR-Navaids for fixes-Identifier (1)	30	45	20	5	2	1	
STAR-Intersection/Fixes on Procedures Identifier (1)	40	35	15	10	1	1	
STAR- Primary Airport Elevation (1)	50	35	10	5	1	1	
IAP Airport Name (1)	55	20	5	20	1	1	
IAP Airport Identifier (1)	65	20	5	10	1	1	
IAP Fix Symbol (1)	70	15	5	10	1	1	
IAP-Navigation Aids Marker Beacon Labels (OM, MM, IM) (1)	50	35	10	5	1	1	
SIDs-Transition Courses Depiction (1)	55	30		15	1	1	
STARS City Location and Name (2)	25	30	35	10	3	2	
SIDs-City Location and Name (2)	25	25	30	20	3	2	
SIDs-Airport Elevation (1)	45	20	15	20	1	1	
SIDs-Airport Name (1)	40	30	15	15	1	1	
STARS Airport Name (1)	40	25	25	10	1	1	
STARS Airport Identifier (1)	55	15	20	10	1	1	
STAR-Transition Name (1)	50	20	20	10	1	1	
SIDs-Procedure Name (1)	50	15	15	20	1	1	
SIDs-Transition Name (1)	50	20	15	15	1	1	

Percent of Items in Each Group	Criteria 1	Criteria 2	Criteria 3	Briefing Only	Card Sort	ARP 5621[16]	Engineer
SIDs-Airport Identifier (1)	45	10	20	25	1	1	
SIDs-Procedure Identifier (2)	55	20	15	10	1	2	
IAP-Procedure Navaid Symbol (1)	65	10	15	10	1	1	
STAR-Transition Courses depiction (1)	65	15	15	5	1	1	
STARS Procedure Name (1)	45	30	15	10	1	1	
STARS Procedure ID (2)	40	35	10	15	1	2	
STAR-Transition Course-Magnetic Values (1)	40	15	35	10	1	1	
SIDs-Navaids for FIXES-IDENTIFIER (1)	40	25	30	5	1	1	
STAR-Transitions	50	35	10	5	1		
SIDs-Intersection/Fixes on Procedures-	55	25	15	5	1		
SIDs-Navaids for Legs-Names (2)	45	35	15	5	1	2	
SIDs-Intersection/Fixes on Procedures-Names (2)	55	20	20	5	1	2	
STAR-Intersection/Fixes on Procedures Symbol (1)	35	45	20		2	1	
STAR-Intersection/Fixes on Procedures Names (2)	50	30	20		1	2	
SIDs-Navaids for Legs-Identifier (1)	40	45	10	5	2	1	
STAR-Navaids for Fixes-Symbol (1)	35	35	20	10	1,2	1	
SIDs-Navaids for Fixes-Names (2)	40	25	30	5	1	2	
SIDs-Course Definition-Segment Mileages (2)	35	35	30		1,2	2	
STAR-Navaids for legs-Names (2)	30	50	15	5	2	2	
SIDs-Navaids for fixes-Symbol (1)	40	40	15	5	1,2	1	
SIDs-Course Definition-Radial (1)	40	30	25	5	1	1	
STAR-Navaids for Fixes-Names (2)	45	20	25	10	1	2	
SIDs-Intersection/Fixes on Procedures-Identifier (1)	50	25	20	5	1	1	
STAR-Course Definition-Segment Mileages (1)	30	30	30	10	1,2, 3	1	
STAR-Transition Courses-Segment Mileages (2)	35	30	25	10	1	2	
SIDs-Navaids for Legs-Symbol (1)	45	20	25	10	1	1	
SIDs-Transition Courses-Segment Mileages (2)	45	20	30	5	1	2	
STAR-Holding Pattern Courses (2)	45	30	20	5	1	2	
IAP Runway Layouts (1)	40	35	15	10	1	1	
IAP-Communications Ground Freq (2)	35	40	20	5	2	2	
STAR-Navaids for fixes-DME Distances that Form Fixes (2)	40	25	25	10	1	2	
SIDs-Navaids for fixes-DME Distances that Form Fixes (2)	35	25	35	5	1,3	2	
STAR-Course Definition-Radial (1)	50	25	25		1	1	
SIDs-Navaids for legs-Frequency/Channel (2)	40	35	25		1	2	

Percent of Items in Each Group	Criteria 1	Criteria 2	Criteria 3	Briefing Only	Card Sort	ARP 5621 [16]	Engineer
STAR-Navaids for fixes-Navaid Radials/Bearings that Form Fixes (2)	35	10	40	15	3	2	
SIDs-Navaids for fixes-Navaid Radials/Bearings that Form Fixes (2)	40	30	25	5	1	2	
STAR-Navaids for legs-Frequency/Channel (2)	40	30	30		1	2	
STAR-Navaids for fixes-Frequency/Channel (2)	35	35	25	5	1,2	2	
STAR-Course Definition-Heading (1)	40	35	20	5	1	1	
SIDs Transition Course-Magnetic Values (1)	30	50	15	5	2	1	
IAP Procedure Track (1)	70	20	5	5	1	1	
IAP Procedure Track Altitude (1)	55	30	15		1	1	
SIDs-Instrument Procedure Course/Tracks-Identifier (1)	55	30	15		1	1	
STAR-Instrument Procedure Courses/Tracks-Symbol (1)	70	10	10	10	1	1	
STAR-Course Definition-Track (1)	60	10	25	5	1	1	
SIDs-Course Definition-Heading (1)	60	20	15	5	1	1	
STAR-Instrument Procedure Courses/Tracks-Identifier (1)	60	15	20	5	1	1	
SIDs-Course Definition-Track (1)	65	15	20		1	1	
SIDs-Instrument Procedure Course/tracks-Symbol (1)	60	30	10		1	1	
IAP Procedure Track Mileage (1)	50	30	20		1	1	
IAP-Navigation Aids Primary Approach Localizer Symbol (1)	65	15	10	10	1	1	
IAP Obstacle Symbols (2)	40	45	10	5	2	2	
IAP Procedure Turn Distance Limit (1)	55	30	15		1	1	
IAP-Communications Approach Freq (2)	45	35	15	5	1	2	
IAP-Communications Tower Freq (1)	55	25	20		1	1	
STAR-Communications A-TIS Arrival Freq (2)	50	15	25	10	1	2	
STAR-Primary Airport Runway Layout (1)	30	15	30	25	1,3	1	
SIDs-Runway Layout (1)	15	40	25	20	2	1	
SIDs-Holding Pattern-Holding Pattern Speed (2)	20	40	30	10	2	2	
IAP-Procedure Navaid Frequency (2)	55	35	10		1	2	
STAR-Textual Information Speed Restrictions (1)	40	40	10	10	1,2	1	
SIDs-Textual Information-Crossing Altitude Restrictions (1)	35	45	15	5	2	1	
SIDs-Course Definition-VOR change Over Points (2)	15	35	35	15	2,3	2	
STAR-Navaids for Legs-Symbol (1)	25	45	25	5	2	1	
STAR-Navaids for Legs-Identifier (1)	20	45	35		2	1	
STAR-Communications-Approach Control (Arrival) (2)	15	45	35	5	2	2	
SIDs-Navaids for Fixes-Frequency/Channel (2)	15	40	35	10	1	2	
SIDs-Communications-Departure Control Freq (2)	25	50	20	5	2	2	

Table A-2. Card Sort Results and Allocation of Across

Percent of Items in Each Group	**MFD Criteria 1**	**MFD Criteria 2**	**MFD Criteria 3**	**PFD Criteria 1**	**PFD Criteria 2**	**Briefing Only**	**Card Sort**	**Allocation Across Cockpit**
IAP-Landing Minimums Height above Airport (HAA) (2)	10	35	5	40	10		**PFD 1**	PFD/ MFD
IAP-Landing Minimums CAT 2 Decision Altitude (DA) (2)	15	5	5	55	15	5	**PFD 1**	PFD
IAP-Landing Minimums CAT 2 Radio Altimeter (RA) (1)	15	5	5	60	15		PFD 1	PFD
IAP-Landing Minimums Minimum Descent Height (MDH) (2)	10	10		75	5		**PFD 1**	PFD
IAP-Landing Minimums Decision Height (DH) (2)	10	10		70	5	5	**PFD 1**	PFD
IAP-Landing Minimums Minimum Descent Altitude (MDA) (1)	10			75	15		PFD 1	PFD
IAP-Landing Minimums CAT 1 Decision Altitude (DA) (1)	10			80	5	5	PFD 1	PFD
SIDs-Textual Information-Climb Gradient – Obstacle (1)	15	10	30			45	**Brief**	
STAR-Transition Courses Notes (2)	5	20	40	5		30	**MFD 3**	
STAR-Textual Information Performance Limitations (2)	5	20	50			25	**MFD 3**	
STAR-Textual Information General Notes (2)		15	40		5	40	**MFD 3, Brief**	
SIDs-Textual Information-Procedural Data Notes (2)	10	5	55			30	**MFD 3**	
STAR-Textual Information Notes (2)	10	20	30			40	**Brief**	
SIDs-Transition Text (1)	15	30	30			25	**MFD 2, 3**	
SIDs-Textual Information-Performance Limitations (2)	15	25	20			40	**Brief**	
SIDs-Textual Information-Climb Gradient- ATC (1)	5	15	30		10	40	**Brief**	
SIDs-Textual Information-Notes (2)	5	20	35			40	**Brief**	
IAP Obstacle Heights and Related Datum (2)	20	15	35		10	20	**MFD 3**	
IAP-Navigation Procedural Data Notes (2)	10	30	30		5	25	**MFD 2,3**	
STAR-Textual Information Text--only Procedures (1)	20	20	30			30	**MFD 3, Brief**	
SIDs-Textual Information-Text-only Procedures (1)	25	5	45			25	**MFD 3**	
IAP-Navigation General Notes (2)	10	15	40			35	**MFD 3**	
STAR-Textual Information Procedural Data Notes (2)		25	40			35	**MFD 3**	
SIDs-Textual Information-Runway Departure Text (1)	5	25	30			40	**Brief**	
STAR-Transition Text (1)	10	10	40		5	35	**MFD 3**	
STAR-Textual Information Noise Abatement (2)	5	15	45			35	**MFD 3**	
SIDs-Textual Information-Noise Abatement (2)	10	15	30			45	**Brief**	

Percent of Items in Each Group	**MFD Criteria 1**	**MFD Criteria 2**	**MFD Criteria 3**	**PFD Criteria 1**	**PFD Criteria 2**	**Briefing Only**	**Card Sort**	**Allocation Across Cockpit**
SIDs-Textual Information-General Notes (2)	5	15	35			45	**Brief**	
STAR-Textual Information Crossing Altitude Restrictions (1)	35	30	15	5	5	10	**MFD 1**	
STAR-Textual Information Runway Arrival Text (1)	10	40	30			20	**MFD 2**	
SIDs-Transition Courses Notes (2)	20	25	30		5	20	**MFD 3**	
SIDs-Textual Information-Speed Restrictions (1)	25	25	30		5	15	**MFD 3**	
STAR-Communications-Transponder Setting, where appropriate (2)	10	40	15		10	25	**MFD 2**	
IAP City Location and Name	20	25	20		5	30	Brief	
IAP-Geography Visual Landmarks (not required for navigation) (2)	15	20	30			35	**Brief**	
IAP-Geography International Boundaries (2)	20	35	25			20	**MFD 2**	
IAP-Communications Helicopter Freq (1)	25	10	30		5	30	**MFD 3, Brief**	
IAP-Navigation Aids Localizer Morse Code		15	40	5	15	25	MFD 3	
SIDs-Geography-International Boundaries (2)	10	10	50			30	**MFD 3**	
SIDs-Navaids for Legs-Morse code (2)	15		55			30	**MFD 3**	
STAR-Navaids for Legs-Morse code (2)		20	45		5	30	**MFD 3**	
STAR-Navaids for Fixes-Morse code (2)		15	50			35	**MFD 3**	
SIDs-Navaids for Fixes-Morse code (2)	5	15	50			30	**MFD 3**	
IAP-Navigation Prohibited, Restricted, and Danger Airspace Graphic (1)	15	20	50	5	10		**MFD 3**	
STARS-Prohibited, Restricted and Danger Airspace Graphic (1)	20	30	45			5	**MFD 3**	
IAP-Navigation Special Use Airspace-Other (2)	5	20	40		5	30	**MFD 3**	
IAP-Secondary Airports Source Doc-Runway Layouts and Name	5	15	40		5	35	MFD 3	
STAR-Other Airport Names (2)	5	5	50			40	**MFD 3**	
IAP-Secondary Airports IFR Airports in Plan View	15	10	45			30	MFD 3	
IAP-Secondary Airports VFR Aprts within Spec Dist. App Track		25	45	5		25	MFD 3	
SIDs-Other Airport Names (2)		15	50			35	**MFD 3**	
STARS-MSA Reference Point/Center (2)	15	25	25		10	25	**MFD 2,3,4**	
STARS-MSA Distance, when other than 25nm (2)	5	25	40		15	15	**MFD 3**	
SIDS-MSA Sector Radials. (2)	5	20	45		5	25	**MFD 3**	
IAP-Navaids in the Vicinity of the Procedure Frequency (2)	10	25	40		10	15	**MFD 3**	

Percent of Items in Each Group	**MFD Criteria 1**	**MFD Criteria 2**	**MFD Criteria 3**	**PFD Criteria 1**	**PFD Criteria 2**	**Briefing Only**	**Card Sort**	**Allocation Across Cockpit**
IAP-Navaids in the Vicinity of the Procedure Names (2)	5	20	50		5	20	**MFD 3**	
IAP-Navaids in the Vicinity of the Procedure Identifier (1)	10	25	45		10	10	**MFD 3**	
SIDs-Communications Boundaries (2)	5	35	40			20	**MFD 3**	
IAP-Navaids in the Vicinity of the Procedure Symbol (2)	10	30	40		5	15	**MFD 3**	
SIDS-MSA Reference Point/Center (2)	15	25	30		5	25	**MFD 3**	
IAP MSA Distance, when other than 25nm (2)	10	30	30		5	25	**MFD 2,3**	
SIDS-MSA Distance, when other than 25nm (2)	5	20	50		5	20	**MFD 3**	
SIDs-Other Airport Elevations (2)		15	35			50	**Brief**	
IAP-Geography Range (1)	10	25	30			35	**Brief**	
STARS Range	10	15	55		5	15	MFD 3	
SIDs-Geography-Parallels and Meridians with AMAs, OROCAs, MORAs (2)		20	45			35	**MFD 3**	
STARS-AMA, OROCA or Grid MORA, where est. (2)		20	60			20	**MFD 3**	
SIDS-AMA, OROCA or Grid MORA, where est. (2)		25	45			30	**MFD 3**	
SIDs-Geography- Range (1)	5	25	35		5	30	**MFD 3**	
STAR-Other Airport Symbols (2)	5	25	45		5	20	**MFD 3**	
SIDs-Communications-Transponder Setting, where appropriate (2)	5	25	40		5	25	**MFD 3**	
STARS Terrain Contours (2)	5	40	20	5		30	2	
STARS Contour Interval Legend (2)		35	25	5		35	MFD 2, **Brief**	
IAP-Geography Visual landmarks Label (not required for navigation) (2)	5	45	30			20	MFD 2	
SIDs-Geography-Terrain Contours (2)	10	40	25		5	20	MFD 2	
STARS Geography	10	30	30			30	MFD 2,3,4	
STARS Terrain Contour Elevations (2)	10	45	30			15	MFD 2	
SIDs-Course Definition-MEA/MOCA (1)	5	25	45	5	5	15	**MFD 3**	
IAP-Geography Spot Elevations (2)	5	35	40			20	**MFD 3**	
STAR-Communications-Lost Comm Procedure Outline Lines (2)	5	20	45			30	**MFD 3**	
SIDs-Other Airport Symbols (2)	10	20	55			15	**MFD 3**	
SIDs-Transition Course-MEAs, MOCAs (2)	5	35	40		5	15	**MFD 3**	

Percent of Items in Each Group	**MFD Criteria 1**	**MFD Criteria 2**	**MFD Criteria 3**	**PFD Criteria 1**	**PFD Criteria 2**	**Briefing Only**	**Card Sort**	**Allocation Across Cockpit**
STAR-Communications-Communications Boundaries (2)		20	65			15	**MFD 3**	
SIDs-Communications-Lost Comm Procedure (2)		25	30			45	**Brief**	
STAR-Communications- Lost Comm Procedure (2)		25	40		5	30	**MFD 3**	
SIDs-Communications-Lost Comm Procedure Outline Lines (2)	5	25	40			30	**MFD 3**	
STAR-Course Definition-MEA/MOCA (2)	15	25	35	5	5	15	**MFD 3**	
STAR-Transition Course-MEAs, MOCAs (2)	20	25	35		5	15	**MFD 3**	
STARS-Special Use Airspace-Other (2)	5	30	40		5	20	**MFD 3**	
SIDs-Geography-Spot Elevations (2)	15	35	25			25	MFD 2	
IAP-Geography Terrain Contours (2)	20	20	35	5		20	**MFD 3**	
IAP-Geography Terrain Contour Elevations (2)	10	40	25		5	20	MFD 2	
SIDs-Geography-Terrain Contour Elevations (2)	5	40	35			20	MFD 2	
STAR- Primary Airport Shaded Area (2)	10	30	45		5	10	**MFD 3**	
SIDs-Geography-Highest Reference Point (2)	20	20	35			25	**MFD 3**	
IAP-Navigation Terminal Arrival Area (TAA) (2)	35	10	30		10	15	**MFD 1**	
IAP All appropriate Navaid Symbols (1)	40	20	10	10	5	15	MFD 1	
IAP MSA Reference Point/Center (2)	5	35	35		10	15	**MFD 2,3**	
IAP Minimum Area/Sector Altitudes	15	20	30	5	10	20	**MFD 3**	
IAP MSA Sector Radials. (2)	10	30	35		5	20	**MFD 3**	
IAP MSA Minimum Altitudes (2)	15	45	5	15	10	10	MFD 2	
0 MSA Minimum Altitudes (2)	15	35	15	5	10	20	MFD 2	
IAP-Navigation Aids Marker Beacon Symbols (1)	30	20	15	5	20	10	MFD 1	
IAP-Geography Highest Reference Point (2)	25	35	20		5	15	MFD 2	
IAP-Navigation Aids Simultaneous Parallel Loc Symbol	25	30	25	5	10	5	MFD 2	
IAP Rate of Descent (feet per minute) (2)	20	15	20	5	30	10	PFD 2	MFD
IAP Threshold Crossing Height (2)	25	30	5		30	10	PFD 2, MFD 2	MFD
IAP-Navigation Aids Localizer Frequency (1)	40	15	10	20	15		MFD 1	
IAP-Navigation Aids WAAS/SVAS-LAAS/GBAS Channel (1)	20	15	15	15	30	5	**PFD 2**	MFD
IAP-Procedure Navaid 0 Identifier (1)	30	30	15	5	15	5	**MFD 1,2**	
IAP-Navigation Aids Localizer Front Course for Back Crs Apprchs (1)	40	5	10	30	15		MFD 1	

Percent of Items in Each Group	**MFD Criteria 1**	**MFD Criteria 2**	**MFD Criteria 3**	**PFD Criteria 1**	**PFD Criteria 2**	**Briefing Only**	**Card Sort**	**Allocation Across Cockpit**
IAP VNAV Intercept Altitude (above Arpt) (QFE) (1)	25	15	10	20	30		**PFD 2**	PFD/ MFD
IAP Localizer Magnetic Course (1)	30	5		45	15	5	PFD 1	
IAP VNAV Intercept Altitude (MSL) (1)	30	10		30	25	5	MFD 1, PFD 1	PFD
IAP GS Intercept Altitude (MSL) (1)	35	5		25	35		MFD 1, PFD 2	PFD
IAP GS Intercept Altitude (above Arpt) (QFE) (1)	35	5	5	35	15	5	MFD 1, PFD 1	PFD
IAP-Landing Minimums Visibility Requirement (1)	40	15	15	10	15	5	MFD 1	
IAP TDZE/Threshold Elevation for Landing Runway (1)	35	5	10	15	25	10	MFD 1	
IAP-Missed Approach Time from FAF to MAP (1)	35	15	15	10	20	5	MFD 1	
IAP Airport Elevation (1)	35	15	5	20	10	15	MFD 1	
IAP Landing Runway Number (1)	45	15	15	15	10		MFD 1	
IAP Glide Slope Angle (2)	35	20		15	15	15	**MFD 1**	
IAP-Procedure Navaid Names (2)	45	25	15	5	10		MFD 1	
IAP VNAV Angle (2)	30	25		20	20	5	**MFD 1**	
IAP Fix Name/Identifier (1)	60	20		5	5	10	MFD 1	
IAP Step-Down Fix Formation (1)	55	15		5	25		MFD 1	
IAP Procedure Turn Altitude (1)	45	25	5		25		MFD 1	
IAP Procedure Name (1)	45	5	10	5	20	15	MFD 1	
IAP Procedure Mag. Course (1)	60	5		10	20	5	MFD 1	
IAP Step-Down Fix Altitude (1)	50	15		15	15	5	MFD 1	
IAP FAF Crossing Altitude (MSL) (HAT) (1)	50		5	15	25	5	MFD 1	
IAP Fix Altitude (1)	60	5		15	15	5	MFD 1	
IAP-Missed Approach Location of MAP (1)	55	10		10	25		MFD 1	
IAP FAF (Maltese Cross) (1)	55			15	25	5	MFD 1	
IAP Runway Location in Profile View (1)	65	5	5	10	15		MFD 1	
IAP-Missed Approach Fix Name/Identifier at MAP (1)	60	15		5	15	5	MFD 1	
IAP Procedure Turn Outbound Course (1)	50	20	5	5	20		MFD 1	
IAP-Navigation Aids Localizer Identifier	45	20	5	15	10	5	MFD 1	

Percent of Items in Each Group	**MFD Criteria 1**	**MFD Criteria 2**	**MFD Criteria 3**	**PFD Criteria 1**	**PFD Criteria 2**	**Briefing Only**	**Card Sort**	**Allocation Across Cockpit**
IAP Lead Radial (1)	40	15	10	10	25		MFD 1	
IAP-Missed Approach Distance from FAF to MAP (1)	35	15	10	10	20	10	MFD 1	
SIDs-DP Type (2)	20	20	25	5	5	25	**MFD 3, Brief**	
IAP Transition Level (2)	15	25	20	5	20	15	MFD 2	
IAP Transition Altitude (2)	25	25	15	5	25	5	**MFD 1, MFD 2, PFD 1**	
STARS-Transition Level (2)	20	25	20	5	20	10	MFD 2	
STAR-Transition Courses computer Codes (2)	20	15	35			30	**MFD 3**	
SIDs-Transition Courses computer Codes (2)	30	25	20			25	**MFD 1**	
IAP-Holding Pattern Holding Pattern Leg Length (2)	20	35	20	5	10	10	MFD 2	
SIDs-Holding Pattern-Holding Pattern Time (2)	15	35	35	5		10	**MFD 2,3**	
IAP-Holding Pattern Holding Pattern Time (2)	25	30	25	10		10	MFD 2	
SIDs-Holding Pattern-Holding Pattern Leg Length (2)	20	45	20		5	10	MFD 2	
STAR-Holding Pattern Time (2)	20	35	35			10	**MFD 2,3**	
STAR-Holding Pattern Altitude (1)	25	20	40	5		10	**MFD 3**	
SIDs-Holding Pattern-Holding Pattern Altitude (1)	35	15	35	5		10	**MFD 1,3**	
SIDs-Holding Pattern-Holding Pattern Depiction (1)	30	30	25		5	10	**MFD 2**	
STAR-Holding Pattern Leg Length (2)	25	10	45		10	10	**MFD 3**	
IAP-Holding Pattern Holding Pattern Depiction (1)	35	15	20	5	15	10	MFD 1	
IAP-Holding Pattern Holding Pattern Courses (2)	40	10	30	5	5	10	**MFD 1**	
IAP-Holding Pattern Holding Pattern Speed (2)	25	40	10		10	15	MFD 2	
IAP-Holding Pattern Holding Pattern Altitude (1)	30	20	15	5	15	15	MFD 1	
STAR-Holding Pattern Speed (2)	20	25	35	5	5	10	**MFD 3**	
IAP-Navigation Aids Localizer for Intersection Formations (1)	30	30	15	15	5	5	**MFD 1,2**	
SIDs-Intersection/Fixes on Procedures-Symbol (1)	35	40	10	5	5	5	**MFD 2**	
IAP Fix Information (1)	40	25	5	10	20		MFD 1	
IAP-Holding Pattern	40	30	5	5	15	5	MFD 1	
STAR-Holding Pattern Depiction (1)	40	35	15	5		5	MFD 1	
SIDs-Holding Pattern-Holding Pattern Courses (2)	25	35	25	5		10	MFD 2	

Percent of Items in Each Group	**MFD Criteria 1**	**MFD Criteria 2**	**MFD Criteria 3**	**PFD Criteria 1**	**PFD Criteria 2**	**Briefing Only**	**Card Sort**	**Allocation Across Cockpit**
STAR-Navaids for Fixes-Identifier (1)	25	40	25	5		5	**MFD 2**	
STAR-Intersection/Fixes on Procedures Identifier (1)	35	30	20	5		10	MFD 1	
STAR- Primary Airport Elevation (1)	35	30	10	15	5	5	MFD 1	
IAP Airport Name (1)	50	15	5	5	5	20	MFD 1	
IAP Airport Identifier (1)	50	20	5	15		10	MFD 1	
IAP Fix Symbol (1)	60	10	5	10	5	10	MFD 1	
IAP-Navigation Aids Marker Beacon Labels (OM, MM, IM) (1)	45	25	10	5	10	5	MFD 1	
SIDs-Transition Courses Depiction (1)	55	25			5	15	MFD 1	
STARS City Location and Name (2)	25	25	40			10	**MFD 3**	
SIDs-City Location and Name (2)	25	25	30			20	**MFD 3**	
SIDs-Airport Elevation (1)	45	10	15		10	20	MFD 1	
SIDs-Airport Name (1)	35	30	15	5		15	MFD 1	
STARS Airport Name (1)	40	15	25		10	10	MFD 1	
STARS Airport Identifier (1)	55	10	20		5	10	MFD 1	
STAR-Transition Name (1)	45	20	20	5		10	MFD 1	
SIDs-Procedure Name (1)	50	10	15		5	20	MFD 1	
SIDs-Transition Name (1)	45	20	15	5		15	MFD 1	
SIDs-Airport Identifier (1)	40	10	20	5		25	MFD 1	
SIDs-Procedure Identifier (2)	50	15	15	5	5	10	**MFD 1**	
IAP-Procedure Navaid Symbol (1)	60	10	15	5		10	MFD 1	
STAR-Transition Courses Depiction (1)	60	15	15	5		5	MFD 1	
STARS Procedure Name (1)	40	25	15	5	5	10	MFD 1	
STARS Procedure ID (2)	40	25	10		10	15	**MFD 1**	
STAR-Transition Course-Magnetic Values (1)	30	10	40	10		10	**MFD 3**	
SIDs-Navaids for Fixes-Identifier (1)	35	25	30	5		5	MFD 1	
STAR-Transitions	50	30	10		5	5	MFD 1	
SIDs-Intersection/Fixes on Procedures-	50	25	15	5		5	MFD 1	
SIDs-Navaids for Legs-Names (2)	40	35	15	5		5	**MFD 1**	
SIDs-Intersection/Fixes on Procedures-Names (2)	50	15	25	5		5	**MFD 1**	

Percent of Items in Each Group	**MFD Criteria 1**	**MFD Criteria 2**	**MFD Criteria 3**	**PFD Criteria 1**	**PFD Criteria 2**	**Briefing Only**	**Card Sort**	**Allocation Across Cockpit**
STAR-Intersection/Fixes on Procedures Symbol (1)	30	40	25	5			**MFD 2**	
STAR-Intersection/Fixes on Procedures Names (2)	45	25	25	5			**MFD 1**	
SIDs-Navaids for Legs-Identifier (1)	35	35	15	5	5	5	**MFD 1,2**	
STAR-Navaids for Fixes-Symbol (1)	35	25	25		5	10	MFD 1	
SIDs-Navaids for Fixes-Names (2)	40	20	30		5	5	**MFD 1**	
SIDs-Course Definition-Segment Mileages (2)	35	30	30		5		**MFD 1**	
STAR-Navaids for Legs-Names (2)	30	40	20		5	5	MFD 2	
SIDs-Navaids for Fixes-Symbol (1)	35	35	20	5		5	**MFD 1,2**	
SIDs-Course Definition-Radial (1)	40	20	25		10	5	MFD 1	
STAR-Navaids for Fixes-Names (2)	45	15	25		5	10	**MFD 1**	
SIDs-Intersection/Fixes on Procedures-Identifier (1)	50	15	25		5	5	MFD 1	
STAR-Course Definition-Segment Mileages (1)	25	30	30	5		10	**MFD 2,3**	
STAR-Transition Courses-segment mileages (2)	30	25	25	5	5	10	**MFD 1**	
SIDs-Navaids for Legs-Symbol (1)	40	15	25	5	5	10	MFD 1	
SIDs-Transition Courses-Segment Mileages (2)	40	15	35	5		5	**MFD 1**	
STAR-Holding Pattern Courses (2)	40	25	20	5	5	5	**MFD 1**	
IAP Runway Layouts (1)	35	25	15	5	10	10	MFD 1	
IAP-Communications Ground Freq (2)	35	25	20		15	5	**MFD 1**	
STAR-Navaids for Fixes-DME Distances that Form Fixes (2)	35	25	25	5		10	**MFD 1**	
SIDs-Navaids for Fixes-DME Distances that Form Fixes (2)	30	25	35	5		5	**MFD 3**	
STAR-Course Definition-Radial (1)	40	25	25	10			MFD 1	
SIDs-Navaids for Legs-Frequency/Channel (2)	35	30	25	5	5		**MFD 1**	
STAR-Navaids for Fixes-Navaid Radials/Bearings that Form Fixes (2)	25	10	40	10		15	**MFD 3**	
SIDs-Navaids for Fixes-Navaid Radials/Bearings that Form Fixes (2)	35	30	25	5		5	**MFD 1**	
STAR-Navaids for Legs-Frequency/Channel (2)	30	30	30	10			**MFD 1,2,3**	
STAR-Navaids for Fixes-Frequency/channel (2)	25	35	25	10		5	MFD 2	
STAR-Course Definition-Heading (1)	30	20	20	10	15	5	MFD 1	
SIDs Transition Course-Magnetic Values (1)	25	40	20	5	5	5	**MFD 2**	
IAP Procedure Track (1)	50	15	5	20	5	5	MFD 1	

Percent of Items in Each Group	**MFD Criteria 1**	**MFD Criteria 2**	**MFD Criteria 3**	**PFD Criteria 1**	**PFD Criteria 2**	**Briefing Only**	**Card Sort**	**Allocation Across Cockpit**
IAP Procedure Track Altitude (1)	50	20	15	5	10		MFD 1	
SIDs-Instrument Procedure Course/Tracks-Identifier (1)	50	25	15	5	5		MFD 1	
STAR-Instrument Procedure Courses/Tracks-Symbol (1)	60		10	10	10	10	MFD 1	
STAR-Course Definition-Track (1)	50	5	25	10	5	5	MFD 1	
SIDs-Course Definition-Heading (1)	45	20	15	15		5	MFD 1	
STAR-Instrument Procedure Courses/Tracks-Identifier (1)	50	15	20	10		5	MFD 1	
SIDs-Course Definition-Track (1)	50	10	20	15	5		MFD 1	
SIDs-Instrument Procedure Course/Tracks-Symbol (1)	50	25	10	10	5		MFD 1	
IAP Procedure Track Mileage (1)	40	20	20	10	10		MFD 1	
IAP-Navigation Aids Primary Approach Localizer Symbol (1)	40	5	10	25	10	10	MFD 1	
IAP Obstacle Symbols (2)	35	30	10	5	15	5	MFD 2	
IAP Procedure Turn Distance Limit (1)	50	25	15	5	5		MFD 1	
IAP-Communications Approach Freq (2)	30	25	15	15	10	5	**MFD 1**	
IAP-Communications Tower Freq (1)	50	15	20	5	10		MFD 1	
STAR-Communications A-TIS Arrival Freq (2)	40	15	25	10		10	**MFD 1**	
STAR-Primary Airport Runway Layout (1)	30	15	30			25	**MFD 1,3**	
SIDs-Runway Layout (1)	15	20	25		20	20	**MFD 3**	
SIDs-Holding Pattern-Holding Pattern Speed (2)	20	35	30		5	10	MFD 2	
IAP-Procedure Navaid Frequency (2)	35	30	10	20	5		**MFD 1**	
STAR-Textual Information Speed Restrictions (1)	35	30	10	5	10	10	MFD 1	
SIDs-Textual Information-Crossing Altitude Restrictions (1)	35	30	20		10	5	MFD 1	
SIDs-Course Definition-VOR Changeover Points (2)	15	25	40		5	15	**MFD 3**	
STAR-Navaids for Legs-Symbol (1)	20	35	30	5	5	5	**MFD 2**	
STAR-Navaids for Legs-Identifier (1)	20	35	40		5		**MFD 3**	
STAR-Communications-Approach Control (Arrival) (2)	15	35	40		5	5	**MFD 3**	
SIDs-Navaids for fixes-Frequency/Channel (2)	10	25	40	5	10	10	**MFD 3**	
SIDs-Communications-Departure Control Freq (2)	20	35	25	5	10	5	MFD 2	

APPENDIX B: DESIGN OBJECTIVES AND METHODS

B.1 Pilot Review Procedure

We invited 45 internal Honeywell flight test pilots to participate in an on-line, web-based review of the software prototype developed for this project. Ten pilots responded to the available time slots set for the evaluation, which we conducted in four separate sessions. During a session, we presented a general overview of the background and basic functionality of the charts manager to the pilots. Once the initial orientation was completed, we conducted a formal walk through on the prototype, including demonstration of the Setup menu, the notes filter mechanism, “My Notes,” and how to “stick pin” notes on the MFD map.

A researcher demonstrated a scenario where he loaded an instrument approach procedure (IAP) into the FMS and then set up charting elements through the Setup menu. In the menu setup, the researcher added charting elements to Layer 1 and others to Layer 2. From the procedure window, the researcher demonstrated the process of decluttering by adding and removing layers. The researcher then demonstrated the notes management system by setting up a departure. Once the departure was added into the flight plan, the researcher showed how the “stick pin” concept of adding several notes to the map functioned. Finally, the researcher demonstrated how to add notes to the “My Notes” section of the tool.

Table B-1 shows the demographics of the pilots that participated in the evaluation. Only eight of the ten pilots returned the questionnaire. Eight out of the ten pilots had an ATP rating. The average number of flight hours was 8,256 hours. The spread was a low of 650 hours and a high of 20,000 hours.

Pilots responded to 20 electronic information charts related to human factors questions on a seven point scale (1-Strongly Disagree to 7- Strongly Agree). The ratings varied from minimum of 3.3 to a maximum of 5.8 with an average rating of 4.9. Average responses to all the evaluation questions are shown in Table B-2. Appendix B.2 reports the detailed pilot comments in response to each question.

Table B-1: Pilot demographics from prototype evaluation.

Pilot	Age	Hours	Current Licenses
1	32	2300	ATP
2	37	5500	ATP
3	58	9600	ATP
4	65	20000	ATP
5	44	650	CPL ASEL/AMEL/IA CFI-A
6	45	5500	ATP
7	60	15000	ATP
8	68	7500	ATP/ASEL/AMEL/Helo/Instrument

Table B-2. Results of pilot feedback from pilot evaluation of prototype.

Question	Description	Average Pilot
1	The E-Chart tool supports my ability to quickly read and interpret the appropriate charting information for the procedure I am flying.	4.4
2	The E-Chart tool allowed for the accurate representation of the necessary charting data.	5.6
3	Markings and indications were clear and unambiguous (data was associated clearly with its textual information).	4.6
4	E-Charts provided enough detail necessary to accomplish flying the procedure without needing to reference a fixed chart.	5.1
5	E-Charts provided the appropriate declutter mechanisms to improve the readability of the procedure, yet display the most critical elements of the procedure.	4.5
6	E-Charts supported my ability to set-up the necessary procedure data using the interface controls.	5.1
7	The information provided by E-Charts on the moving map provided a means to manage the visual clutter associated with complicated procedures.	5.8
8	Interaction with the E-Chart was intuitive to use.	4.0
9	The E-Chart provides all the functions and capabilities I would expect it to have to view and execute my clearance.	4.9
10	E-charts have aesthetic appeal (i.e., I like the way the interface looks).	4.6
11	E-Chart mental workload is similar to what I would have using a paper charts or fixed charts.	3.3
12	Having the E-Chart functionality depicted charting information on my displays will make procedure execution easier than paper or fixed charts.	5.5
13	The E-Chart interface made all the necessary information accessible that would be needed to fly the procedure.	5.6
14	The E-Chart interface concepts were easy to understand.	5.6
15	There is minimal potential for error while using the E- Chart tool.	3.8
16	The procedural data in the menu selection interface was organized logically.	4.8
17	The E-Chart utilities (smart notes, declutter) will make my procedure tasks safer.	4.1
18	The Notes Interface was easy to use.	4.8
19	The Notes Interface provided an easy way to manage and organize the procedure specific notes.	4.1
20	Smart notes are a tool that I could see myself using.	5.3
21	I would enjoy using and having E-Charts to accomplish my flight procedures.	4
22	**General interface design is acceptable:**	

Question	Description	Average Pilot
23	*Pilot Menu Selection Interface*	4
24	*Declutter*	4
25	*Alignment of Text*	5
26	*Notes Interface*	5
27	*Font Size*	4
28	*Size of Controls (buttons, menu items)*	4

B.2 Pilot Comments

Declutter:

- The declutter system was very complex in appearance. After initial setup it may be easier. Perhaps more default models can be added.
- Again, this provides the means to manage clutter – if the pilot knows the EPIC glass window management system.
- Make the pilot de-select so as to ensure critical items were made available.
- In general, starting from "all" and moving to "declutter" would better support ability to quickly read and interpret the APPROPRIATE information needed. Starting from minimum info and moving to APPROPRIATE means reading/interpreting/deciding whether each piece of information must be included to create the final version that is needed. May not know what is being left out if you skip or miss something.
- Generally yes. Screen became cluttered sometimes when textual info was placed on the Moving Map display.
- Someone said let's declutter the clutter and list notes by heading. Good idea.
- My gut tells me that no matter how much thought a pilot puts into setting up the layering filters, one vital piece of information will get filtered out that the pilot will need to have displayed, and the pilot won't realize it until the pressure is on.
- All data should be available—no difference from paper/PDF.
- The declutter of the chart information looked good especially with many options on arrivals and departures.

Workload

- I would say the mental workload would be less with e-charts. I would not have to memorize information; it is simply displayed where I am already looking.
- Workload… It is much higher [*than my workload today*].
- It will always be harder when incorporating new technology declutter takes work but worth it.

Interface HF

- I would suggest adding the ability to completely remove the 1/3 notes window from view, while retaining any of the "My notes" on the map display. As was demonstrated, the map becomes very "busy" with information after loading an approach while displaying the vertical profile of an instrument approach. Removing the notes 1/3 window would give the crew the ability to expand the moving map to the full size which adds additional real-estate and provides the crew easier viewing of the map.
- Format was intuitive.
- For me the logic is quite easy to understand, this could be caused by being familiar with the existing Honeywell system logic.
- Menu selection must be intuitive, having fine granularity is nice but the pilot must understand what that will mean when they are on the approach several hours later.

- The missed approach 'panel' was perfect! Having this sort of pop up in the corner that guides after the missed approach or TOGA button was pressed is wonderful! It would be very valuable to have this for SIDs as well.
- The format and presentation of data chosen was very readable and looked good.
- No more or less accurate than published charts.

Notes

- Edit notes feature would be nice to have. Give the crew the ability to edit the notes to match airport or FDC NOTAMS.
- Note Icons on the moving map display need to be more unique/distinctive from other map symbology and have a defined location.
- I didn't care for the way it was organized. It was too want-ad like (hard to pick out what you're looking for in the long list, especially if you need to go back to find something. I would collapse the information to titles to reduce the size of the list. Click on a title to open up the note.
- I would like to see notes categorized by phase of flight.
- The notes interface is valuable; I would like to see stick pin type categories to know if the note is operational, informational, etc…
- In general, yes. One-third screen option for text notes uses a lot of real estate. Good to have options for using less space for this function.
- As discussed, the interface shown works well for a single- or two-pilot operation, but a multi-crew and/or airline environment would require a way for each pilot's personal preference to be quickly retrieved or for the airline's standard to be locked in.

Setup

- The setup page looked overwhelming to begin with, but made more sense after the presentation.
- Initial setup required high task loading and is best served for 2 pilot operations.
- Organization was good.
- There must be a menu accessible in flight to modify the level of information. A genius thought [I had] several hours ago may be a terrible idea when overlaying weather and a complex approach.

Training

- With a little training… and experience in finding the right level of use —probably differs from pilot to pilot.
- This function has GREAT potential. Good work!
- Maybe after some use – paradigm shift.
- Minor training will be required.
- Looks like a lot of training required.

Miscellaneous

- It's a great tool and looking forward to seeing this feature available for use.
- The data appeared to be accurate when compared to a chart on an iPad.
- Detail was good but will take some getting used to. It's hard to beat an iPad.
- Appeared to be very similar to charted procedures.
- If I failed to display information, I would not know it until I needed it—which could result in an error.
- I think this technology is fantastic!
- Need to determine importance of briefing strip and if something similar is required.
- Overlaying chart information is a giant leap forward.
- Excellent application! Exciting to see these steps to remove charts from cockpit.

APPENDIX C: DESIGN CONCEPTS

C.1 Procedure Specific FMS Programming

Example scenario (Figure C1.1, C1.2): Once the pilot selects the Little Rock transition on the Dallas Nine Departure, all other transitions are removed from the navigation display (ND). This single pilot action reduces the majority of the information on the display and allows the pilot to focus on only the relevant information associated with the cleared departure.

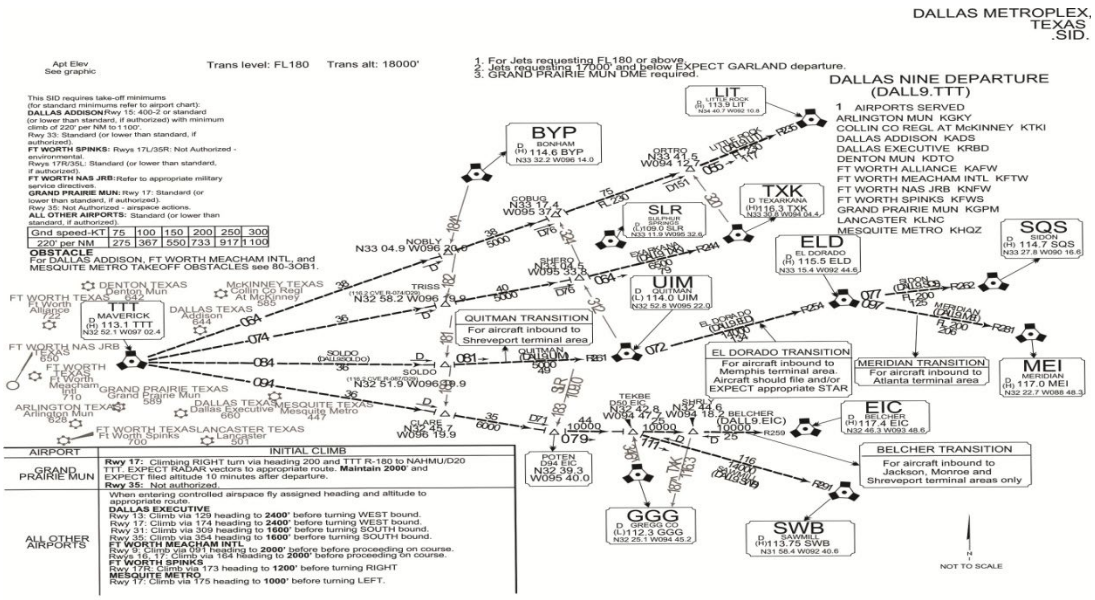

Figure C1.1: Example of a RNAV departure procedure, Dallas Nine

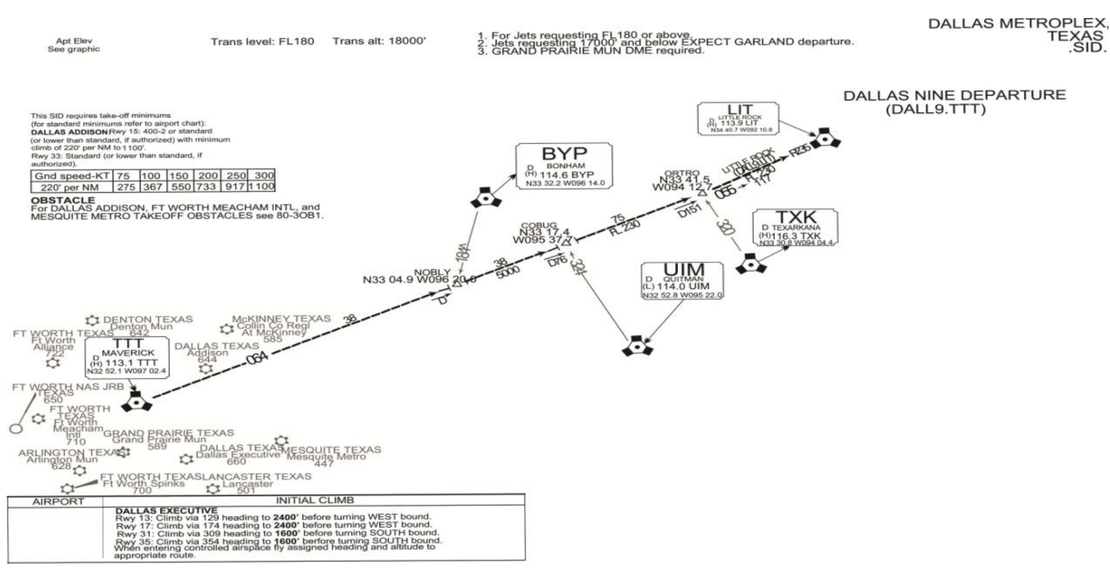

Figure C1.2: Example of the FMS down selections of the RNAV procedure, Dallas Nine LIT Transition

C.2 Removing Notes

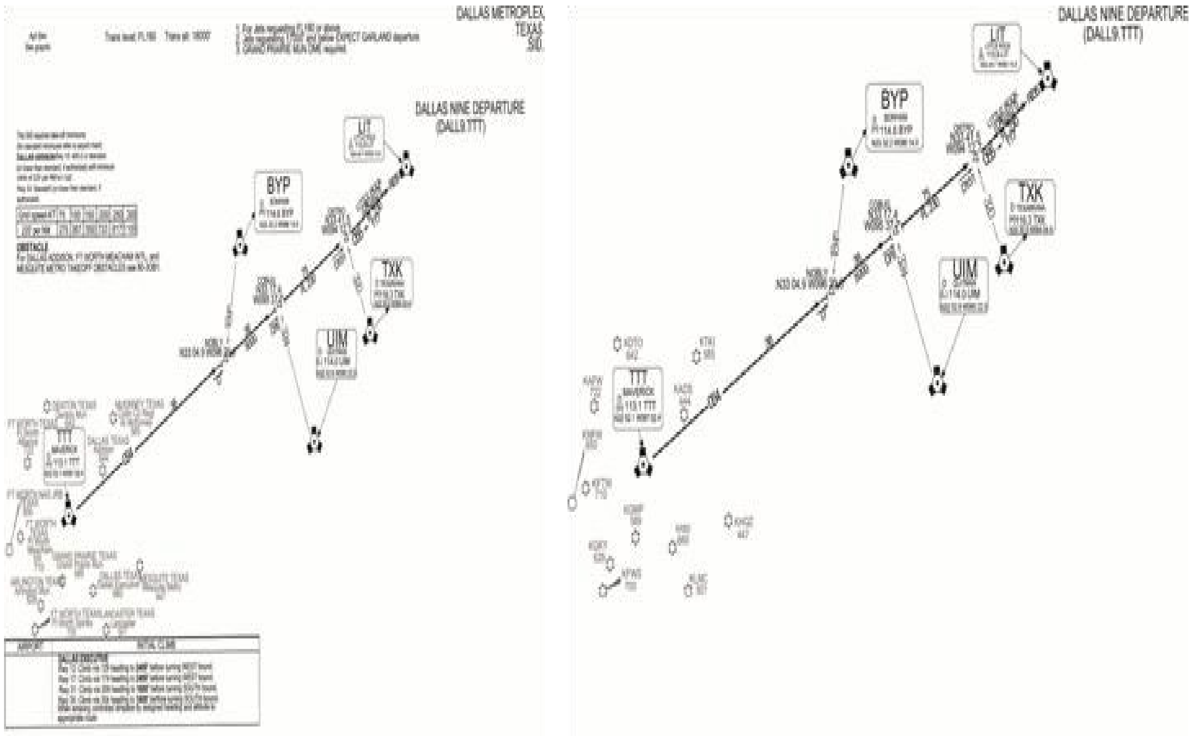

Figure C2.1: Procedural notes removed for additional clutter management

C.3 Radial Positioning Of Labels

Figure C.3.1: As the track of the aircraft changes, text rotates to maintain proper reading orientation.

C.4 Ranging In And Out

Figure C.4.1 shows how ranging in can provide a way to add more details to a segment on the course line. Figure C.4.2 shows how ranging out removes information/text displayed for each segment. A pilot can range out to declutter the display or can range in to see more details associated with each procedural element.

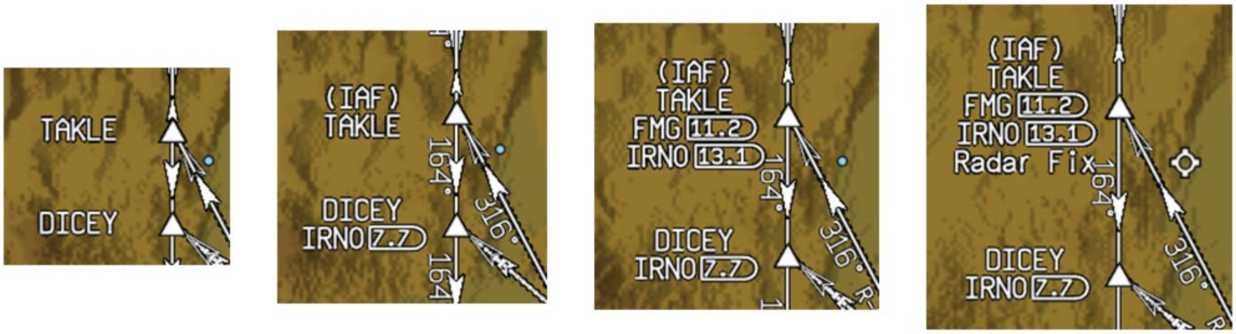

Figure C.4.1: Ranging in increases (left to right) the amount of textual information for each data element

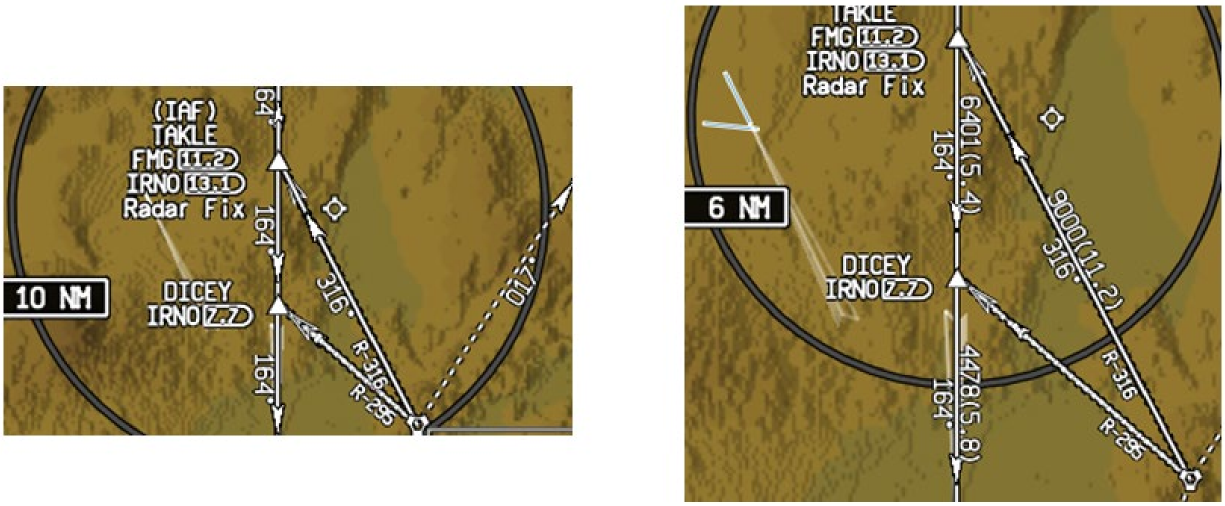

Figure C.4.2: Ranging out decreases the amount of text displayed for each segment

C.5 Point Without Arrowheads

Figure C.5.1: Removing arrowheads on leader lines removes extra visual clutter

C.6: Offset Display of Information

Figure C.6.1: Benefits of an offset pointer drawn to the area where the data belongs

C.7: Hot Spots with Pop-Up Hovering

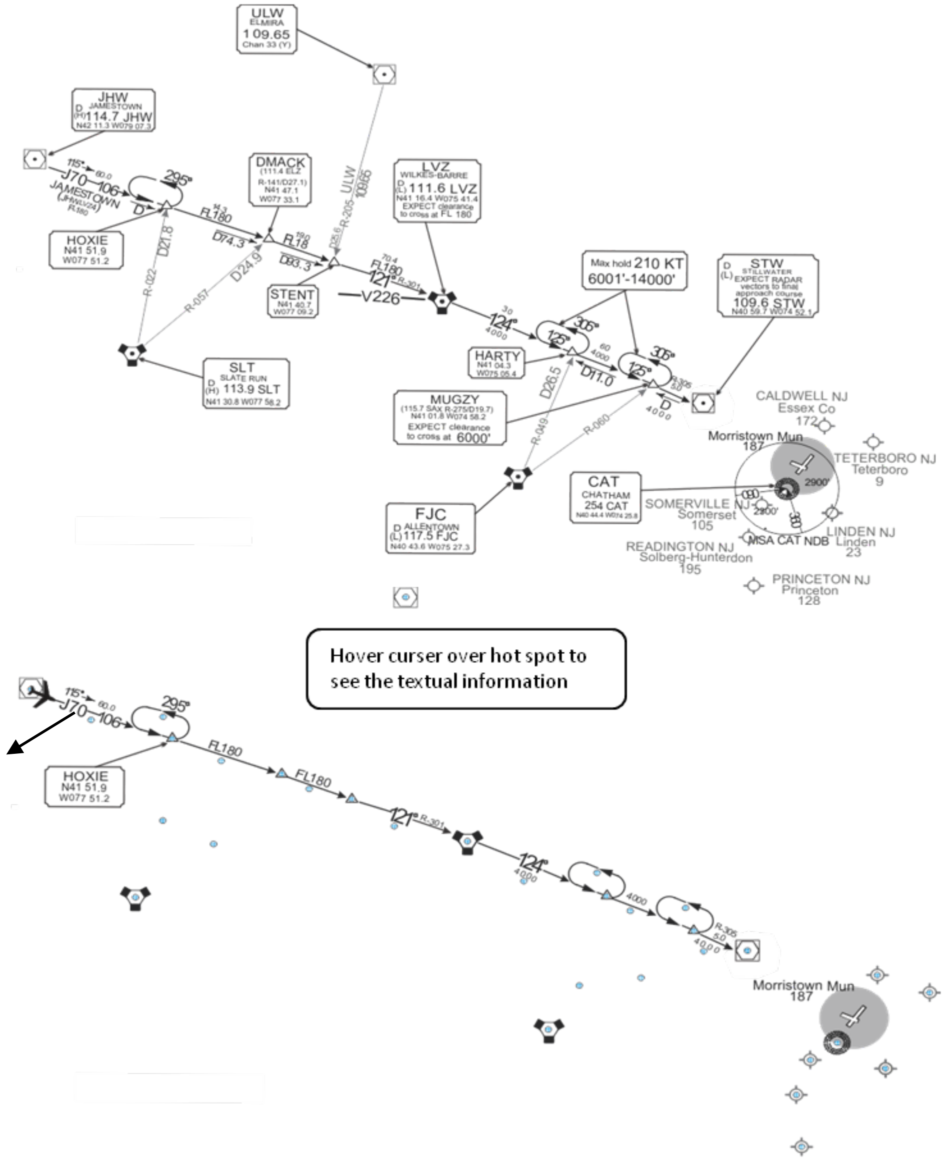

Figure C.7.1: Procedure decluttered, but items can be seen by hovering over the associated hot spots

C.8 Information Pop-Up Based On Relative Position To The Procedural Element

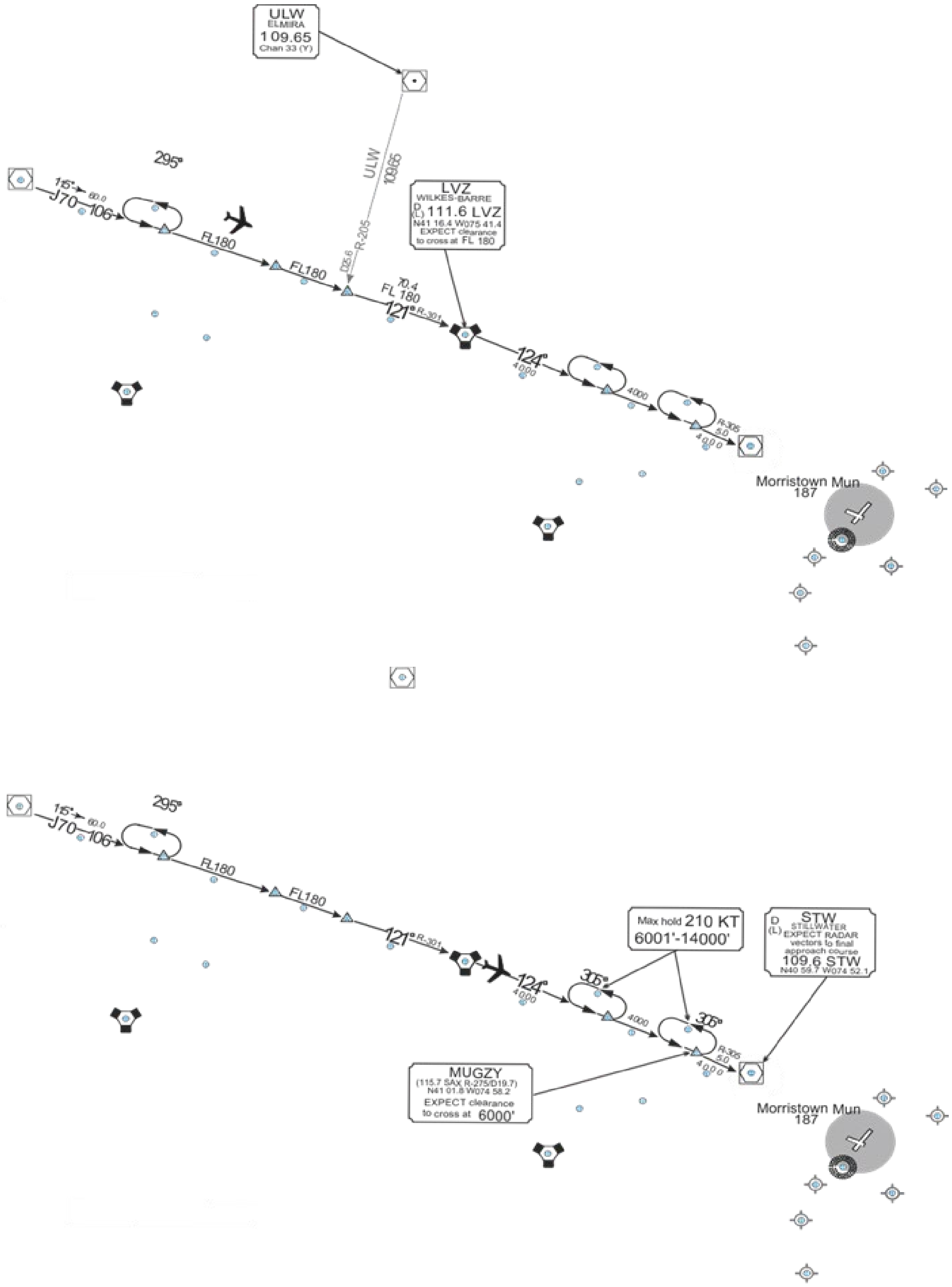

Figure C.8.1: Example of procedural pop-up elements