Efficiency in the Cockpit:
A Comparison of Keypad-Entry and Voice Recognition Systems

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I. Introduction

The primary concern on any airplane flight is the safety of the crew and it's passengers. Throughout the years of aviation, advancements have been made in both concepts and technology in order to improve the safety of air travel. When aircrafts became capable of long-range travel, navigation became a very important concept in flying. Soon instrumentation allowed for flight in conditions of darkness and low visibilities, and this instrumentation allowed for tracking of ground based radio beacons. Today's navigation can be done using a variety of sensors, from ground based to satellites in space.

When used properly, the Flight Management System (FMS) increases the situational awareness, safety, and efficiency of any flight using this equipment. The FMS is basically made up of the Flight Management Computer (FMC) and the Control Display Unit(s) (CDU). It's most basic function is to allow the crew to program a route from one destination to another, then engage it with the autopilot and allow it to fly the programmed route. The FMC has several databases that store waypoints and pre-programmed routes to ease the burden for pilots. The FMC is accessed via the CDU. The CDU has a keypad and buttons that allow pilots to make entries into the FMC. A typical modern airliner/business jet has two or three CDU's, one for each pilot, the third for redundancy (see Fig.1.1) (Casner, 2001).

Cockpit Overview

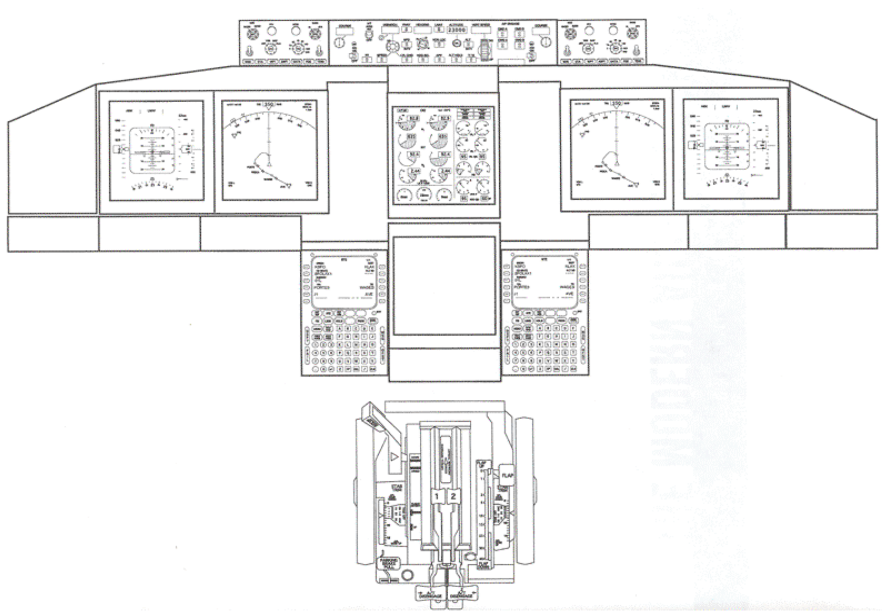

Fig. 1.1 Cockpit Overview

Pilots transitioning to the airlines seldom realize that they will have to put their instrument flying skills to work using modern cockpit technology. This is an exciting new aspect of airline flying. After programming the flight route using the flight management computer, pilots use the airplane’s auto-flight system to help automatically guide them along the route that was built. Pilots must deal with realistic en route scenarios: such as vectors, holds, diversions, intercepts, traffic, surrounding terrain, and many others. Cockpit automation can potentially help or hinder pilots while working as a team to decide the best way to fly the airplane.

Currently, researchers are studying the efficiency of the keypad-entry of the FMS. With all these advancements in navigation came the increased potential to lose situational awareness when the instrumentation was used incorrectly or when the amount of information became overwhelming. This loss of situational awareness is a major contributor to accidents. While these instruments can help a pilot increase their situational awareness, the misinterpretation of or fixation on these instruments can have the opposite effect. Complex navigation procedures increase the pilot's workload. The piece of equipment designed to help minimize the workload in the cockpit is the FMS. The primary goal of the FMS is to allow pilots to program a route from their point of departure to their destination, and then couple it with the autopilot, which then flies the aircraft through the entire route, passing over all the waypoints and performing all the necessary heading changes along the way. This helps reduce the pilot’s workload and allows them to monitor the progress of the flight and all the other systems on board. It also allows them to maintain a more "eyes forward" situation, thus increasing their situational awareness. The current keypad-entry system of the FMS, although it has advanced tremendously over the past few decades is still heavily studied.

In this paper, I will duplicate several tasks in order to perform a GOMS keystroke-level analysis on the current keypad-entry FMS. I will attempt to discover the time and efficiency involved in using this type of system. I will also be taking a look at speech-enabled Flight Management Systems to determine how this technology can help and how it can hinder pilots when navigating airplanes. How does a speech-enabled FMS compare to the traditional keypad-entry systems currently in use on airplanes? What type of interface would increase the efficiency and confidence of pilots, either keypad-entry, speech-enabled or both?

II. The Flight Management System (FMS)

An example of an advanced FMS is the Collins FMS-4200 (see Fig. 1.2 and Fig. 1.3), which is made by the Rockwell Collins Corporation.

Fig. 1.2 FMS-4200 by Rockwell Collins Corporation

The most basic function of the Flight Management System is to allow the crew to program a route from one destination to another, and then engage it with the autopilot/flight director and allow it to fly the programmed route. Most of today's Flight Management Systems can do more than just fly a programmed route. However, pilots still must enter and verify the flight plan route with the FMS. Much of the information for the flight plan is pre-programmed for the pilot by the Global Positioning System (GPS), such as the current date and time. Validating the flight plan requires numerous keystrokes pre-flight because the pilots must verify all the information is correct. Keystrokes require the pilot to scroll from page to page to verify information, and when information needs to be entered more keystrokes are required. Many of these tasks, when broken down to the smallest subtask, are quite simple. For example, checking the time and date requires one keystroke. Changing the current date would require three keystrokes.

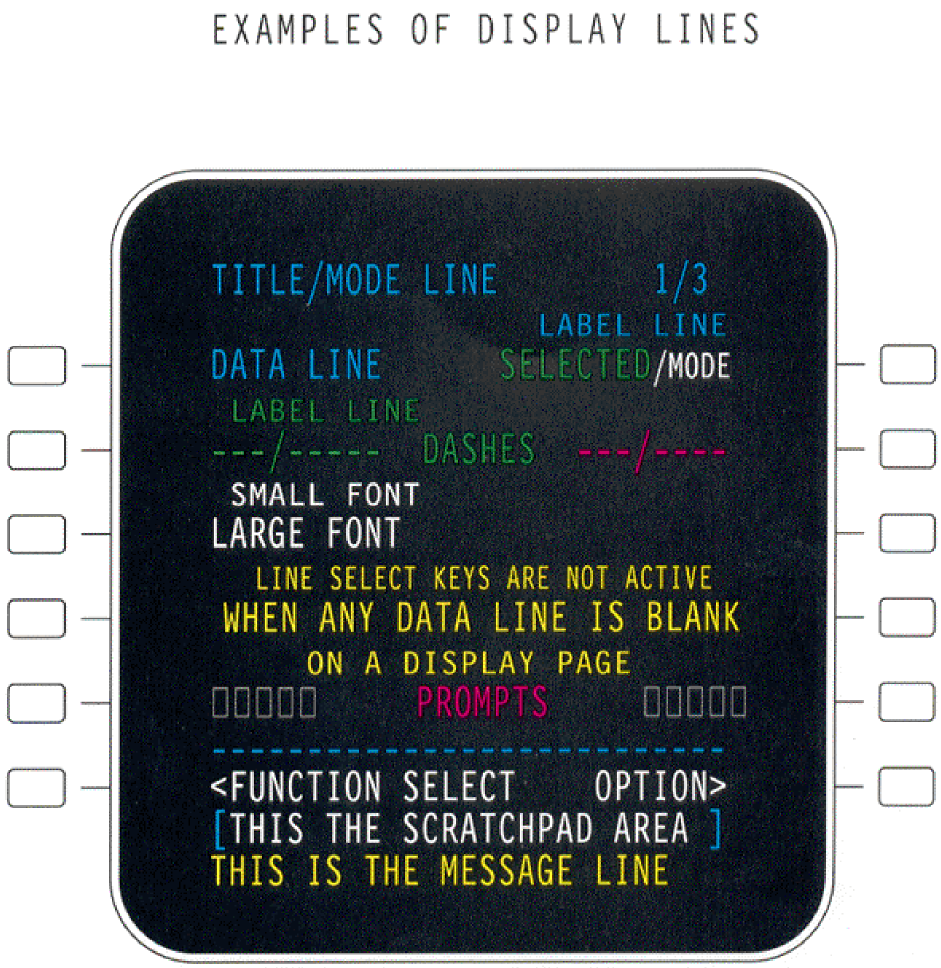

Fig. 1.3 Example of Display Lines

Research revealed that the most basic function of the FMS is, in fact, entering and verifying the flight plan information. Flight plan information is mainly entered pre-flight, but some circumstances require making changes to the flight plan en route. Luckily, the chosen tasks were both pre-flight and en route tasks for reasons we will discuss later. Five tasks were randomly chosen out of *"The Pilot's Guide"* for the FMS-4200 from Rockwell Collins (1999). After speaking with several experts, pilots and FMS trainers, it was verified that these five tasks are fairly common tasks. The five tasks analyzed were:

1) Initializing the position of the aircraft (pre-flight)
2) Entering the fuel weight (pre-flight)
3) Entering the destination airport (pre-flight)
4) Changing Radio Frequency (en route)
5) Changing a flight plan en route to a direct flight (en route)

III. GOMS Keystroke-Level Analysis

By means of careful laboratory experiments, inventors developed a set of timings for different gestures, such as tapping a key on the keyboard (0.2 seconds), pointing (1.1 seconds), homing (0.4 seconds) and mentally preparing (1.35 seconds). Mental preparation time is averaged, and is the most controversial aspect of the GOMS analysis. It is known that pilots must stop to think about their next action at certain points in their decision-making. For the purposes of this general analysis, the GOMS Model proposes the use of an average mental preparation time. The five tasks mentioned above were evaluated in accordance with the GOMS keystroke-level analysis, where K is a key press (0.2 seconds), P is a point with the mouse pointer (1.1 seconds), H is homing and M is mental preparation time (1.35 seconds).

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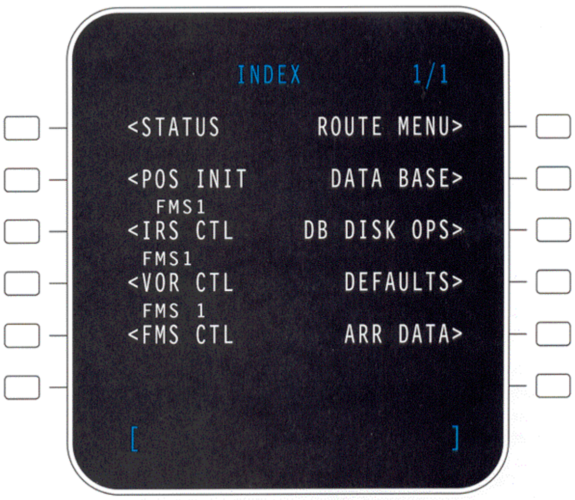
- **Task 1 - Initializing the Position of the Aircraft (Pre-flight)**
  - From INDEX page, push POS INIT display line button to go to the POS INIT page.

- On POS INIT page, push the AIRPORT display line button to copy current airport information into the scratchpad.
- Push SET POS display line button to transfer information for scratchpad to SET POS line.
- Push EXEC to save flight plan.
- M - K - M - K - M - K - M - K = 6.2 seconds

INDEX PAGE



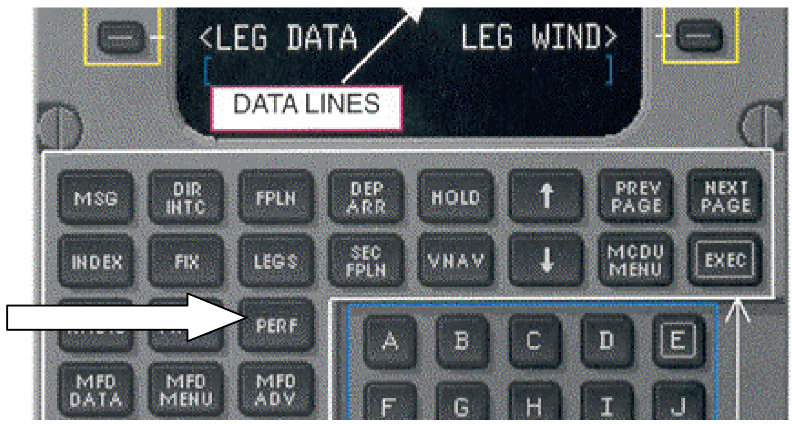
POS INIT PAGE

"SET POS" PROMPT SHOWING

(This area is left blank intentionally)

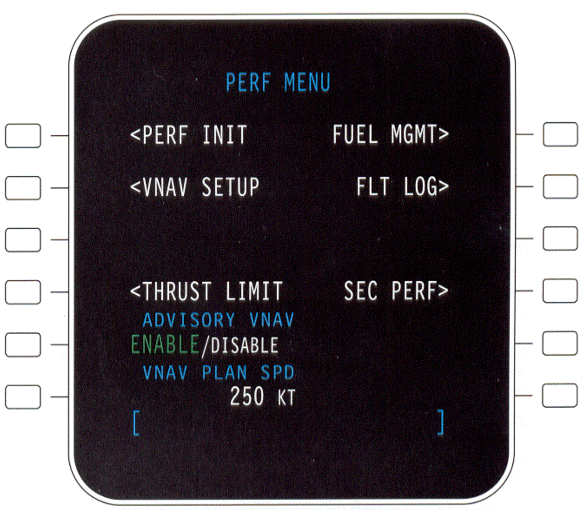
- **Task 2 – Entering the Fuel Weight (Pre-flight)**
  - From INDEX page, push PERF button to go to the PERF MENU page.

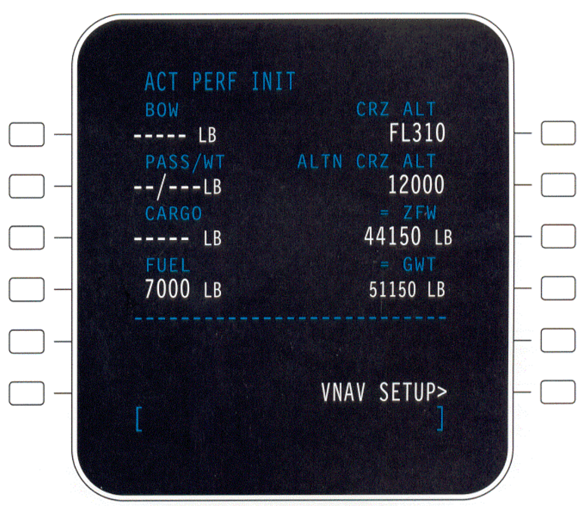
- On PERF MENU page, push the PERF INIT display line button to go to the ACT/MOD PERF INIT page.
- On ACT/MOD PERF INIT page, enter the fuel weight into the scratchpad, 7000.
- Push FUEL display line button to transfer information for scratchpad to FUEL line.
- Push EXEC to save flight plan.
- M - K - M - K - M - K - K – K - K - M - K - M - K = 8.35 seconds



PERF MENU PAGE

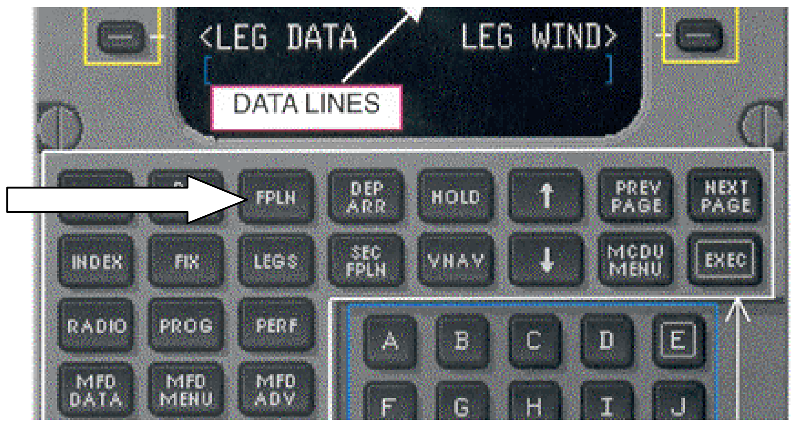
SIMPLE PERF INIT





- **Task 3 - Entering the Destination Airport (Pre-flight)**
  - From INDEX page, push FPLN button to go to the FPLN page.

- On FPLN page, enter the destination airport identifier (KSTL) into the scratchpad.
- Push DEST display line button to transfer information for scratchpad to DEST line.
- Push EXEC to save flight plan.
- M - K - M - K - K - K - K - M - K - M - K = 6.8 seconds

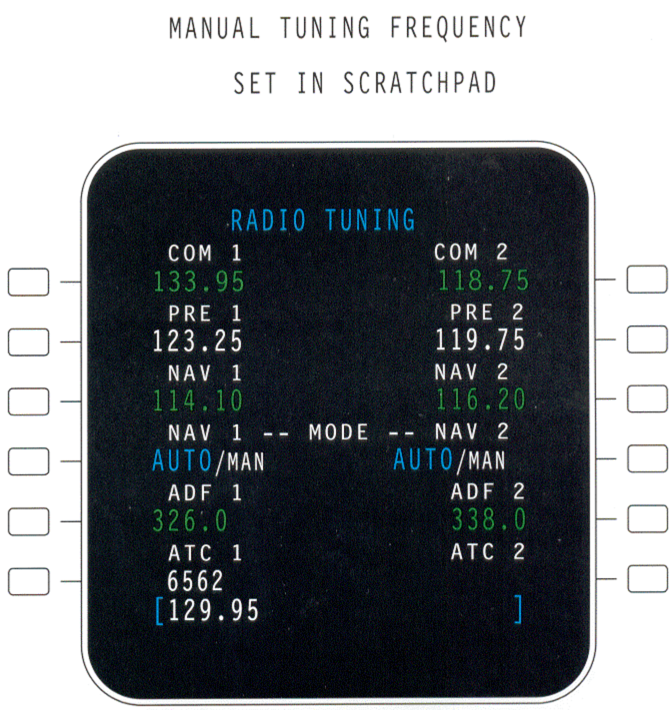


MOD FPLN PAGE WITH

DEST AIRPORT ENTERED

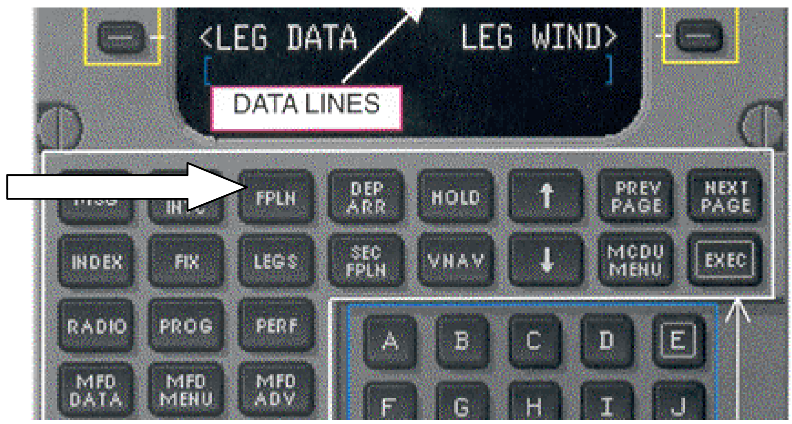
- **Task 4 - Changing Radio Frequency (En route)**
  - From INDEX page, push RADIO button to go to the RADIO page.

- On RADIO page, enter the radio frequency (129.95) into the scratchpad.
- Push COM 1 display line button to transfer information for scratchpad to COM 1 line.
- Push EXEC to save flight plan.
- M - K - M - K - K - K - K - K - K - M - K - M - K = 7.2 seconds

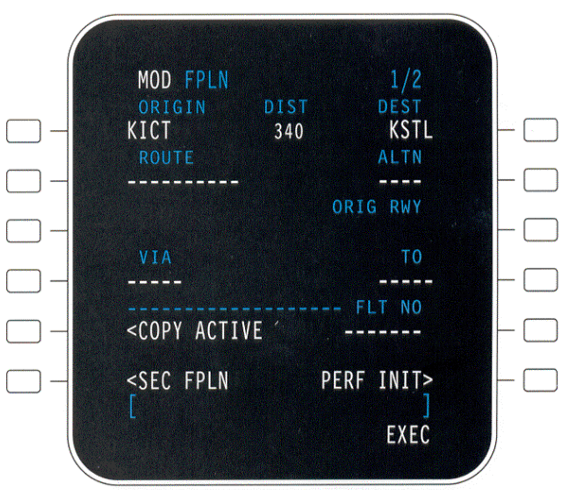


- **Task 5 - Changing a Flight Plan En route to a Direct Flight (En route)**

- From INDEX page, push FPLN button to go to the FPLN page.
- On FPLN page, push NEXT PAGE button to go to the second FPLN page
- On FPLN 2 page, enter waypoint identifier (STL) into the scratchpad.
- Push TO display line button to transfer information for scratchpad to TO line.
- Push EXEC to save flight plan.
- M - K - M - K - M - K - K - K - M - K - M - K = 8.15 seconds



MOD FPLN PAGE WITH
DEST AIRPORT ENTERED



FLIGHT PLAN
WITH DIRECT WAYPOINT

IV. Data Link

In looking at these five tasks, we can easily see why a pilot requires an extensive amount of training to learn the FMS. The FMS is designed so compactly and efficiently that most tasks can be performed with only a few simple keystrokes. One problem however, is that there are many different tasks that the pilot must perform with the FMS. Also, much of the current FMS is already becoming obsolete.

> ARNAV Systems, Inc. is dedicated to the modernization of the general aviation cockpit. ARNAV has been contracted to develop and disseminate weather products. This includes low-cost sensors and data acquisition for the display of aircraft attitude, energy and state vectors. ARNAV has developed a graphical cockpit display of weather information using a low-cost Data Link for ground-to-cockpit transmission for general aviation, and also provides "e-mail" messaging from the cockpit. Global positioning satellite navigation, graphical display on cockpit management systems, and wireless Data Link communications technology have formed the hardware basis for NASA's "Weather in the Cockpit System." NASA's Advanced Weather Information Network Program objectives include flight testing and human factors evaluation of hazardous weather products. The flight teams verify the accuracy and precision of the transmitted weather products and evaluate their use to improve general aviation pilot decision-making. The ARNAV Aeronautical Network broadcasts the weather products to the program aircraft using high-bandwidth transmission techniques with transmission speeds up to 31,500 bits per second (NASA TechFinder, 2000).

A very important note to be made here is Data Link technology is forthcoming, and automating many of the tasks that are currently completed by the pilots. In the above example, the weather is sent electronically and in real-time to the airplane through the Data Link technology. This in turn, updates all the maps and information available to the pilots in real-time. Data Link is currently being tested in various other areas as well. For example, if a pilot's flight plan were changed while in flight, the ground-to-cockpit Data Link would update the airplane's FMS automatically. This technology when and if implemented, would eliminate many of the keystrokes currently required by pilots.

V. Voice Recognition

Within the last few years, increasingly sophisticated voice recognition technology has made this a viable means of control, although such technology has both costs and benefits. We can assume that a purely speech-enabled system would be faster, since we can eliminate all keystrokes, but is that desirable in the cockpit?

1) Benefits of Voice Recognition

While chording is efficient because a single action can select one of several hundred items, an even more efficient linguistic control capability can be obtained by voice, where a single utterance can represent any of several thousand possible meanings. As we know, voice communication is usually a very "natural" communication channel for symbolic linguistic information, for which we have nearly a lifetimes worth of experience. This naturalness may be, and has been, exploited in certain control interfaces when the benefits of voice control outweigh their technological costs.

Particular benefits of voice control can be observed in dual task situations. When the hands and eyes are busy with other tasks, interfaces in which the operator can "time-share" by talking to the interface using separate resources are of considerable value. Some of the greatest successes have been realized, for example, in using the voice to enter radio-frequency data in the heavy visual-manual load environment of the helicopter (Wickens, Gordon, Liu, 1998).

2) Costs of Voice Recognition

The costs can be arrayed into four distinct categories that limit the applicability of voice control (Wickens, Gordon, Liu, 1998):

1) Confusion and Limited Vocabulary Size
    - Because of the demands on computers to resolve differences in sound that are often subtle (even to the human ear), and because of the high degree of variability in the physical way a given phrase is uttered (from speaker to speaker and occasion to occasion), voice recognition systems are prone to make confusions in classifying similar-sounding utterance (e.g., "cleared to" verses "cleared through").
2) Constraints on Speed

- Most voice recognition systems do not easily handle the continuous speech of natural conversation. For recognition, the speaker may need to speak unnaturally slow, pausing longer between words.

3) Acoustic Quality and Noise Stress
   - Two characteristics can greatly degrade the acoustic quality of the voice and hence, challenge the computer's ability to recognize it. First, a noisy environment will be disruptive if there is a high degree of overlap between the signal and the noise. Second, under conditions of stress, one's voice can change substantially in its physical characteristics (e.g. a high-pitched "Help, emergency!").
4) Compatibility
   - Voice control is less suitable, or compatible, for controlling continuous movement than most of the available manual devices. Consider trying to drive a car down a curvy road by saying "a little left, now a little more left."

An important note, the intelligibility of female and male speech is equivalent under most ordinary living conditions. However, due to small differences between their acoustic speech signals, called speech spectra, one can be more or less intelligible than the other in certain situations such as high levels of noise. Anecdotal information, supported by some empirical observations, suggests that some of the high intensity noise spectra of military aircraft cockpits may degrade the intelligibility of female speech more than that of male speech (Nixon et al., 1998).

3) Voice Recognition and Keystroke Balance

There are also many circumstances in which the combination of voice and manual input for the same task can be beneficial. Such a combination, for example, would allow manual interaction to select objects, and voice to convey symbolic information to the system about the selected object. This type of system would be ideal for the cockpit, because we can leave some tasks as manual and speech-enable those that we feel pilots would benefit from most. Most systems that are speech-enabled also include manual input, simply because a system that is strictly speech-enabled is currently very error-prone.

V1I. Voice Recognition in Aviation

Military and aviation settings are perhaps the noisiest man-made environments. The noise level routinely exceeds tolerable levels. Moreover, for obvious reasons, clearer communication among personnel in military and aviation environments is crucially important. Voice recognition and speech-enabled interfaces are becoming increasingly more popular. This technology is already being used in aviation today.

Melbourne-based Adacel Technologies has developed an air traffic control (ATC) simulator around speech recognition technology. For trainees it brings a new level of reality to simulation. The student can sit at a computer wearing headphones, looking at a display that accurately represents an operational ATC radar. With aircraft and flight information on screen, the trainees can issue commands such as increase or decrease altitude and the aircraft will respond as in real-time situations. No one is needed to play the role of pilot and the system does not require any sort of specialized hardware. It can run on standard PCs and does not require training to use. According to George Watts, the sales and marketing director of Adacel, “This is a classroom trainer the student can take home and use to go through ‘self-paced’ learning. It does not need an instructor looking over the trainee's shoulder.” It is understood that Adacel is close to a deal with the U.S. Federal Aviation Administration (FAA) with this ATC simulator (Ballantyne, 2000).

V1I. Voice Recognition in the Cockpit

The busiest and most crucial times for pilots are the flight take-off and the flight landing. In fact, most accidents occur two minutes after take-off and eight minutes before landing. This is due to the fact that airplanes are closer to the ground at these times, leaving pilot’s with less time for recovery from any errors that may occur (Kasenchak, 2001). Voice recognition is already being used in the cockpit today. Boeing and BAE Systems, a leading provider of speech-based products for the U.S. Government, have selected ITT Industries' Voxware voice-recognition system for use in the Joint Strike Fighter (JSF) cockpit. The advanced system includes a rugged, lightweight, continuous-speech device that permits selected cockpit controls to be operated solely with voice commands. The device and related software allow pilots to avoid some manual tasks so they can remain better focused on their flight environment, without having to move his head or hands to adjust switches, knobs or buttons. "Voice-recognition technology will enhance the pilot's aircraft management capabilities," said Stan Kasprzyk, Boeing JSF cockpit manager. The Voxware system incorporates speech-recognition technology specifically designed and optimized for ultra-high accuracy in the often-noisy cockpit environment. Boeing successfully demonstrated the voice-recognition capability in Seattle last year during a full-mission simulation of its JSF for its U.S. and U.K. government customers. Voice-recognition capabilities augmented the advanced avionics that allow the JSF to gather, integrate and display essential information in the format most useful to the pilot (Boeing, 2000).

V1II. Conclusion

The fact that the busiest and most crucial times for pilots are the take-off and landing is very important when considering speech-recognition technology. At these crucial times in the flight, the pilot's are extremely pressured with multiple channels already, visual, and audio specifically. During these times, the pilot's cognitive load is extremely heavy. Pilots are not only busy with the FMS, but they are also speaking to each other, as well as the ground and flight crews. Because of these factors, I do not believe that it would be ideal to speech-enable any of the tasks that occur during these periods of time. I received a lot of resistance from pilots and FMS trainers about this. Many of the people I spoke with were adamant about keeping voice-recognition out of these phases of flight because the probability for error seemed quite high.

This was ultimately why I chose to perform the GOMS analysis on keystrokes from both pre-flight and en route task lists. The tasks preformed en route are preformed with much less of a cognitive load on the pilot, i.e. at a time when flight is running smoothly. I believe speech-enabling en route tasks (changing the radio frequency and changing the flight plan en route to a direct flight) is more possible than trying to speech-enable tasks during the crucial flying times. The en route tasks could be easily speech-enabled partially, if not totally. Rockwell Collins has been studying a speech-enabled radio frequency tuner within a Flight Deck Simulator for quite some time.

The determination that needs to be made is whether the benefits of a speech-enabled outweigh the costs of having such a system in the cockpit. For example, since computers routinely misinterpret our spoken words it would not be surprising to suggest visual feedback of the audio input. However, doing this cancels out the benefit of using purely an audio channel, now we must use and audio and visual channel.

Many researchers say definitively that speech-recognition should not be used in the cockpit for two main reasons. 1) The pilot has enough to worry about with the current FMS channels, and 2) There is too much background noise for a speech-enabled system to work effectively. So, what is the answer? Is voice recognition possible in the cockpit? As I have proposed, speech-enabled components can be limited to en route tasks. We should avoid adding more complexity to the crucial flying times, pre and post flight. This relieves the dilemma of having "too many" channels during vital flying time. As for background noise in the cockpit, many speech-enabled interfaces are being developed currently with a more acute "sense" of hearing, and will be more sensitive to specific (pilot) voices.

Lastly, instead of looking at what we have today, and what is coming tomorrow, we should focus on what we have tomorrow and what is coming beyond tomorrow. For example, if Data Link is developed and delivered in the cockpit, the pilot's will have a significantly reduced workload. If this happens in the future, perhaps there are more tasks that could be speech-enabled.

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