OPTIMIZED MINIMA INFORMATION ON DATA DRIVEN AERONAUTICAL CHARTS

T. Grasse, P. Wipplinger, T. Wiesemann, J. Schiefele
Jeppesen GmbH
Frankfurter Strasse 233, 63263 Neu-Isenburg
Germany

OVERVIEW

The approach is considered to be the flight phase with highest workload for pilots. New systems should support pilot tasks to reduce their workload as far as practical. This also applies to retrieving navigational information from charts. It has become common, to display aeronautical charts on electronic devices such as on an Electronic Flight Bag (EFB) [1] [2]. These aeronautical charts currently are displayed as pre-composed charts. The charts do not allow user interaction to filter information or alter displayed data. Approach charts for instance contain more information than a flight crew requires for executing the approach under a certain condition (e.g. aircraft approach category). Pilot workload during the approach could be decreased by providing and displaying only approach chart related information relevant to the current approach condition.

This paper describes a study performed for a real-time data driven generation of approach charts. Generation was performed deterministically and managed by a predefined set of composition rules. The rules automatically determine which information is relevant and needs to be displayed to the pilot. This study identified algorithms necessary to define the relevant information real-time. Various de-cluttered approach display concepts were evaluated with US and European pilots in terms of information retrieve ability, information location identification, error rates, workload, and readability. Based on the human factors results, a specific display concept solution was integrated into an EFB.

1. INTRODUCTION

As the execution of approaches is deemed to be the flight phase with highest pilot workload, new systems should be developed to better support pilot tasks and to reduce their workload as far as practical. This also applies to retrieving navigational information from charts.

Today's pre-composed charts depict all information which can be useful for a pilot. The information on approach charts, for instance, covers a variety of different possible approach conditions. According to a certain approach condition the corresponding set of information must be retrieved by the pilot and be applied to the performed operation. The most complex to retrieve information on approach charts is the *Minima Information*, which comprises Runway Visual Range (RVR) respectively Visibility (VIS) and Decision Height (DH) respectively Minimum Descent Altitude (MDA). These values are given subject to a couple of parameters outlining the approach condition. The following points are examples for parameters influencing the minimum values:

- aircraft category
- climb gradient of the aircraft for missed approach procedure
- the envisioned landing maneuver, which can be either 'straight in', 'side step' or 'circle to land'
- several approach related component out conditions or restrictions of the airport facilities, like centerline lighting out

In a specific approach only one set of minimum information is applicable and needed, determined by the current aircraft type with its climb capability, the envisioned landing maneuver and the condition of the airport facilities. By using a pre-composed chart, a pilot has to determine, which is the minimum information related to the current situation. Due to space constraints, it cannot be taken for granted, that the whole amount of information is located at one place on a pre-composed chart. Therefore, the locating, retrieving and delimitation of the minimum values requires time, increases the workload of the pilot and an element of risk remains that the pilot chooses the wrong set of values.

Since it has become common, to display aeronautical charts on electronic devices such as an EFB it is possible to display not only charts with pre-composed information. The introduction of *data driven* technology allows for filtering and alternation of a chart's content. Accordingly, the minimum information on approach charts can be arranged by considering the current approach condition. Subject to the parameters outlining the situation, as described above, is that the pilot can be provided only with the minimum information for the specific approach condition. A pre-defined set of decision rules enables the selection of the desired Minimum values. The decision rules can be derived from standard regulations with the most common regulations consisting of:

- JAR-OPS 1 [3]
- TERPS [4]
- New concept proposed in NPA-OPS 41 [5]

This paper describes the research work performed to generate Data Driven Hybrid approach charts. Hybrid means that both pre-composed and data driven technologies were utilized to compile a chart. The study comprises an analysis of the mentioned regulations, the development and evaluation of new concepts to display data driven minima information and the design of a system integration concept.

2. AERONAUTICAL APPROACH CHARTS

An approach chart, whether it is a digital or paper product, is composed in accordance with the ICAO Annex 4 [8].

This regulation requires the depiction of aerodromes, obstacles, prohibited, restricted and danger areas, radio communication facilities and navigation aids, minimum sector altitude or terminal arrival altitude, portrayal of procedure tracks, aerodrome operating minima and supplementary information. This information needs to be structured for appropriate readability by a pilot. For example, a Jeppesen approach chart consists of the following sections:

1) Header
2) Briefing Strip™
3) Plan View
4) Profile
5) Minima Table
6) Changes and copyright.

In FIG 1 these sections are bordered in red from the top to the bottom in the given sequence. This layout is called Display Concept 1 (DC1) throughout this document.

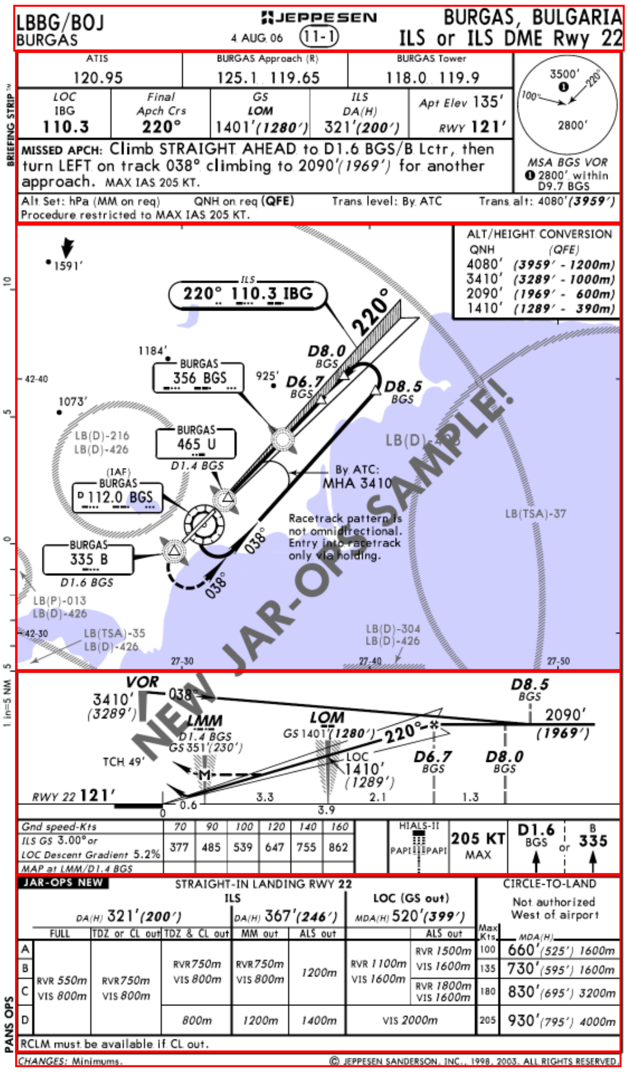

FIG 1. Standard Jeppesen layout of an approach chart

The header contains basic information regarding the airport and the charted approach, like ICAO code of the airport, approach procedure, the identifier of the runway, and effectivity date.

The Briefing Strip™ contains in the first row information about the available communication frequencies. The second row contains information regarding the primary navigation aids for the charted approach as well as global minima information and the elevation of the airport and the considered runway. A textual description of the missed approach procedure is given in row three. To the right of the description is the Minimum Sector Altitude (MSA) depicted as a diagram. The last row provides pilots with various approach related supplemental information.

Plan view and profile view depict the track of the procedure from a lateral and vertical point of view. The profile view also includes the ground speed box and the missed approach icons.

The depicted minima table on the lower part of an approach chart provides Decision Height (DH)/Minimum Descent Altitude (MDA) and Runway Visual Range (RVR) /Visibility (VIS) information for the various different landing maneuvers, aircraft categories, climb capabilities and component out conditions possible for the approach. Figure FIG 2 shows an example of a complex minima table.

JAR-OPS NEW	STRAIGHT-IN LANDING RWY 16 ILS with MH DME: Missed apch climb gradient mim 3.0% DA(H) 1064′(200′)			Missed apch climb gradient mim 2.5% DA(H) 1 C: 1124′(260′) D: 1134′(270′)			LOC (GS out) with BLM DME MDA(H) 1180′(316′)		CIRCLE-TO-LAND 3 Circling height based on rwy 16 thresh elev of 864′		
	FULL	TDZ or CL out	ALS out	FULL 2	FULL	ALS out		ALS out	Max Kts	MDA(H)	VIS
A	550m	750m	1200m	550m	750m	1200m	750m	1400m	110	1570′ (706′)	1500m
B	550m	750m	1200m	550m	750m	1300m	750m	1400m	135	1600′ (736′)	1600m
C	550m	750m	1200m	600m	750m	1300m	750m	1400m	180	2030′ (1166′)	2400m
D	550m	750m	1200m	600m	750m	1300m	750m	1400m	205	2230′ (1366′)	3600m

1 CAT A: 1104′ (240′), CAT B: 1114′ (250′). 2 AUTH OPERATORS. 3 Circling to rwy 34: VIS 5000m.

FIG 2. Minima table of an approach chart for an ILS approach on runway 16 of Basle airport

3. NEW AERODROME OPERATING MINIMA

The Joint Aviation Authorities (JAA) has published the Joint Aviation Requirements for Commercial Air Transportation (JAR-OPS 1) [3]. Subpart E of this document with its associated appendices describes how an operator in a JAA Member State has to apply minima information. These so called *Requirements for Aerodrome Operating Minima (AOM)* have been under review for a long time, mainly as a result of the harmonization work undertaken with the Federal Aviation Administration (FAA). Other reasons for reviewing the requirements were new desired flight techniques, like stabilized instrument approaches, and the introduction of new equipment, like Head-Up Display Landing System (HUDLS) or Enhanced Vision System (EVS), which are not taken into account by the current AOM tables. In succession of a couple of workshops the JAA issued the Notice(s) of Proposed Amendment (NPA) NPA-OPS 20 [6] and NPA-OPS 41 [5], which intends to reflect the mentioned deficiencies in JAR-OPS 1.

The new AOM concept describes a set of rules how an RVR value has to be calculated. The following points set the parameters for the calculation:

- Approach procedures are distinguished between non-precision and precision approach procedures. Non-precision approaches are procedures using Non-directional Radio Beacon (NDB), VHF Omni-directional Radio Range (VOR) or Localizer (LOC) each with or without Distance Measuring Equipment (DME). Procedures using VHF Direction Finding (VDF), Surveillance Radar Approach (SRA) and Area

Navigation with Lateral Navigation (RNAV/LNAV) are also considered as non-precision approaches. However, precision approaches are procedures using Instrument Landing System (ILS), Microwave Landing System (MLS), Global Navigation Satellite System Landing System (GLS), Precision Approach Radar System (PAR) and Approaches with vertical guidance (APV).

- A non-precision approach can be flown as a Continuous Descent Final Approach (CDFA) or in a traditional way, like Dive and Drive.
- The Approach Lighting System (ALS) available at an airport also influences the calculation. Possible equipages are Full, Intermediate, Basic and None ALS.
- Several component out conditions of the airport facilities are possible, including Centerline Lighting, Touchdown Zone Lighting or both are out.
- Special equipment of an aircraft, like HUDLS or EVS, is considered.
- The DH and the MDA for the certain approach must be provided by the state, based on PANS-OPS or TERPS procedure design rules.

The new JAR-OPS concept will determine that the result of the minima calculation is an RVR value. But a state will also be allowed to publish a VIS value. Also a state will be allowed to overrule the definitions and publish independent RVR (or VIS) values.

4. HUMAN FACTORS ANALYSIS

Four sets of new Data Driven (DD) Hybrid mock-ups were created based on input from pilots with respect to the Briefing Strip™ and minima table. The purpose of the human factors evaluation was to test these four new DD Hybrid generated minima table and Briefing Strip™ concepts in terms of:

- Information layout
- Information location
- Information retrieval
- Transition easiness in respect to aeronautical information retrieval from the pre-composed approach charts to the new DD Hybrid charts

The following hypotheses were defined as part of this evaluation:

Aeronautical Information Retrieval

For a specific approach type with associated aircraft and environmental constraints test subjects retrieve aeronautical minima information from a new DD Hybrid minima presentation in same or less time than when they retrieve the same information from a pre-composed aeronautical chart. The number errors test subjects wrongly retrieving aeronautical minimum information for a specific approach type with associated aircraft and environmental constraints by test subjects using a new DD Hybrid minima information presentation is equal or lower than when retrieving the information from pre-composed charts.

Identification of Aeronautical Information Location

For a specific approach type with associated aircraft and environmental constraints test subjects identify the location to retrieve specific aeronautical information from a new DD Hybrid minima presentation in same or less time than when they identify the location of the same information from a pre-composed aeronautical chart.

For a specific approach type with associated aircraft and environmental constraints test subjects identify the location to retrieve specific aeronautical information from a new DD Hybrid minima presentation with less error than when they identify the location of the same information from a pre-composed aeronautical chart.

Transition from DD Hybrid Chart Information to Pre-composed Chart Information

The number of test subjects wrongly retrieving specific minima aeronautical minimum information from a pre-composed chart is equal or less when transitioning from the DD Hybrid chart Display Concept (DC) 2 than other DD Hybrid charts.

The time test subjects require to retrieve specific minima aeronautical minimum information from a pre-Composed chart is equal or less when transitioning from the DD Hybrid chart DC2 than other DD Hybrid charts.

4.1. Evaluation Test Variables

Five different aeronautical minima information layouts were evaluated as independent test variables:

1) Pre-composed Instrument Approach Charts as currently in production at Jeppesen today (Display Concept 1)
2) DD Hybrid Instrument Approach Chart presentation with only specific aircraft approach category minimum information displayed in the Briefing Strip™. Additionally all facility and/or lighting dependent minima of a single aircraft approach category are displayed in a minima table right beneath the Briefing Strip™ and above the plan view. The minimum field in the briefing table displays decision/ minimum descent altitude, facility and environment condition and the necessary visibility conditions. This display concept has the MSA diagram lowered by one line with the airport elevation table moved to the right chart edge. This approach chart presentation allows the briefing minimum field to depict more information in width. If required constraint and note information will be depicted in the minimum table. (Display Concept 2).
3) DD Hybrid Instrument Approach Chart with the Briefing strip identical to that of today's pre-composed approach chart, but with a minima table specific to an aircraft approach category displayed between traditional Briefing Strip™ and plan view (Display Concept 3).
4) DD Hybrid Instrument Approach Chart presentation similar to 2) with the only difference that the minima table is displayed beneath the profile view (Display Concept 4).
5) DD Hybrid Instrument Approach Chart without a minima table. In the briefing table the MSA diagram is lowered by one line and the airport elevation moved further to the right providing more available space in the minimum box. This box displays minimums, required visibility and notes applicable to a specific

aircraft approach category and facility/environmental conditions. (Display Concept 5).

Dependent variables for this evaluation were:

- Aeronautical information retrieval error
- Time to retrieve a specific aeronautical information
- Post run questionnaire:
    - Workload NASA Task Load Index (TLX)
    - Display Readability Rating
- Debriefing questionnaire
- Open Interview after each test trial

4.2. Methodology and Evaluation Set-Up

This human factors evaluation focused on the minima information currently depicted in the minima table and to some degree also in the Briefing Strip™. The Briefing Strip™ was designed to provide an approach overview for the flight crew during the approach briefing. A previously conducted task and information analysis at Darmstadt University of Technology revealed that pilots used Briefing Strip™ depicted information only during the approach briefing and only in some occasions, retrieved information from this strip during the execution of the approach [9]. This information retrieved during the approach execution was limited to Missed Approach text information and Decision/Minimum Descent Altitude. Based on this and in order to keep a high level of control over the evaluation environment and to minimize any possible external disturbances this DD Hybrid evaluation was performed in form of a desktop evaluation.

Three phases of desktop evaluations were performed. Phase 1 was performed to assess the retrieval of specific information on a chart. Phase 2 focused on the location of specific chart information, whereas phase 3 was determined to evaluate transition easiness from a DD Hybrid display concept to the corresponding pre-composed chart. All display concepts were evaluated in a randomized order. For the desktop evaluation all display concepts were embedded within a PowerPoint presentation.

Prior to the evaluation run test subjects underwent a chart familiarization phase to get acquainted to each new display concept. For each display concept a PowerPoint presentation was utilized to conduct the evaluation.

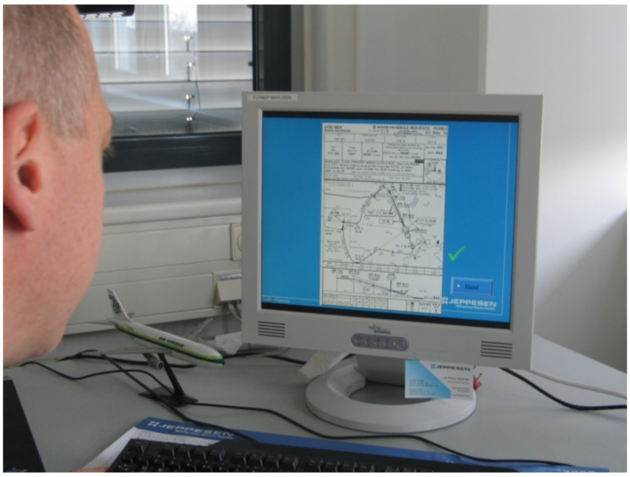

FIG 3. DD Hybrid Desktop Evaluation

FIG 3 illustrates the desktop evaluation performed within this DD Hybrid experiment.

Evaluation Proceeding:

Phase 1 focused on the retrieval of specific information from the Briefing Strip™ and minima table where available. The DD Hybrid approach chart was embedded within a PowerPoint presentation. An approach chart specific question was initially displayed (see FIG 4). The test subject using the PC mouse then acknowledged understanding the question by clicking on the question label. This acknowledgement was captured through the recording of the event in a log file and the presentation immediately displayed the approach chart. The test subject was prompted to click the right answer of the stated question on the chart using the mouse (depicted red rectangle in FIG 4). Mouse click location and time was captured in the log file.

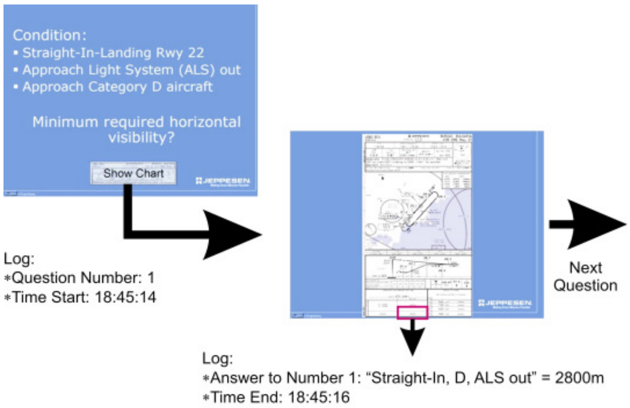

FIG 4. Methodology for chart information retrieval evaluation

Data captured were:

1) Elapsed time to select answer on the approach chart
2) Errors in chart item selection
3) NASA-TLX (workload) [10]
4) Display Readability Rating (DRR) [11]

Approach charts utilized in this evaluation phase were charts proposed by Jeppesen Data Standards and Jeppesen chart compilers from both Eastern and Western Hemisphere. These 25 charts were considered to be complex and challenging regarding briefing and minima table.

After each display concept evaluation post-run questionnaires covering workload and display readability were handed out to the test subject.

Phase 2 of the desktop evaluation focused on location detection of information from either the briefing table or minimum table or both. As in phase 1 the approach charts were embedded within a PowerPoint presentation. An approach condition was displayed followed by a question specific to the approach condition. By selecting the next PowerPoint slide the user acknowledged understanding approach condition and question. With the transition to the next slide the question number and time of slide transition was captured in a log file (see FIG 6). The following slide would then depict an approach chart with only the Briefing Strip[TM] information and minima fields. Only the field boundaries of briefing and minima table (if available) were clearly visible (see FIG 5) and no field content would be visible to the participant. The test subject was then asked to identify the location of the previously depicted question on the chart. By clicking the mouse over the field of interest (red rectangle in FIG 6) the correct answer would be displayed through a check mark. Retrieved information was captured in a log file together with time of retrieval.

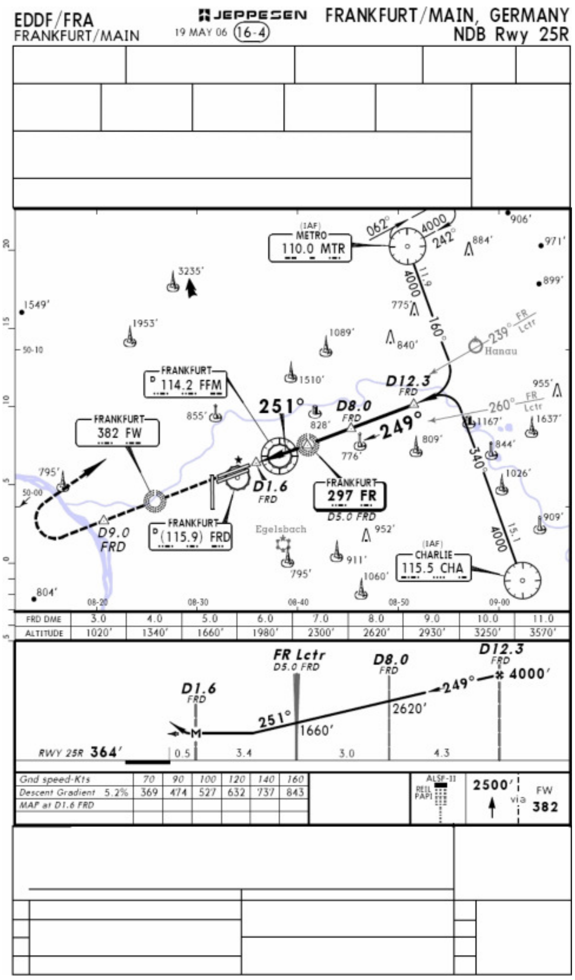

FIG 5. Phase 2 – Blank fields in Briefing Strip[TM] and minima Table

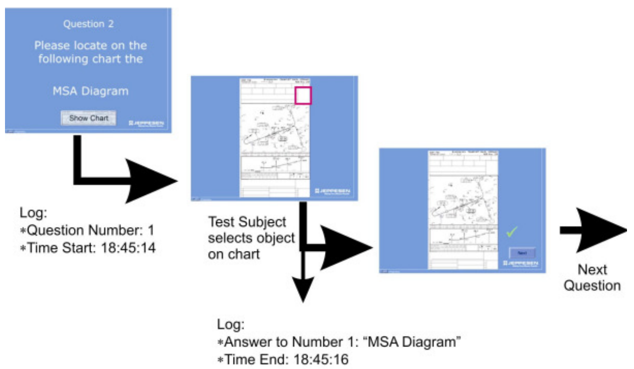

FIG 6. Methodology for chart information location evaluation

Data captured were:

1) Elapsed time to select answer on the approach chart
2) Errors in chart item selection

The third evaluation phase focused on the transitioning from a DD Hybrid chart to the corresponding pre-composed chart to determine transition easiness. This 3rd phase of the evaluation was also performed using a chart embedded PowerPoint presentation. Specific information in the DD Hybrid chart was highlighted on the chart (see red rectangle FIG 7). The test subject acknowledged this information of interest by calling the following slide. When requesting a next slide the information of interest together with time was captured in a log file. In the following slide the corresponding pre-composed chart was displayed. The test subject was then asked to identify and double click on the corresponding information which was previously displayed on the DD Hybrid chart. Time and information of selection was captured in the same log file.

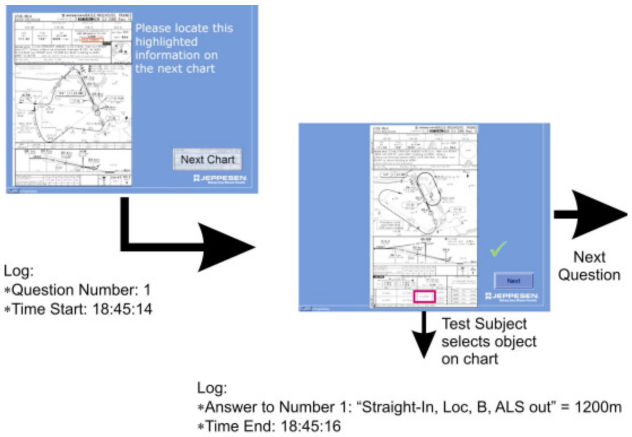

FIG 7. Methodology for DD Hybrid to Pre-Composed Information Retrieval Transition Easiness

Data captured were:

1) Time to select answer on the pre-composed approach chart
2) Errors in chart item selection on the pre-composed chart

4.3. Participants

A total of 11 pilots participated in this human factors evaluation. Background experience of these pilots is summarized in TAB 1. The average pilot's age was 36.7 years.

Variable	Mean	Minimum	Maximum
Age	36.7	22	50
Total Flying hours	3481	280	11600
IFR Hours	2513	45	11300

TAB 1. Ranges of Ages and Flying Hours

36% of the participants pursued their main duty as a pilot flying for domestic and internationally operating airlines, while the remaining 64% were Jeppesen employees flying in their spare time.

The pilots sampled were general, business, and commercial aviators. 73% of the participants possessed a valid Air Transport License and the remaining had a Commercial Pilot License. All participants stated to be familiar with Jeppesen charts. 36% of the participants were qualified to fly ILS CAT II and III approaches and 81% of the participants were familiar with the execution of RNAV GPS approaches.

73% of the participants predominantly flew in North America while the other 27% flew in Europe.

4.4. Results

4.4.1. Phase1 – Specific Information Retrieval

No significant differences in required information retrieval times were detected among the DC groups (p< 0.5) [12]. Mean times in seconds were longest for the participants to retrieve aeronautical information from the pre-composed charts (DC1) (see FIG 8). Participants interacting with the DD Hybrid display concepts required in mean less time to select the correct information from the charts. Here the test participants needed less than half of the mean time than utilizing DC1.

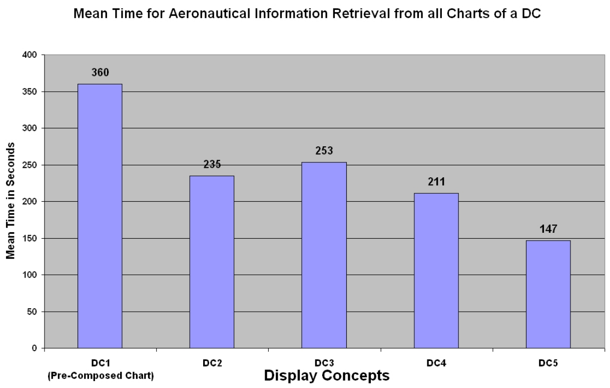

FIG 8. Phase 1 – Mean Time for Aeronautical Information Retrieval

Participant's errors while retrieving the aeronautical information from the charts were captured. A comparison among the DC groups reveals no statistical significance (p< .20.). FIG 9 depicts the mean error rate participants have conducted when retrieving aeronautical information. It shows that most mean errors were performed using the pre-composed charts (DC1). Least mean errors were captured for DC5. Mean error rates for DC2, DC3, and DC4 are approximately half the rate of DC1.

A direct comparison between the DD Hybrid Display Concepts and the pre-composed chart (DC1) indicated a statistical significance for all direct comparisons. The results of these analyses revealed the greatest difference to be in performed errors between DC5 and the pre-composed DC1 layout.

DC5 was rated by the pilots to induce less workload compared to the other display concepts. The pre-composed chart (DC1) was rated to provide most workload. Statistical analyses of the display workload ratings indicate no significant difference between the display concept ratings, $F(1,10)= 7.458$, $p<.597$, $MSA=6.251$ [12].

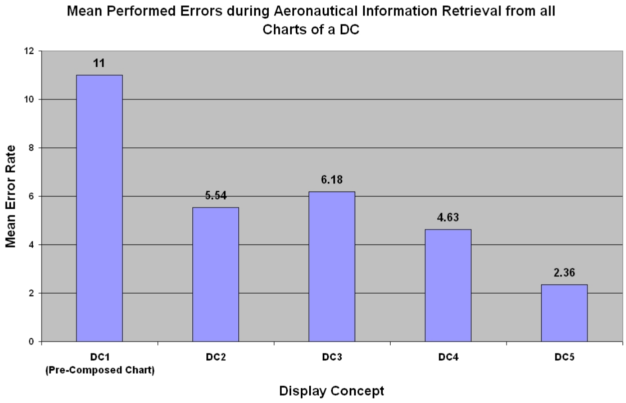

FIG 9. Phase 1 – Mean Error Rate for Aeronautical Information Retrieval

A direct comparison between the DD Hybrid Display Concepts and the pre-composed chart (DC1) revealed a statistical significance for all direct comparisons. The results of these analyses showed the greatest difference between DC5 and the pre-composed DC1 layout.

Participants' information readability and retrieve ability rating of the 5 display concepts under is depicted in the following FIG 10. Here DC5 was rated best.

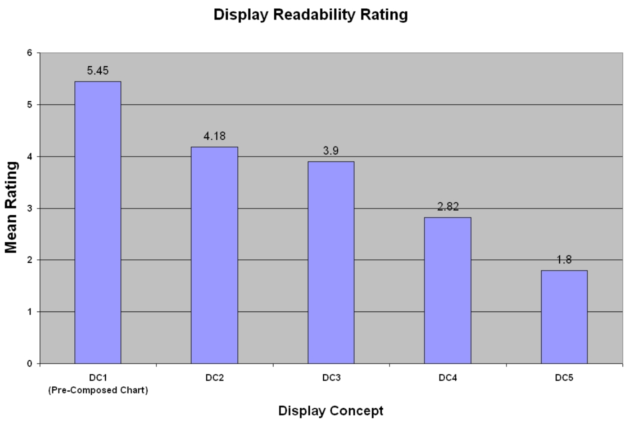

FIG 10. Phase 1 – Participant's Mean Display Readability Rating by DC

Participants in average rated the pre-composed Chart (DC1) to have moderately objectionable deficiencies. Minor but annoying deficiencies were observed by the participants for DC2 and DC3. DC1, DC2, and DC3 were rated not to be satisfactory and requiring improvement. DC4 was in average rated to be fair with some mildly unpleasant deficiencies when reading and retrieving aeronautical information. DC5 was rated to be satisfactory without improvement, providing negligible deficiencies.

Statistical analyses of the display readability ratings indicated significant difference between the display concept ratings (p<.031). A direct comparison between the DD Hybrid Display Concepts and the pre-composed chart (DC1) showed a statistical significance for all direct comparisons. The result of this analysis reveals a greatest difference between DC5 and the pre-composed DC1 layout.

4.4.2. Phase2 – Information Location Identification

There were significant differences among the display concepts in terms of mean times required to locate the field of information. ($p < 0.05$). Mean times in seconds were longest for the participants to locate the information field on the corresponding chart using DC3 (see FIG 11). DC1, DC2, and DC3 mean times were in the mean range of 30 seconds. Participants interacting with the DD Hybrid DC4 and DC5 required less time, with participants requiring half the mean time with DC5 than DC1, DC2, or DC3 (see FIG 11).

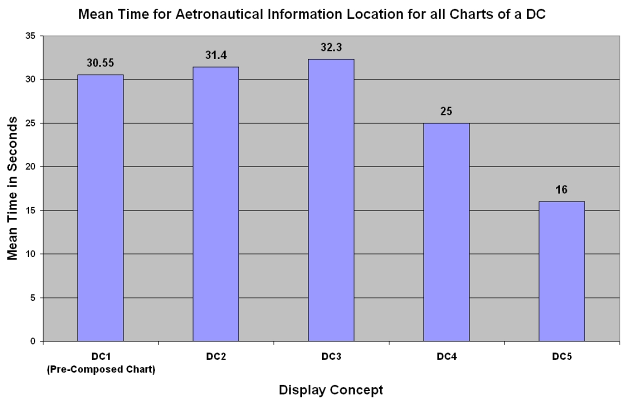

FIG 11. Phase 2 – Mean Time for Aeronautical Information Location

A direct comparison between the DD Hybrid Display Concepts and the pre-composed chart (DC1) revealed no statistical significance for all direct comparisons. The results of these analyses indicated the greatest time difference between DC5 and the pre-composed DC1 layout. A comparison among the DC groups revealed statistical significance in terms of performed errors when locating the field on the chart ($p < .05$). FIG 12 depicts the mean error rate participants have conducted when locating the field on the charts. It shows that most mean errors were performed using DC3. Participants using DC1, DC2, and DC4 achieved similar lower mean error rates. Least mean errors were captured for DC5.

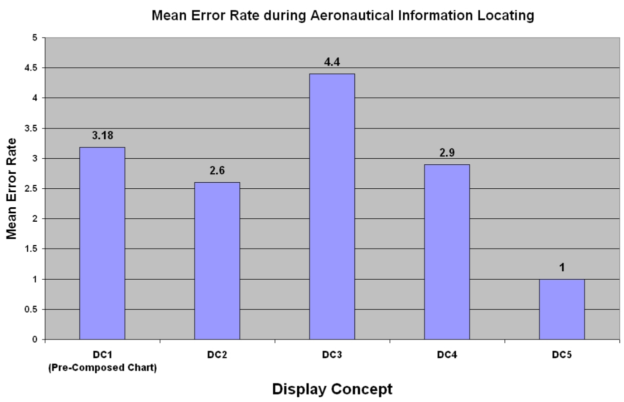

FIG 12. Phase 2 – Mean Error Rate for Aeronautical Information Location

Direct comparison between the DD Hybrid Display Concepts and the pre-composed chart (DC1) indicated no statistical significance for direct comparisons except for the direct comparison between DC5 and DC1. The results of these analyses revealed that greatest differences in performed errors occurred between DC5 and the pre-composed DC1 layout.

4.4.3. Phase3 – Transition to Pre-Composed Charts

Statistical analysis of mean transition times required to locate same aeronautical information from a DD Hybrid Chart on the pre-composed cart revealed no significant differences among the DD Hybrid charts. FIG 13 depicts mean time in seconds the participants needed to locate aeronautical information from the corresponding DD Hybrid chart on the pre-composed chart (DC1). Here participants using DC3 required in mean half the time compared to using DC2. DC4 and DC5 mean times were slightly higher than DC3.

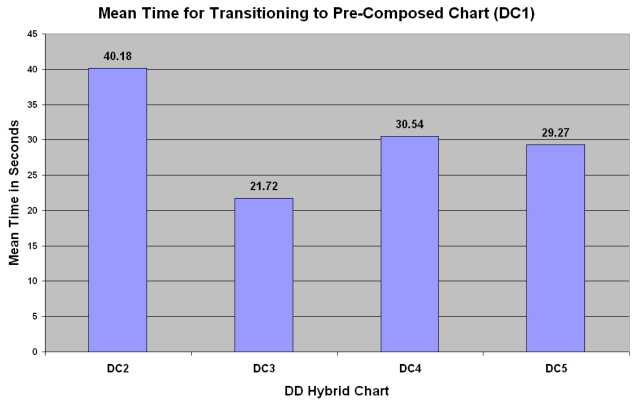

FIG 13. Phase 3 – Mean Time for Transitioning from Hybrid DC to Pre-Composed Chart

A comparison among the DC groups revealed statistical significance in terms of performed errors when locating the field on the chart ($p < .05$). FIG 14 depicts the mean error rate participants have conducted when locating the field on the charts. It shows that most mean errors were performed using DC3. Participants using DC1, DC2, and DC4 achieved similar lower mean error rates. Least mean errors were captured for DC5.

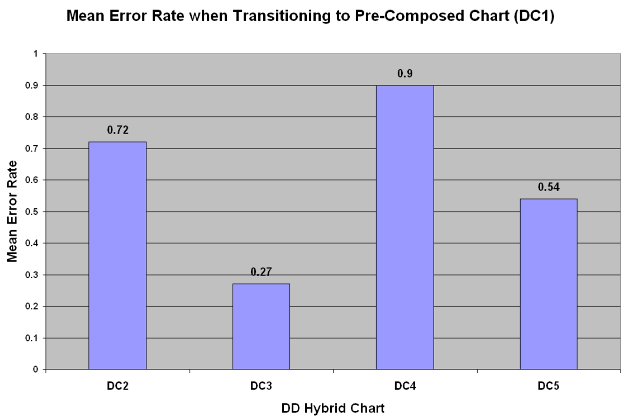

FIG 14. Phase 3 – Mean Error Rate when Transitioning from Hybrid DC to Pre-Composed Chart

4.4.4. Post-Trial Questionnaire

Pilot feedback clearly shows, that they do not require all possible minima associated to a specific approach displayed at once. Pilots stated to only require displayed information pertaining to a specific approach condition as long as other approach information is quickly and easily retrievable. This also applies to the aircraft approach category. Pilots see no necessity to retrieve information regarding an aircraft approach category other than the one that applies to the aircraft they are currently flying.

A item of the post-trial questionnaire asked the participant to select the chart concept of their preference. FIG 15 displays the number of preferences for each display concept. The figure shows that 64% of the participants preferred DC5 and 18% preferred DC2 or DC4. The pre-composed chart layout (DC1) and DC3 were not selected by any participant.

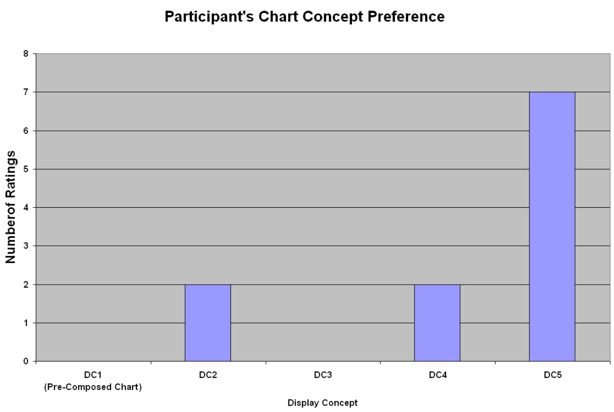

FIG 15. Participant's Chart Concept Preference

All participants, which selected DC5 rated that this concept utilized display real estate most effectively and that all key information associated to a specific approach and constraint were retrievable at one location on the chart. Those participant's, who preferred DC2 argued similar.

Observations and feedback of pilots using DC3 showed that the information presentation of minimum information in the Briefing Strip™ did not meet expectations of "getting the information quickly". The arrow in the minimum box to indicating more information available in the minimum table was noticed by the majority of the pilots. The existence of such an arrow required the pilots to thoroughly view the minimum table and then ignore the information in the minimum box of the Briefing Strip™.

5. SYSTEM INTEGRATION CONCEPT

As a proof of concept the DC5 was realized by enhancing the functionality of the terminal charting application of the Jeppesen EFB. Based on the available infrastructure a system integration concept was researched, which main objectives were:

- Downward compatibility to old data files
- Upward compatibility, so that an old application works with new data files
- Data Driven generation of the Briefing Strip™ of an approach chart.
- Pre-composed depiction of the header, plan view, profile and changes and copyright section of an approach chart.
- Real-time minima calculation and composition

To adapt the current infrastructure, it was necessary to (1) provide the front end application with the needed data and (2) modify the airborne system to utilize the provided data for displaying DC 5.

5.1. Infrastructure and Data Preparation

To support a hybrid data driven depiction of aeronautical approach charts, the current data production infrastructure was adapted. FIG 16 illustrates the system framework which represents an end-to-end solution from data ingest to airborne data depiction. The four main components to support the generation and management of hybrid charts are comprised of Data Ingest, Asset Development, Asset Management, and Consignment and Delivery systems. In conjunction with parallel operating Change and Quality Management components, the revision control of data updates, the traceability of single execution steps and an overall certifiable DO-200A system is supported.

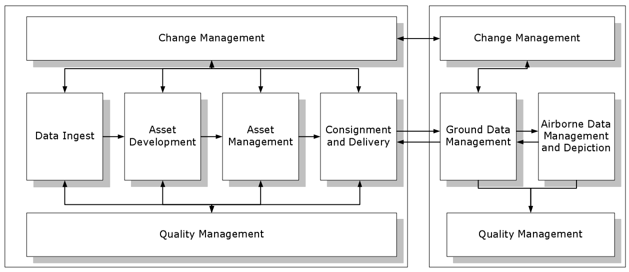

FIG 16. System framework

The two ground based components adapted to support the hybrid solution were covered by enhancing sub-components within the Data Ingest and Asset Development systems. Related to the Data Ingest component, additional meta-data sections for the new JAR-OPS data elements and minima concepts were added. Since the new JAR-OPS concepts are describing a generic and harmonized approach of calculating and defining minima values applicable for any airport or runway, only the parameters defining the specific JAR-OPS categories are covered within the meta-data. In conjunction with the Minima Calculator (see Chapter 5.2), corresponding minima values for a specific operational approach scenario are then calculated airborne and in real-time. With this, no specific airport/runway minima values are needed to be stored explicitly anymore, reducing the amount of data as well as limiting the file size of chart data updates.

In case a support of airline or state tailored minima values is desired, specific minima values can take precedence over the JAR-OPS category specification. The corresponding meta-data sections are setup to provide even single DA(H), MDA(H), RVR or VIS values for each aircraft category or landing maneuver specification.

The second enhancement is related to the Asset Development system. Within an automatic chart generation module, pre-composed data elements of an approach chart are combined with the new meta-data information from the Data Ingest system. The chart generation module basically retrieves the generic JAR-OPS category information and all supplemental airport/runway specific parameters from a central database and automatically merges it to any applicable approach chart. To support upward and downward compatibility with new and already deployed airborne components, the system can be configured to

a. provide both pre-composed and meta-data sections related to Briefing Strip™ and minima information

b. provide meta-data only.

The resulting data files for each approach chart are then automatically processed and tailored into the Jeppesen Database server, using customer subscription information as well as update cycle and data distribution system settings.

5.2. Airborne Integration

The integration of this solution into an airborne system was performed by enhancing the existing Jeppesen EFB, and in particular, the Terminal Charting application (TermCharts), which is responsible for digital approach charting. It is common practice in software design to utilize the Model-View-Controller pattern [7] to design interactive client applications. Hence, the TermCharts application was designed in accordance to this pattern as well. Naturally, the most changes to the application have been necessary to the View component, which is basically the user interface (UI) of the application. Due to the remaining pre-composed parts of the chart data, the UI module was separated into two sub-modules, responsible for rendering the pre-composed and the data driven sections.

The high level system architecture is shown in FIG 17. Prior to the TermCharts application enhancement the whole rendering was performed by Jeppesen's MC3 library. The available renderer could stay unmodified. For the data driven parts of the chart a complete new renderer was introduced to the library. This new module renders the Briefing Strip™ of an approach chart, in accordance with the new display concept. The algorithm behind this module works in four steps:

1) Read the meta data from the data file.
2) Calculate the minima information.
3) Calculate the layout of the Briefing Strip™.
4) Render the Briefing Strip™.

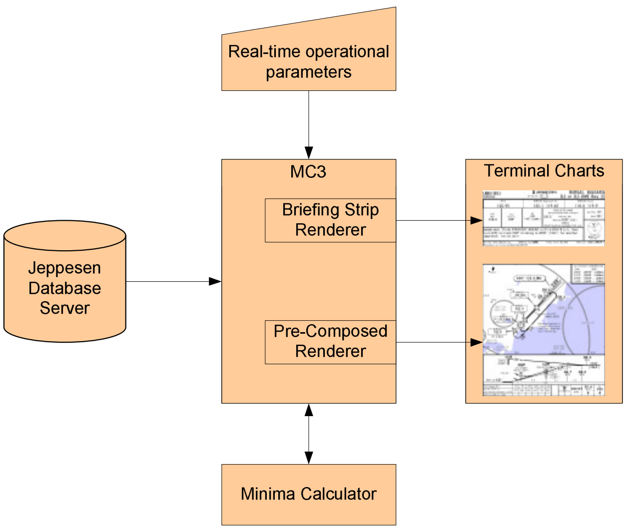

FIG 17. Architecture of the airborne part of the system

The capability for calculating the minima information is provided by an independent software module. The advantage of this approach is the reusability in other domains. Wherever minima information is needed, it can be applied in a consistent way.

The minima calculator needs several real-time operational information as input parameters for the minima calculation. In the considered solution the input parameters are provided by the MC3 library and in particular from the Briefing Strip™ renderer in combination with the TermCharts application. How the application will be fed with the necessary information was not scope of the study. However, the following information needs to be specified:

- Aircraft category
- Missed approach climb gradient
- Landing maneuver
- ALS condition
- Runway Lighting condition
- ILS condition, if applicable
- DME condition
- Aircraft equipment condition
- Information whether the operator is authorized to perform approaches with reduced minima

Finally, the MC3 library must be provided with the data files containing the charting information for the selected approach. They're stored in the Jeppesen Database Server (JDS), which is a relational database system certified for in-flight use. JDS was utilized as the backend for the TermCharts application.

6. CONCLUSION AND FUTURE WORK

The realized system provides a first step into the real-time and data driven generation of aeronautical information and resultant depiction. By providing context sensitive minima information in a de-cluttered and need-to-know fashion, the new display concept provides an easy and intuitive retrieval of applicable minima values. Additionally, error rates of identifying minima values are decreased as well as a pilot's workload reduced.

Future work activities are dealing with efforts to integrate the whole system into an operational environment at an airline or airframer and to use it as a certified or operationally approved system.

Topics to extend the data driven composition of aeronautical information to all chart related sections or other departure and arrival charts also define current and future work activities.

7. REFERENCES

[1] M. Shamo.: *What is an Electronic Flight Bag and What is it Doing in My Cockpit?* Proceedings of the International Conference on Human-Computer Interaction in Aeronautics 2000 (HCI-Aero 2000), Sept. 27-29, 2000, Toulouse, France.

[2] U.S. Department of Transportation, *Human Factors Considerations in the Design and Evaluation of Electronic Flight Bags (EFBs)*, Office of Aviation Research Washington, DC 20591 D. Chandra & M. Yeh, September 2003

[3] *JAR-OPS 1: Commercial Air Transportation (Aeroplanes)*, JAA publication, http://www.jaa.nl/publications/jars/jar-ops-1.pdf, last checked June 27, 2007.
[4] *United States Standard for Terminal Instrument Procedures*, 3rd edition, FAA publication, http://www.faa.gov/about/office_org/headquarters_offices/avs/offices/afs/afs400/afs420/policies_guidance/orders/media/Order%208260.3_1-18.pdf, last checked June 27, 2007.
[5] *NPA-OPS 41: Subpart E All Weather Operations*, JAA publication, http://www.jaa.nl, last checked June 27, 2007
[6] *NPA-OPS 20: Stabilised Approach*, JAA publication, http://www.jaa.nl, last checked June 27, 2007
[7] F. Buschmann: *Pattern-orientierte Software-Architektur . Ein Pattern-System*, 2nd edition, Addison-Wesley 1998, ISBN-10: 3827312825
[8] *ICAO Annex 4: Aeronautical Charts*, International Civil Aviation Organization (ICAO) Order No. AN 4
[9] Technische Universitaet Darmstadt, *Task & information Analysis during Arrivals and Approaches*, internal study, P. Wipplinger, November 2004
[10] NASA, *NASA Task Load Index (TLX): Computerized Version*, Moffet Field, CA: NASA-Ames Research Center, Aerospace Human Factors Division, 1986
[11] R. Mewman, K. Grelly, *Cockpit Displays: Test and Evaluation*, Ashgate 2001
[12] M. Wiggins & J. Stevens, *Aviation Social Science: Research Methods and Practice*, Studies in Aviation Psychology and Human Factors, Ashgate, 1999