The Design of an Advanced In-flight Information Management System for Naval Rotary-Wing Aircrews

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ABSTRACT

This paper presents an overview of a comprehensive research program which is investigating how to generate and present information to Navy helicopter aircrews to help them manage mechanical fault information, monitor aircraft parameters, and access flight procedures. The work represents five years of research and development which has included experimentation in simulators, knowledge elicitation, and a detailed human-computer interface evaluation performed within the Naval aircrew community.

This work has sought to provide the basis for an aircrew interface for alerting aircrews to problems that are identified and potentially diagnosed by a Health and Usage Monitoring System (HUMS). HUMS alerting is combined with a concept for an interactive, electronic flight manual to produce a complete aircrew aiding system. Since the basis for the flight manual information is the Navy's NATOPS, the system is designated as Interactive Electronic NATOPS (IE-NATOPS).

INTRODUCTION

Rapid identification of mechanical faults is a crucial priority in the Naval rotary-wing community. The speed and accuracy with which a pilot can detect, diagnose, corroborate, and respond to mechanical faults has a great effect not only on aircrew safety but also on the ability to complete the mission. In the past decade, research has addressed this safety issue on two fronts; advanced mechanical diagnostics and aircrew aiding. This paper present an overview of a five year research effort which began as an investigation of aircrew aiding concepts and has now led to a design and implementation of a comprehensive cockpit information management system.

Significant progress has been made in the field of mechanical diagnostics. New systems designated as Health and Usage Monitoring Systems (HUMS) have continued to mature and have increasingly been integrated into operational aircraft over the past decade. HUMS utilizes new sensors to provide critical information for maintainers on the presence of potential mechanical faults which may not be detected by current Warning Caution Advisory (WCA) systems. Additionally, HUMS is invaluable for corroborative secondary information for WCA alerts. (A summary review of HUMS technology is available in [1].)

Pilot alerting via the present WCA system, or a new HUMS system, provides only an indication of a potential mechanical fault. Once the pilot is alerted, he or she must quickly understand the nature of the fault, assess its impact on safety of flight, decide on a course of action, and initiate corrective actions. The above sequence of actions has been incorporated in Navy doctrine and is embodied in all Naval flight manuals designated as NATOPS (for Naval Air Training and Operating Procedures Standardization). NATOPS training is paramount for all Navy aviators and requires memorization of much of the information contained in the operator's manual. To offset potential memory errors, NATOPS Pocket Checklists (PCL) are used in-flight. The PCL contains normal, special, and emergency checklists in the form of quick reference steps to assist the pilot in performing the correct procedures during normal and emergency situations. During emergency situations, time pressure, workload, and stress all increase, thus creating a need for aircrew aiding.

Our present research has investigated how to generate and present information to Navy helicopter aircrews to help them manage mechanical fault information, monitor aircraft parameters, and access flight procedures. We have utilized empirical studies, knowledge elicitation/engineering techniques, and iterative development, evaluation, and refinement of prototypes. Our efforts have led to the design and implementation of an advanced in-flight information system which is designated as Interactive Electronic NATOPS (IE-NATOPS).

This paper begins with an overview of relevant research in this area and a description of our own empirical findings. The design, implementation, and evaluation of our present version of IE-NATOPS is then discussed. The paper concludes with a discussion of our plans for the continued development of IE-NATOPS.

BACKGROUND

The concept of providing an information management system in the cockpit seems a natural evolution of paper manuals and checklists. Integration of these data into a computer-based form also offers the infrastructure for communication with advanced diagnostic systems as well as future applications such as intelligent agents and intelligent embedded training.

Electronic checklists have been introduced in some recent commercial aircraft, such as the Boeing 777 and the Airbus A330/A340. These advanced aircraft also offer integrated aircraft status information systems (the Airplane Information Management System, AIMS, for the Boeing 777, and the Electronic Centralized Aircraft Monitor, ECAM, for the Airbus A330/A340).

The linkage of electronic checklists to HUMS type systems raises many research issues in addition to the natural concerns about diagnostic system reliability and efficacy. Does the aircrew really need the information provided? If not, it could instead serve as a costly distraction. Does the system and information present an unacceptable workload for the pilot? Do the pilots get distracted from their primary tasks by the need to interpret confusing or ambiguous guidance, which could be the case if an intelligent agent required the pilot to make judgements on multiple competing uncertain hypotheses?

Research and guidelines for the development of electronic versions of aircraft flight manuals have, however, been slow to appear. Outside of our own research program, we have identified only one prior research program in this area. A NASA research effort about a decade ago addressed the fundamental issues of human factors of flight deck checklists ([2], [3]) and was followed by two experimental studies concerning the human performance aspects of electronic checklists ([4], [5]). The experimental studies point to some possible human performance problems associated with electronic checklists which automatically monitor system state parameters and accordingly execute relevant checklist items. Although this NASA program has provided valuable guidance for the development of flight deck checklists and their electronic implementation, there are many empirically unresolved issues in checklist design for aircraft cockpits. For example, should pilots be required to explicitly indicate completed items in the electronic checklist, or would that requirement impose an unjustified workload? How do we avoid the problem of "hyperspace disorientation" which can result from navigation of multiple hypertext links between related checklists (a problem which Degani & Wiener [2] report to be evident even in the hardcopy version of flight deck checklists). For elements of flight manuals beyond the checklists, we find essentially no empirical guidance. We are concerned here with all of the tutorial text describing how all of the aircraft subsystems and components operate; presentation of aircraft performance data and component specifications via tables, nomograms, and graphics; and detailed explication of aircrew responsibilities and procedures.

Accordingly, we have begun a research program to identify critical design issues for development of interactive electronic flight manuals. We started with two empirical studies to identify aircrew information needs during mechanical emergencies, both conducted in the context of Navy H-46 aircraft and missions. We have implemented IE-NATOPS Version 1.0 for the SH-60F aircraft, including integration with the warning-caution-advisory (WCA) alerts of the existing aircraft. Based on this prototype IE-NATOPS, we have conducted one study to evaluate speed and accuracy in emergency problem prosecution between baseline hardcopy NATOPS and the new IE-NATOPS system. We are also committed to future experimentation as the IE-NATOPS system evolves in terms of functionality.

EMPIRICAL STUDIES

We have conducted three formal empirical studies in the course of the IE-NATOPS investigation and development. The first study investigated aircrew performance in handling mechanical emergencies in the existing H-46 aircraft. The second study provided an example of the kind of aiding that could be generated from current mechanical fault diagnostic technologies and examined how aircrew used this information in contending with simulated mechanical problems. The first two studies were conducted with H-46 aircrews at Naval Air Station North Island using a motion-base simulator. The third study was conducted in the context of an SH-60F in order to evaluate performance in accessing critical information in IE-NATOPS as compared to accessing the same information in conventional hard-copy NATOPS.

The purpose of the first study was to conduct systematic interviews with flight crews regarding their current procedures for in-flight mechanical system emergencies ([6], [7]). The study assessed cognitive activities expected to be important when responding to mechanical emergencies, and the attention devoted to each activity. A secondary goal of the first study was to identify the information requirements of a new diagnostic system to be used to predict and mitigate in-flight mechanical system emergencies. The study represented a first step towards identifying the information requirements of aircrew in determining the status of aircraft mechanical systems using advanced sensor and processing technology. The results from the first study provided the basis in the second study for the development and implementation of a user interface for an in-flight diagnostic system.

As reported in [6] and [7], the emphasis in the first study was to use survey techniques to assess aircrews' use of information, potential sources of workload, and the utility of diagnostic systems. A key finding of that study was the need for a system that could diagnose mechanical problems and assess the impact of those problems on a mission. Aircrews also requested a diagnostic system that could provide action recommendations to help complete a mission. Figure 1 displays the frequency with which aircrews indicated interest in various categories of information during simulated emergencies. Results are included for both the questionnaire and from an analysis of actual aircrew communication during a simulated mission.

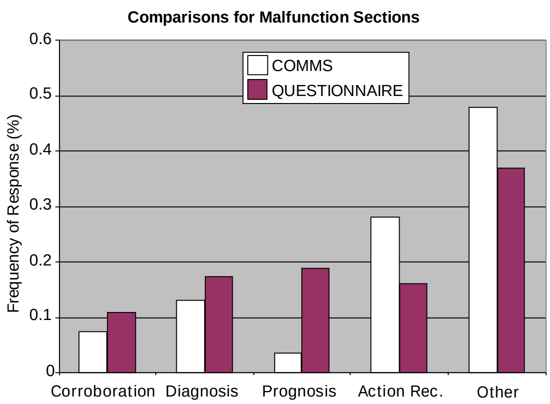

Figure 1. Study 1 Results

The second study was designed to assess the usefulness of various kinds of information relevant to mechanical fault management (see [8]). As such, it explored the feasibility and potential benefit of new technologies to help aircrews in mechanical fault management. More specifically, the purpose of this study was twofold: (1) to evaluate the value that various kinds of information have on the ability of the aircrew to successfully manage in-flight mechanical faults, and (2) to demonstrate an initial interface concept and explore its potential benefits to the aircrew. To this end, the following objectives were established for the second study:

- to develop a clear understanding of the kind of information that can eventually be offered to helicopter aircrews via a real-time mechanical diagnostic system,
- to demonstrate that this additional information is of significant value and interest for the aircrew, and
- to demonstrate an approach for producing an effective aircrew interface.

The second simulator study built upon the foundation established by the first study, used the results of that study to develop a prototype user interface for the diagnostic system, and assessed that diagnostic system and user interface in helicopter operations. The goal was to determine the merits of aiding the aircrew with an automated diagnostic system when compared to the current, unaided situation.

The approach was successful in identifying a number of important factors that can significantly influence the development of this kind of aiding technology, as well as in raising general issues for consideration in the development of cockpit automation technology. First, the results clearly indicate that automated technologies can enhance aircrew performance when correctly designed, improving aircrew ability to diagnose true failure conditions and recognize false alarms. Second, the potential utility of certain types of information (and the type of aiding that information implies) was revealed, with pilots indicating primary interest in the ‘analysis’ category of information. In addition, the results show differences in information requirements based on crew position. Third, aircrews were unanimous in their desire to have an electronic NATOPS as a means to access and to display emergency procedures. Fourth, the communication data indicated an insignificant effect of the automated diagnostic system on communication content or frequency, which implies that the technology does not significantly alter crew workload or crew coordination requirements as discussed in [9]. Figure 2 presents a summary of the results of the second study. This histogram shows relative attention (i.e., screen dwell times) which were observed for specific categories of information.

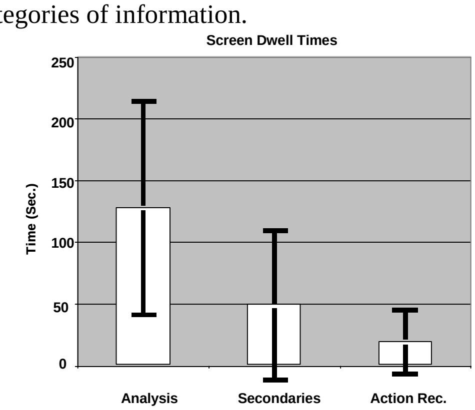

Figure 2. Study 2 Results

IE-NATOPS DESIGN

The approach used in this effort included the development of a design specification, production of several prototype demonstrations, and the identification and evaluation of Navy institutional integration issues. The design specification focused on:

- aircrew access during an emergency with automatic triggering,
- aircrew access during an emergency based on aircrew initiative and problem identification,
- aircrew access during non-emergency periods, and
- aircrew access to automatic and interactive performance data calculations.

The first step taken to develop the design specification was to interview experienced Navy aircrews regarding the concept of an IE-NATOPS with specific reference to the Navy's emerging CH-60S and SH-60R aircraft. Based on those interviews and an analysis of aircrew information needs, a design specification was formulated addressing both event-triggered needs and aircrew initiative information needs. Six modes of IE-NATOPS functionality were defined: PCL, NATOPS tutorial text and graphics, performance data, alerts, trends, and notes. Only the first four modes will be discussed in this paper since they are essential functions that are in near-term development, while the other functions (trends and notes) are being postponed for design refinement.

The initial analysis focused on the SH60B NATOPS Flight Manual and associated PCLs and more recently on the SH-60F variant of the same information. The goal of the analysis was to review the overall structure of the NATOPS outline, identify the Parts, Chapters, Sections, and sub-Sections that are used most by the aircrew in the cockpit, and to suggest potential design features for an effective interface structure.

Included in the documentation analysis was a detailed analysis of the aircraft performance data charts. This analysis was conducted to determine requirements for screen design and aircrew interactive capabilities. Each chart was reviewed to identify the particular function it performs and to determine what information it required and what information it produced.

The analysis was conducted to develop an interface design that would not conflict with the current structure of the manual, the PCLs, and HUMS related information. The first goal of this analysis was to identify the information that will be used most frequently by the aircrews in the cockpit. After a review of the categories of information, it was determined that the order of frequency of use should be - Checklists, Trends, Performance Data, Alerts, NATOPS, and Notes.

An integral component of our aircrew interface design was the iterative development, evaluation and refinement of prototypes. Over the two-year software development effort, five distinct fully functional prototypes were produced and evaluated by the Navy's operational test squadron (VX-1). Several pilots from VX-1 participated in these evaluations and made valuable recommendations that led to the evolution of our ultimate design. These pilots served not only as subject-matter experts but also as design partners.

The default mode of IE-NATOPS is shown in Figure 3. The six required categories of information were maintained as system mode buttons at the top of the screen. Clicking a mode button changes the data in the main body of the IE-NATOPS application. The 11 large buttons on the default screen correspond to the actual tabs on the PCL which is familiar to all aircrew. Selection of one of these buttons produces a directory tree structure of the individual checklists within the given sub-section. Selection of an item within a tree produces an electronic checklist (see Figure 4).

Figure 3. IE-NATOPS Main Mode

Figure 4. Checklist Text Screen

Alternatively, the user can follow a similar path through the NATOPS mode hierarchy menus to access individual chapters of the flight manual. Figure 5 provides an example of a NATOPS text screen. Navigation within IE-NATOPS is based on an Internet browser metaphor (i.e., navigation functions such as back, forward, history, and bookmarks). This form of navigation is familiar to the target user community and has been well received in our evaluations.

As shown in Figures 3 through 5, the basic design concept provides a quick and efficient method of navigating through NATOPS and PCL information. When dealing with performance data, however, additional dynamic interactive capabilities are needed, thus requiring a different design concept. Figure 6 illustrates a screen design that was developed for the “Ability to Maintain Level Flight, Single Engine” Chart.

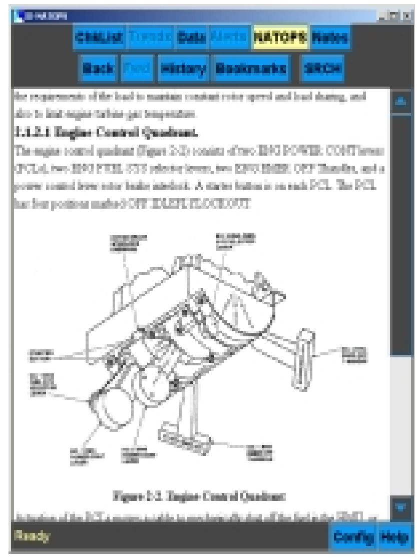

Figure 5. NATOPS Text Screen

Figure 6. Performance Data Screen

The “Ability to Maintain Level Flight, One Engine” performance chart provides the aircrew with the minimum and maximum velocities the aircraft should be flown to maintain level flight with one engine inoperable. These velocities are determined using the pressure altitude, outside ambient temperature, gross weight, and operating engine torque of the current aircraft flight profile. This information will be obtained from aircraft sensors, and the velocities can then be calculated automatically. Alternatively, the aircrew can manually input any of the parameters to obtain the limiting velocities.

The final concept developed in the design specification is to present emergency procedures to the aircrew based on automatic detection of problem conditions using alerting triggers based on automated condition diagnosis. In this design concept, our automatic diagnostic system would detect a problem condition and alert the aircrew by a flashing red Alerts mode button located on the modes button bar. The aircrew would select the Alerts button and go immediately to the Alerts mode screen (Figure 7). The screen provides detailed information concerning the fault, associated aircraft systems parameters, and linkage to appropriate NATOPS, checklist, and performance data information. The design of this mode will undergo further revision as research and technology development continues.

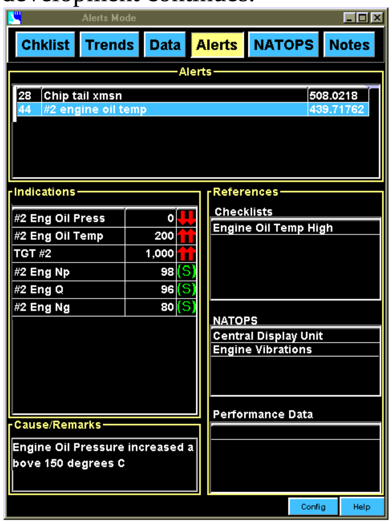

Figure 7. IE-NATOPS Alerts Mode Screen

AIRCREW INTERFACE TESTING

A benchmark evaluation was recently performed to compare aircrew performance when using the traditional paper copy of NATOPS and the PCL with that of the IE-NATOPS system. This evaluation effort attempted to establish whether or not there are notable differences in resolving problem situations dependent upon the format of the NATOPS and PCL used. Major findings of this study demonstrated that the average response time for training scenarios using the electronic version of NATOPS was significantly faster than the average response time using the paper version (see Figure 8). Since the training scenarios focused on pure access time to specific information, this is indicative of a strong advantage of IE-NATOPS over the paper version. In the main experimental trials more extensive problem solving and decision making was required and, not surprisingly, the comparison of IE-NATOPS versus hard-copy performance varied considerably with problem characteristics. Overall, however, there were no significant differences in response time between electronic and paper versions of NATOPS for the main experimental scenarios.

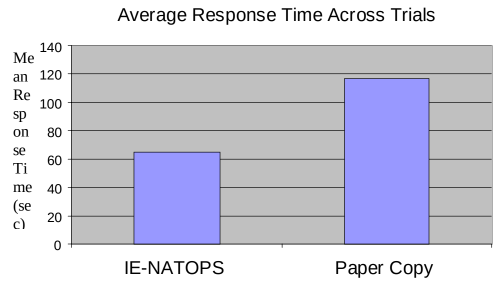

Figure 8. Preliminary Evaluation Results

PLANS AND CONCLUSIONS

IE-NATOPS is expected to offer several significant benefits over hard-copy NATOPS for the Navy helicopter aircrew. It will provide for rapid access to emergency procedures by the aircrew, both via automatic alerting (i.e., through an automatic diagnostic system) and via manual search by the aircrew.

Although the prototype IE-NATOPS design has focused on the SH-60B and SH-60F/HH-60H, the design concepts employed here can be used across all Navy helicopter and fixed-wing platforms. However, because these platforms vary in cockpit configuration, systems, and procedures, any development beyond this general specification must be aircraft specific.

Any software used to develop an operational system must conform to aircraft standards to eliminate conflicts with the software of other systems in the aircraft. Hardware development must focus on existing displays, real estate availability, and interoperability with other systems in the aircraft. For continuation of this effort, further research must be conducted in the areas of institutionalization, aircraft integration, and interface design. Institutionalization research will include coordination with NATOPS committee members and the Naval Air Systems program offices.

Finally, this research will continue coordination with operational aircrews to obtain quantitative data on the current limitations and issues associated with use of the current hardcopy NATOPS, and to obtain feedback from these aircrews on design concepts developed to address these problems. Results of these research efforts will be used to modify the current IE-NATOPS design concept and produce a more complete, operational system.

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