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## The Effects of Automation on Crew Coordination in the Corporate Cockpit

Yves P. Koning

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**THE EFFECTS OF AUTOMATION ON CREW  
COORDINATION IN THE CORPORATE COCKPIT**

by

**Yves P. Koning**

A Thesis Submitted to the  
School of Graduate Studies and Research  
in Partial Fulfillment of the Requirements for the Degree of  
Master of Aeronautical Science

Embry-Riddle Aeronautical University

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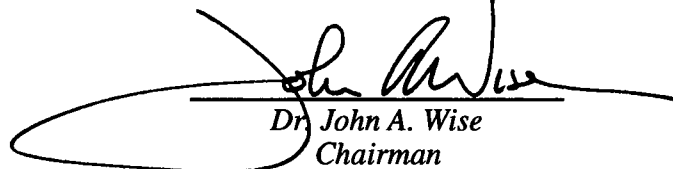
# THE EFFECTS OF AUTOMATION ON CREW COORDINATION IN THE CORPORATE COCKPIT

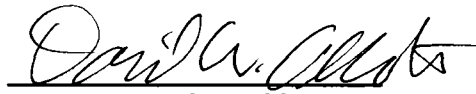
by

Yves P. Koning

This thesis was prepared under the direction of the candidate's thesis committee chairman, Dr. John A. Wise, Department of Aeronautical Science, and has been approved by the members of his thesis committee. It was submitted to the School of Graduate Studies and Research and was accepted in partial fulfillment of the requirements for the degree of .  
Master of Aeronautical Science.


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**To my parents,**

who taught me what is most valuable in life, especially  
about the Living God who still fulfills His promises  
today:

*"I will instruct you and teach you in the way  
you should go;  
I will counsel you and watch over you."  
Psalm 32:8*

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## ABSTRACT

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**Degree:** Master of Aeronautical Science  
**Year:** 1992

The implementation of automated systems in the cockpit has somewhat changed pilots' working environment. The present study, which focus is on corporate aviation, looks at the influence automation has on crew coordination.

A questionnaire including both Likert scale and open-ended questions was sent to 880 qualified pilots. A descriptive as well as an inferential analysis of the data provided by the Likert scale questions was conducted. Out of the five variables tested, the only one to generate any significant differences ( $p < .05$ ) was aircraft category. These results were further confirmed by the responses given to the open-ended questions.

Overall, pilots pointed out the importance of verbal communication and cockpit resource management training, emphasizing the strong need for crew coordination. They also cited automation as contributing to some changes in the role of pilots and some improvements in situational awareness.

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## LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
ASRS	Aviation Safety Reporting System
ATC	Air Traffic Control
CADC	Central air data computer
CDU	Control display unit
CL-601	Challenger 601
CRM	Cockpit resource management
DA-900	Dassault 900
DME	Distance measuring equipment
DoT	Department of Transportation
EFIS	Electronic flight instrument system
EICAS	Engine indicating and crew alerting system
E-RAU	Embry-Riddle Aeronautical University
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FMS	Flight management system
G-IV	Gulfstream IV
GPWS	Ground proximity warning system
ICAO	International Civil Aviation Organization
ILS	Instrument landing system
INS	Inertial navigation system
KAL	Korean Airlines
KLM	Koninklijke Luchtvaart Maatschappij – The Royal Dutch Airlines
LOFT	Line oriented flight training
MAC	Military Airlift Command

NASA	National Aeronautics and Space Administration
NAV AIDS	Navigation aids
NBAA	National Business Aircraft Association
NTSB	National Transportation Safety Board
ONS	Omega navigation system
PF	Pilot flying
PNF	Pilot not flying
TCAS	Traffic alert and collision avoidance system
VHF	Very high frequency
VOR	VHF omni range
USAF	U.S. Air Force

***Statistical Abbreviations:***

M	Mean
SD	Standard deviation
p	probability
F(x,y)	Fisher's function

## Introduction

It was not until WW2 that human factors were recognized as a critical issue. Before that, systems were designed, hardly taking into account the human. However, increasing number of incidents and accidents led the industry to progressively transform its design philosophy. Designers started to consider that human beings had to operate the machines they created. This change in philosophy was particularly felt in the aviation industry. One obvious outcome could be seen in the cockpit where different shapes of knobs began to be used for different kinds of functions, thus giving to the crew members tactile information in addition to visual information. New types of analog displays (e.g., airspeed indicator) were also installed to ease the information transfer between the machine and the pilot. Most of the early changes dealt with human physical interactions with the system. However, as technology has changed over the years, the human factors specialists have started to address cognitive issues (e.g., workload, fatigue, information transfer).

The rapid development of solid-state electronics led to the production of powerful, yet cheap, microprocessors. Due to this tremendous leap, the new technology worked its way into the cockpit and became what today is referred to as automation. In the late 1970s, concerns regarding the implementation of automated devices in the new generations of airplanes started to arise (Edwards, 1976; Boehm-Davis, Curry, Wiener, & Harrison, 1981; Wiener & Curry, 1980). Although automation was and is still synonymous with progress and improvement in areas like navigation, fuel management, and flight planning, the community, nevertheless, seemed to question the overall benefit of the new technology regarding issues such as workload, manual skill retention, or human machine interaction.

In addition to automation, the human factors community also devoted some of its attention to other growing concerns of the aviation industry. One of those concerns dealt more precisely with what was going on in multi-person cockpits. Inadequate communication, lack of interpersonal skills, and poor decision making processes were among the problematic issues identified. A study carried out by Ruffell-Smith (1979) played a key role in awakening the industry to these shortcomings. This research effort marked the birth of yet another discipline of human factors now known as crew coordination or cockpit resource management (CRM). This discipline focused on the evaluation of the obstacles that hinder teamwork within the cockpit as well as the identification of the skills necessary to achieve good interaction between crew members (Orlady & Foushee, 1982). After identifying the problems, corrective actions were taken in the form of special training devoted to teaching crew member those teamwork skills.

Automation and crew coordination have been the subject of separate research studies for over a decade now. However, until recently no attempt had been made to determine if the automated cockpit environment had any effects on traditional crew coordination skills. One obvious consequence of automation is a changed working environment for pilots. Traditional cockpit aircraft and "glass cockpit" aircraft share the same purpose: transporting passenger and/or goods from A to B. Nevertheless, this does not mean that all the tasks that have to be accomplished to fulfill this common mission are the same. For example, with the implementation of automated devices, the importance of monitoring and cross-checking seems to have been increased.

All the information presented in the preceding paragraphs is based on research studies carried out in the scheduled air carrier environment or within a military framework. This leaves out an important part of the aeronautical industry – corporate aviation. The automated features presently available for corporate aircraft are similar to, and in some cases more sophisticated than those found onboard modern airliners. Additionally, crew coordination is also an element that corporate flight departments have to deal with. The

extreme flexibility that characterizes the corporate industry suggests that similar, as well as additional findings might exist in this unique environment.

### **Statement of the Problem**

The purpose of this study is to investigate within the corporate environment how cockpit automation affects crew coordination. Based on the research already carried out in the scheduled air carrier environment (e.g., Curry, 1985; Wiener, 1985b, 1989), a number of basic problems can be expected in corporate aviation. However, additional concerns specific to this particular industry are also anticipated.

The term automation as used in this report specifically refers to advanced technology aircraft equipped with at least an electronic flight instrument system (EFIS) and a flight management system (FMS), possibly supplemented by additional automated features (e.g., auto-throttles, engine indicating and crew alerting system [EICAS], traffic alert and collision avoidance system [TCAS]). The definition of crew coordination used throughout this study was provided by Lauber (1987). He defines it as "the effective utilization of all available resources – hardware, software, and liveware – to achieve safe, efficient flight operations" (p. 9). Finally, the environment within which the study has been carried out (corporate aviation) is defined by the National Business Aircraft Association (NBAA, 1991) as the "use of aircraft, owned or leased, that are operated by a corporation for transportation of personnel or cargo and are flown by a professional flight crew who receive direct salary or compensation from the corporation for that service" (p. 112).

### **Review of the Related Literature**

Automation and crew coordination are two issues that have been the subjects of human factors research studies for more than a decade now. A wide variety of literature related to either one of these topics is available; however, literature that address both topics



simultaneously is scarce. For that very reason, this review of literature will initially focus on automation and crew coordination separately before examining the two issues together.

**Automation.** Since the early years of aviation, people have tried to improve the capabilities of aircraft through the use of new equipment. One of the first attempts to do so dates as far back as 1914 when Sperry (son of the founder of the Sperry Gyroscope Company) demonstrated that airplane stability could be greatly increased through the use of gyroscopes (Calvert, 1985). At that time, improvements were primarily in the area of mechanical devices (e.g., altimeter, magnetic compass, airspeed indicator). Now, however, electronic devices are rapidly replacing mechanical instruments. Analog displays, once the main instruments in the cockpit, are only used as backups today. Digital displays and computers have become key elements in most recent generations of aircraft. On-board computers can now fly the aircraft from early climb all the way to a full stop landing. This evolution is illustrated in Figure 1.

Wiener and Curry (1980) have identified three main factors that enabled those changes to take place. The first one, already mentioned, is *technology*. With the advent of solid-state electronics, the speed and capabilities of the advanced technology equipment increased significantly while at the same time the weight of those devices became less of a problem. The second factor is *safety*. Concern for safety has created a demand for the implementation of new automated protection devices. A good example which illustrates this point is the ground proximity warning system (GPWS). This very piece of equipment has probably saved several lives by alerting pilots when terrain threatened the safety of flight. *Economics* is the third factor. The oil crises have been a major contributor to this trend toward automation. The new automated devices have enabled more accurate navigation and better control over the engines, therefore providing more opportunities for fuel and time savings, consequently reducing personnel costs.

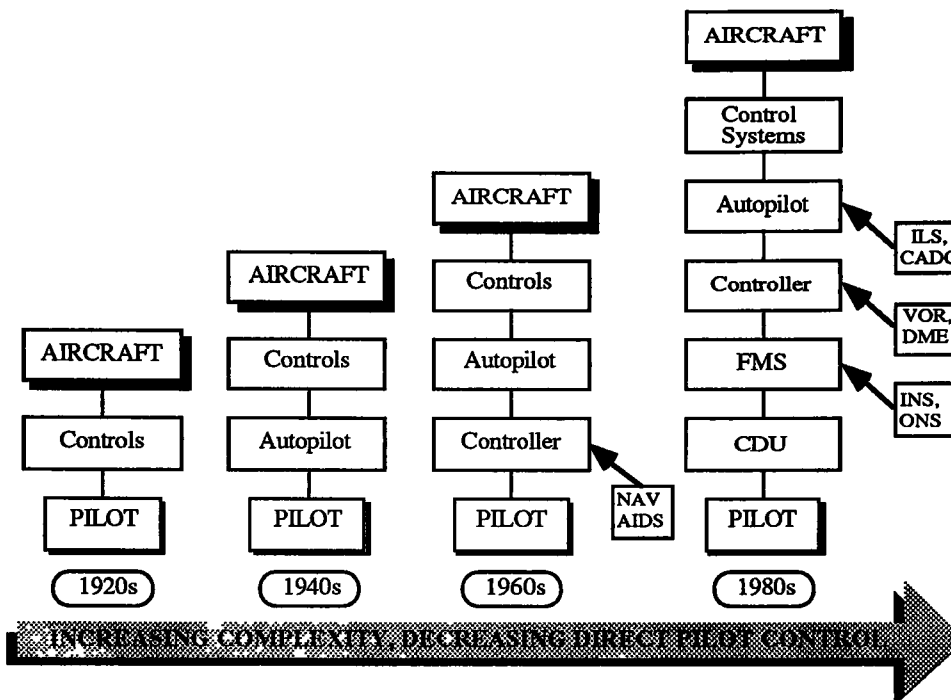


Figure 1. Increasing Complexity of Aircraft Automation (from Billings, 1991b, p. 10)

Nevertheless, automation has been cited by the National Transportation Safety Board (NTSB) as a contributing factor in several accidents. In December 1972, an Eastern Air Lines Lockheed L-1011 crew became preoccupied by a suspected gear malfunction. While troubleshooting the problem, the crew did not realize that the autopilot became disengaged and that the aircraft's path changed from level flight to a slow descent. This flight tragically ended in a crash 20 miles from the airport — 101 persons lost their lives. The NTSB determined that "the probable cause of this accident was the failure of the flight crew to monitor the flight instruments" (NTSB, 1973, p. 1).

A few years later, the crew of a DC-9 aborted takeoff just after rotation speed. This decision was based on false alarms generated by the automated system. No fatalities resulted from this accident, however, the airplane was extensively damaged and some passengers were injured (NTSB, 1977). Based on this particular accident, Wiener and Curry (1980) asked a very interesting hypothetical question regarding the flight crew's decision to abort the takeoff: "what might have occurred if this decision had been

automated?" (p. 7). They did not provide any answers but left it to the readers to decide for themselves.

The year 1979 was also a year where automation was involved in a major aviation crash. An Air New Zealand DC-10 crashed into Mount Erebus in Antarctica killing 257 persons. This accident has been the source of much controversy (Mackley, 1982). The whole issue revolved around automation, or more precisely around the navigation system and the way the automated systems were programmed and operated. A route change was selected by the airline dispatch for this sight-seeing flight. The crew, however, was not properly briefed on this change and descended during the flight below minimum safe altitude. This, combined with the fact that the automated system was controlling the course of the flight, contributed to the aircraft crashing on the mountain side. No error could be identified as a malfunction of the machine.

Another controversial accident happened in September, 1983. A Korean Airlines B-747, flight KAL 007, was shot down because the crew inadvertently entered Soviet airspace. Several reasons have been presented to explain why the airliner was so far off course. Wiener (1988) suggested, along with several others (ICAO, 1983; Machado, 1984), that "in all likelihood the track deviation was due to improper programming of the INS [inertial navigation system]" (p. 441). Once again, the machine probably operated properly but with the wrong set of data, resulting in a 300 mile deviation.

Several other NTSB reports exist where automation has played a role in aviation accidents. In addition to those, there are also incident reports filed with the aviation safety reporting system (ASRS) that identify automated systems installed on board aircraft as contributing factors. One critical issue brought up by those incident reports is the concern regarding the amount of altitude deviations experienced by pilots of new generation airplanes.

The involvement of automation in those incidents/accidents as presented here is just one factor in a whole chain of events that led to the mishap. The reader should not discredit

automation because of those reports but must realize that despite its enormous benefits some improvements and additional research efforts are still needed. In 1967, Shackel highlighted some ergonomics research needs not solely restricted to the improvement of automation, but also encompassing demands to better "match automation to mankind" (p. 627). Machine programming, decision making, vigilance, and workload were some of the needs identified. Shackel mentioned that despite the understanding already acquired, some "gaps in ergonomics knowledge relevant to automation" (p. 631) existed and that further research was needed to increase knowledge and improve the "techniques of application" (p. 631).

In a similar effort, Edwards (1976) presented some issues specific to the civil aviation industry. His argument was based on two rules whose importance should still be acknowledged today. The first rule addressed workload. He stated that "the introduction of automation does not necessarily ease the load upon the human operator" (p. 14). The second rule dealt with the implementation of automated systems: "The requirement for ergonomics input into the design and operation of systems is in no way diminished by the introduction of automation, which changes the nature of the human factors problems without reducing their significance" (p. 15). Edwards illustrated those rules by depicting areas of concerns. The most critical one was the change of the pilot's role due to the increased importance of monitoring. This concern by itself raises several other issues such as the training programs and the ability of pilots to consciously revert to a controller's role when experiencing system failures.

Shackel (1967) and Edwards (1976) provided some useful insights into the automation question, but they did not give any directions concerning the improvement of the design or the operation of automated devices. In 1980, Wiener and Curry, in addition to giving an overall presentation of the automation issue, provided the industry with the first set of guidelines "for designing and using (or not using) automated systems" (p. 19). The 15-item list developed addressed separately two types of tasks: control tasks and

monitoring tasks. Even though those items should not be considered as formal design specifications, they should be used to avoid potential pitfalls of automation and to realize that "the question is no longer whether one or another function can be automated but, rather, whether it should be" (p. 2).

A series of guidelines followed this first set. Ciciora and his colleagues (Ciciora, Leonard, Johnson, & Amell, 1984) provided some directions for different aspects of automation (e.g., human adaptation, human-machine interface) as it relates to the aviation industry. Bergeron and Hinton (1983) addressed the issue of pilot interface and came to the conclusion that automation has "frequently been implemented without sufficient consideration given to the man/machine interface problem inherent to the designs" (p. 102). Their approach towards correcting this problem was through the elaboration of a set of guidelines pertaining to interface design. Hoagland (1984) did not provide a new list but explained "why [such] guidelines are needed for cockpit automation" (p. 155). For him there are at least two reasons for such guidelines: first to "determine what role automation should play in the piloted cockpit" (p. 159), and second to put to rest some misconceptions about automation. Braune and Fadden also addressed this issue in 1987 and formulated new guidelines around three points: when to automate, how to automate, and the pitfalls of automation. Finally, the latest work on this issue focused on the more recent philosophy of automation called human-centered automation. Besides giving a set of general guidelines, Billings (1991b) also provided specific guidelines for three different aspects of automation: control automation, information automation, and management automation.

The different guidelines produced over the years are either at the source or the result of human factors research. One particular document really triggered this research effort for the aviation industry. In the summer of 1980, the National Aeronautics and Space Administration (NASA) organized a workshop which purpose was "to define the important research areas involved in the human factors of flight-deck automation and to create a list of

general and specific research questions" (Boehm-Davis, Curry, Wiener, & Harrison, 1981, p. 2). The outcome of this workshop was a list of questions articulated around six major categories: systems questions, implementation, methodology, selection and training, man-machine interaction, and field studies. Most of the questions formulated then have now been addressed at least to a certain extent.

Another workshop was organized more recently by NASA (Norman & Orlady, 1988) in collaboration with the Federal Aviation Administration (FAA). The different working groups addressed issues such as "design, training, operations, and certification of the aircraft" (p. 5). Special attention was also devoted to the understanding of the automated systems, and both normal and irregular operational situations were studied. Additionally, the workshop addressed difficult questions like the following: Has the role of pilots been changed by the implementation of automated devices? With respect to the Federal Aviation Regulations (FARs), their role has not changed; however, the nature of their work has been modified. To cite but one fact, several of the control functions have been replaced by monitoring functions.

As a direct result of the 1980 workshop, two reports which present the findings of field studies were published in 1985. Both of these studies (Curry, 1985; Wiener, 1985b) focused on problematic issues encountered during the early introduction of automated aircraft within fleets of traditional airplanes. In both cases, the same type of instruments were used to collect data (i.e., questionnaires, cockpit observations, and structured interviews with crews). The two research efforts, however, focused on different aircraft. The population targeted by Curry was Boeing B-767 pilots, while Wiener's attention was devoted to the McDonnell Douglas MD-80. Some similar conclusions were reached by both researchers regarding automation, such as the acceptance of the new technology, the perception of a possible loss of flying skills (even though no data were found to support that concern), the need for new training approach, and the changes in monitoring requirements. Additionally, Curry suggested that the implementation of "turn-it-off"

training was needed. The lack of such training probably found its origin in the unwritten company policy stated by Wiener: "We bought it, you use it" (p. 92). Another finding of Wiener's study suggested that automation was not necessarily synonymous with workload reduction, therefore confirming what Edwards had reported in 1976. Both of those field studies provided the research community with some valuable insight on operational problems existing in the airline industry. Wiener (1985c) suggested a reason why some of those problems existed: "It would appear...that machine development has outstripped the ability of humans to dependably operate the equipment, as well as the ability of human factors researchers to understand and cope with the problem" (p. 369). The technology growth has been so rapid that new devices were installed on-board the latest generation of aircraft before any of the impact on the pilot's environment could be studied.

New pieces of equipment increased the capability of the system and at the same time reduced the amount of traditional errors. Nevertheless, with the new devices also came new types of errors. According to Wiener (1985a) "automation tunes out small errors and creates opportunities for large ones" (p. 83). Data entry error, which has become a common occurrence today, is a good illustration of this new kind of error. If no careful cross-checking is done by the crew, wrong waypoints may be entered into the system, thus resulting in an altitude deviation or airspace penetration. This type of error has the potential to lead to a tragic error such as the airspace violation experienced by the Korean Airlines flight KAL 007. For Norman (1989), the problem does not reside with automation itself, but in the feedback the crew receives from the machine or the lack thereof. He stated that "when automatic devices compensate for problems silently and efficiently, the crew is 'out of the loop,' so that when failure of the compensatory equipment finally occurs, they are not in any position to respond immediately and appropriately" (p. 5).

Because the problem seems to be in the transfer of information between the crew and the machine, some have suggested removing the human from the cockpit. Responding to this issue, Chambers and Nagel (1985) raised an interesting question. Even if it were

feasible to transport passengers in a flying robot, would it be socially acceptable to do so? For now "no" is the answer, and it will probably not change for several years. The human adaptability to new and unknown situations has not yet been matched by any machine. Therefore, other alternatives are needed to remedy the information transfer problem.

A first step toward finding such a solution may reside in the answer to the following question: "Should the automated system serve as the human pilot's assistant, or vice versa?" (Chambers & Nagel, 1985, p. 1147). Billings (1991a) suggested: "Automation is a tool; it must assist the pilot in managing as well as controlling the aircraft" (p. 18). For him, this very point constituted the core of human-centered automation. He defined this concept in another report (Billings, 1991b) as "automation designed to work cooperatively with human operators in the pursuit of stated objectives" (p. 7). As long as the FARs assign the responsibility of flights to the captains, automation should not be anything else than one of the resources available to pilots to safely reach their destinations. Albers (1991) also addressed the issue of human-centered automation, which for him consisted of designing the pilot's environment in such a way that they "perceive themselves as being the focus of control" (p. 9). In order to reach this goal he provided the following recommendation:

Human centered automation systems must be designed to allow for human interaction and involvement with a system which is consistent with human intellectual abilities, skill level, and responsibility; allow for the joint and collaborative interaction and responsibilities of flight crew, controllers, and ground personnel; and enhance unique human capabilities. (p. 10)

This objective established by Albers (1991) has not yet been reached. The most recent field study (Wiener, 1989) done in the U.S. showed that the particular issue of pilots/controllers interaction has been the source of critical problems. This concern may exist because aircraft and air traffic control (ATC) have been developed separately. This factor might hinder the crew of an advanced technology aircraft to use the automated system to its full extent. The focus of the study carried out by Wiener was on the Boeing B-757. In addition to the ATC issue, he also addressed the following topics: cockpit



equipment, training, cockpit errors, crew coordination, workload, and attitude toward automation. One important finding was what Wiener referred to as the *paradox of automation*. "When circumstances of the flight add up to a very high workload, pilots often find the automatic features so difficult to manage that they abandon them in favor of more manual modes" (Wiener, 1989, p. 179). This point seriously questions the validity of the assumption that automation reduces workload.

The issue of workload was also identified by a similar field study (McClumpha, James, Green, & Belyavin, 1991) carried out in the United Kingdom. The complete population of glass cockpit aircraft in the UK was targeted. The data collection was done through the use of a questionnaire. The following four topics were addressed by their study: understanding, workload, design, and skill. One interesting result found by the researchers was that age was related to the understanding which pilots had of the automated system. This particular issue had been mentioned in previous studies, but McClumpha et al. were the first to formally establish a statistically significant correlation between understanding and age. "Factor A [understanding] ... showed a significant interaction with age ( $p < .05$ ). The data indicated that the younger pilots (< 40 yr.) have a better understanding of the 'system' than older pilots (> 40 yr.)." (p. 194).

In summary, a large research effort has been dedicated to cockpit automation: Field studies have been carried out, other type of research studies done, and workshops organized. By reviewing those documents, one realizes that real concerns regarding automation exist. For example, concerns about workload, training, and human-machine information transfer. However, one should not forget that automation is also at the source of great benefits. Among them is the fact that the aviation industry has maintained a very good safety record over the past two decades while experiencing increasing traffic demands. Moreover, one should also recognize that automation is here to stay, and that the only way to keep or improve the current safety record will be to refine the automated

systems already on the market and develop new improved systems according to proven existing guidelines.

***Crew coordination.*** The concept of crew coordination emerged out of the research effort carried out by Ruffell-Smith (1979). The study focused on the interaction of pilot workload with errors, vigilance, and decisions. While observing crews during full mission simulation, researchers began to realize that "large variations in respect to leadership, resource management, and decision-making" (p. 28) existed. Therefore, Ruffell-Smith recommended that "special training in resource management and captaincy be developed and validated" (p. 35).

The results of this study came around at a time when the aviation community was awakening to the fact that improved teamwork within the cockpit was needed in order to reduce the number of accidents attributed to human error. Several of those accidents happened in the 1970s and early 1980s, thus, leading to an increasing awareness by the aviation community and the public. The most tragic aircraft accident in the history of aviation has been the crash of two Boeing B-747s in Tenerife, Spain in 1977 where 574 persons lost their lives. A KLM B-747 was already in position for takeoff while a Pan Am B-747 was back-taxiing on a portion of the runway on its way to the departure end. This procedure was used due to parking problems on the ramp. Heavy fog restricted the visibility, and the crews could not see the other airplane. The captain of the KLM flight started takeoff while the other aircraft was still on the runway. This captain was a very experienced instructor pilot and was well recognized within the company he worked for. His first officer, on the other hand, had little experience in the B-747. The cockpit voice recorder showed that very poor crew coordination technique was used by this crew. Despite the set of contributing factors, the probable cause of this accident was the lack of teamwork of the crew. The flight engineer demonstrated a tragic lack of assertiveness. Realizing that the Pan Am B-747 was still on the runway while the captain was pushing the throttles forward, he simply queried the captain about the position of the other aircraft. The

captain did not listen to what the other crew members mentioned to him, and tragedy occurred.

Since then, other accidents have also occurred where poor resource management was demonstrated by the crew. In 1985, shortly after takeoff, the crew of a Lockheed Electra L-188C requested to return to the departure airport because of vibration in the airplane. One and a half minutes after departure, the aircraft crashed. According to the NTSB (1986), a breakdown in crew coordination occurred. This led the safety board to make the following recommendation to the FAA: "Provide, to all operators, guidance on topics and training in cockpit resource management so that operators can provide such training to their flight crew members" (p. 43).

A little over two years later, on August 16, 1987 a McDonnell Douglas DC-9 crashed shortly after departure. The accident resulted in 154 fatalities. The NTSB (1988) later determined that the aircraft was not properly configured for takeoff. As an outcome of the investigation, the NTSB (1988) reinforced the recommendation cited above by asking the FAA to:

Expedite the issuance of materials for use by Parts 121 and 135 operators in the implementation of team-oriented flight crew training techniques, such as cockpit resource management, line-oriented flight training [LOFT], or other techniques which emphasize crew coordination and management principles. (p. 68)

A first step toward providing a solution to this kind of problem was taken when, in 1979, NASA organized a workshop entitled "*Resource Management on the Flight Deck*" (Cooper, White, & Lauber, 1980). One of the primary objectives of this workshop was to assess what the industry status was on the issue of crew coordination. Another objective was to develop guidelines or at least recommendations to improve crew coordination between flight crew members.

Probably the most significant workshop since was a workshop organized in 1986 (Orlady, & Foushee, 1987) by NASA in collaboration with the USAF Military Airlift Command (MAC). During this workshop, Lauber (1987) provided a definition of CRM. It "is the effective utilization of all available resources – hardware, software, and liveware –

to achieve safe, efficient flight operations" (p. 9). Helmreich (1987) further explained this definition by saying that "these resources are both inside and outside the aircraft and are both material and human, including especially the knowledge, judgment and decision-making skills of all crew members and the ability of the crew to bring them together in optimal fashion" (p. 15). In addition to this definition, a major outcome of this workshop was the development of a curriculum for CRM training programs. According to two working groups, the following seven topic areas should be part of any such curriculum: "communication, situation awareness, decision-making, leadership/followership, stress management, critique, and interpersonal skills" (Orlady & Foushee, 1987, pp. 198-199). The working groups identified those as areas where pilots needed to have working skills in order to demonstrate good crew coordination within the cockpit.

Besides this workshop, other efforts have been made to identify skills contributing to effective crew coordination. The USAF Air Training Command was among those who addressed this issue. According to Shaud (1989) "crew coordination problems can be grouped into three broad categories: task prioritization problems . . . ineffective communication, . . . and lack of coordinated action" (p. 601). He further provided a list of skills the pilots need to start solving those problems: command, discipline, leadership, followership, cockpit cross-check, situational awareness, judgment, decision-making, prioritization, workload sharing, and communication. The Naval Training Systems Center has also tackled this issue. Like the 1986 workshop, they identified seven dimensions of team behavior. These skills include mission analysis, decision-making, assertiveness, flexibility, situational awareness, communication, and leadership (Franz, Prince, Cannon-Bowers, & Salas, 1990).

Communication, decision-making, situational awareness, and leadership are the four topics common to all three lists presented above. Of those, communication is, according to Lassiter, Vaughn, Smaltz, Morgan, & Salas (1990), "the most important

aspect of crew coordination" (p. 1372). The general term of communication can encompass different things, however, for Kanki, Greaud, & Irwin (1989)

...there are two aspects of the communication process that are particularly relevant to aircrew performance. First, communication is clearly a means or tool by which crews accomplish their task. They coordinate actions by commands, statements of intent, by sending and receiving information to each other, etc. . . . The second aspect of communication is more descriptive than prescriptive, and refers to the way in which crews can be distinctively characterized. This aspect of communication refers more to the "when" and "how" things are communicated as opposed to "what" is communicated, and indexes some quality of the way in which crews interact with each other. (p. 419)

In 1981, Foushee and Manos studied the communication patterns of flight crews in correlation with their performance. The analysis was based on data recorded during the research effort of Ruffell-Smith (1979). Foushee and Manos concluded that communication and performance were highly related. However, it was not the quantity but the type and quality of the information transfer that was important. Along the same line, Kanki and Foushee (1989) have shown that better performance was found in the cockpit where the crew demonstrated more homogeneity in their speech patterns.

Three other skills have also been the subject of recent research. Jensen and Adrion (1988) have addressed the issue of decision-making within the aeronautical environment. They believe that "new cockpit technology has tended to place even more importance on the pilot as an information processor, decision maker, and manager" (p. 1). For them, good decision making involves two things: "the ability to search for and establish the relevance of all available information...[and] the motivation to choose and authoritatively execute a suitable course of action" (p. 2). Concerning situational awareness, Sarter and Woods (1991) consider that it "has become a [sic] ubiquitous phrase and the frequent topic of research projects even without consensus on its meaning or much knowledge about existing problems that need to be addressed" (p. 46). Therefore, as a first step toward consensus on this issue, Sarter and Woods defined situational awareness as "all knowledge that is accessible and can be integrated into a coherent picture, when required, to assess and cope with a situation" (p. 55). Finally, Lauber (1987) defined leadership as "the ability of

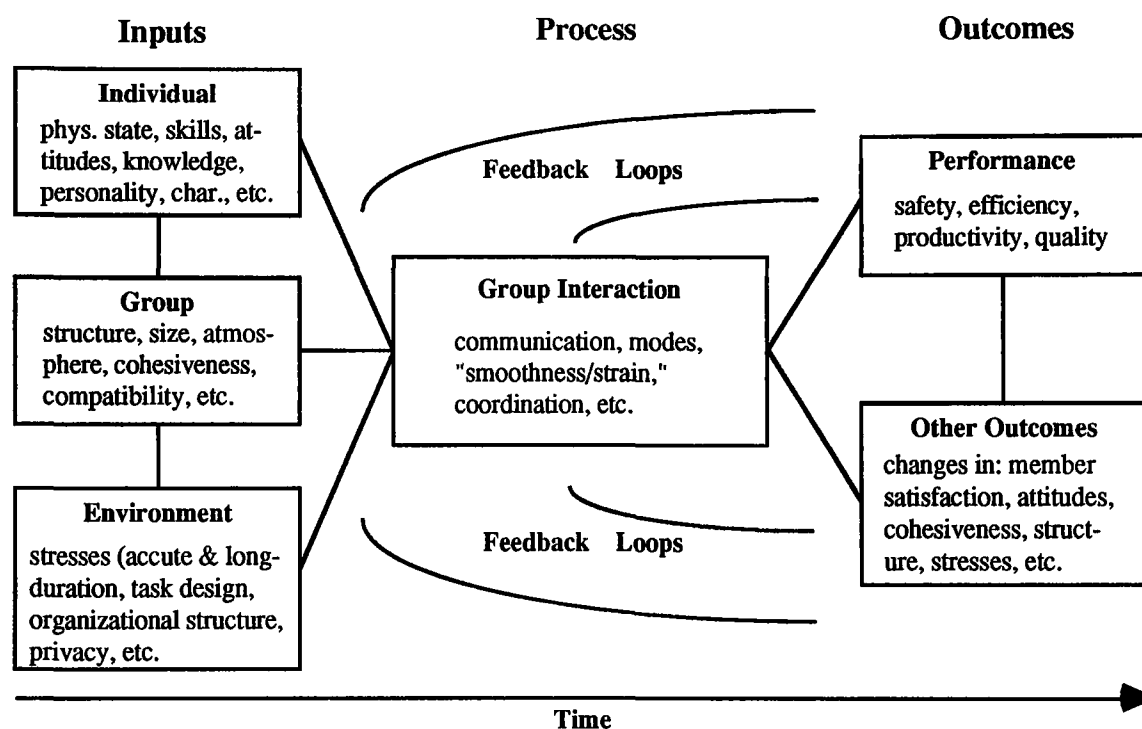
the pilot in command to establish an atmosphere where he or she is clearly in command, but which encourages participation and critique by subordinate crew members" (p. 11).

According to Lauber, this skill is one of the most difficult to implement within the cockpit. He even goes further saying that "the effects of leadership — good or bad — are pervasive and far-reaching" (p. 11).

Although research has been done on particular topics of crew coordination training, there is little empirical data addressing "the impact that such programs may have in terms of reducing the number of aircrew coordination errors" (Swezey, Llaneras, Prince, & Salas, 1991, p. 302). For Franz and his colleagues "part of the failure of existing aircrew coordination training programs to evaluate training effectiveness is the absence of a means for measuring the effects of training" (Franz et al., 1990). Foushee (1984a) has suggested several reasons for this situation. One of them was the fact that "it is difficult to assimilate the sheer number of variables that can potentially affect group processes" (p. 886). In order to clarify the complexity of group processes, Foushee and Helmreich (1988) elaborated a model (see Figure 2) where the factors affecting team work were categorized into three classes: input variables, process variables, and outcome variables. For more detailed information on this point, refer to Foushee (1984a), and Foushee and Helmreich (1988).

Assessing the impact of CRM training at a group level is, as seen in the above paragraph, a difficult task. The industry has adopted principally two methods to reach this goal. The first approach consists in measuring changes at the individual pilot level. To do so, a pre-test and post-test method has been developed by NASA and the University of Texas (Helmreich, Wilhelm, & Gregorich, 1988). The same questionnaire was administered to pilots before and after they went through CRM training. Confidential identification codes were used to compare the two sets of data. The second method is measuring "crew behavior in line and simulator settings" (Helmreich, Foushee, & Wilhelm, 1990, p. 5). Two approaches are taken for this method: expert ratings and micro-analysis of communications. For the first approach, an expert observer collects data

by watching crews perform their duties either in flight or during simulation sessions. The second approach is more labor-intensive. It consists of analyzing the cockpit voice recorder or video taped LOFT session. Several parts of the industry, both civilian and military, are currently participating in the data collection effort. This should be proved valuable in determining the effectiveness of crew coordination training.



*Figure 2.* Factors Affecting Group Performance (After Foushee & Helmreich, 1988)

Until final results are published, there will not be any justification for CRM training except the fact that this is the only method available to fight the crew coordination problem existing within the cockpit. Some preliminary results suggest that such training is beneficial. Nevertheless, no hard evidence is available to support those results or quantify to what extent this training is useful. Therefore, the only approach available to the federal government is CRM training. That is why in December 1989, the FAA issued an advisory

circular providing "guidelines for developing, implementing, and evaluating a cockpit resource management training program (DOT, 1989, p. 1). This advisory circular came as a result of many recommendations made by the NTSB over the years and was mainly based on the 1986 NASA/MAC workshop. On the international level, the International Civil Aviation Organization (ICAO) modified Annex 1 (i.e., Personnel Licensing) to require that pilots go through a human factors training program (Johnston & Maurino, 1990). In addition to modifying Annex 1, ICAO also published a series of circulars addressing this issue in order to increase the awareness of the aviation industry. One of those circulars is dedicated to flight crew training program such as CRM and LOFT (ICAO, 1989).

*Impact of automation on crew coordination.* As reported in the paragraphs above, automation and crew coordination are two issues that separately have generated large research efforts. Until recently, however, these efforts were independent from each other. A few researchers in the past have mentioned the idea of studying the two issues together. One of the early reports on the subject was authored by Lauber (1984) who identified seven areas where he expected new technology to have some implications for CRM. These included communication, task prioritization and delegation, monitoring, and problem assessment.

More recently researchers (Helmreich, Foushee, & Wilhelm, 1990) have expressed some concerns about these expectations. They considered that automation had an impact the pilot's ability to prioritize and distribute work as well as avoiding overload. However, according to Helmreich and his colleagues special crew coordination training could help crews adapt to the modern environment. In 1984, Foushee making a point for CRM training addressed briefly the issue of new technology. For him "improved design and advanced automation were just partial answers" (Foushee, 1984b, p. 249) to human errors in the cockpit. He further suggested that "human factors engineering and automation approaches to the reduction of human error were promising but that ultimately this



approach would not be completely successful because inevitably a new class of human error would be created" (p. 254).

The point made by Foushee goes along with what Wiener observed several times during his field studies (Wiener, 1985b, 1989). New errors were generated by the new technology. One question then has to be answered: "Is the crew coordination technique that was developed for the traditional cockpit still appropriate for advanced technology aircraft?" During a recent NASA/FAA/Industry workshop (Norman & Orlady, 1988) the point was made that automation has changed the working environment of pilots. "The most obvious direct effects include changes in task structure, changes in the interpersonal aspects of traditional and standard procedures, and changes in information flow and communication channels" (p. 107). The fact that this kind of changes has been observed makes the previous question a pertinent one. Knowing that communication is such a crucial element for effective crew coordination, it is therefore very important to determine how automation impacts communication, and thus, in the same time, crew coordination.

Several researchers have addressed the issue of communication as it relates to the automated environment. A British study (Costley, Johnson, & Lawson, 1989) compared the communication patterns observed in traditional and advanced technology aircraft. Three types of aircraft were used (i.e., B-737-200, B-737-300, B-757). Preliminary conclusions pointed out some differences. It seemed that a trend existed "toward lower inter-pilot communication as the degree of cockpit automation increased" (p. 418). However, the study suggested that this decrease in inter-pilot communication might have been replaced by a new channel for information transfer (i.e., via the automated device).

The change in communication as a result of the implementation of automated devices within the cockpit has been studied to a certain extent by Segal (1989, 1990). The reduction of switches in the new generation of cockpit has reduced the information transfer (i.e., non-verbal communication). In traditional aircraft, if one of the crew members were reaching for a certain switch the rest of the crew could get some information regarding the

action accomplished just by knowing the location of the switch (Brown, Boff, & Swierenga, 1991). With the new technology pilots can change the status of almost any system through the use of a single interface called a *control display unit* (CDU). Depending on which page of the display the crew member is, he or she can do various things like input a new way point or something totally different such as changing the air conditioning setting. One of Segal's (1990) recommendations to designers is that "the design flexibility afforded by new technology must be applied carefully, keeping and [sic] eye – as well as an ear – on the ultimate quality of crew communication." (p. 252).

Wiener (1989) devoted special attention in his B-757 field study to the issue of crew coordination. He mentioned that an apparent breakdown existed in the traditional pilot-flying/pilot-not-flying (PF/PNF) structure. "Although certain duties are clearly assigned to the PF and PNF, there can be a relaxation of this discipline: Often one pilot will take over the programming duties from the other, particularly at times of high workload" (p. 120). This finding confirmed the point made during the 1988 workshop that "the PNF who previously provided PF backup...has become a more integral part of the PF's flight control duties" (Norman & Orlady, 1988, p. 108).

In addition to this change in structure, Wiener (1989) also introduced the concept of a specific crew coordination training for pilots flying glass cockpit aircraft. Until then it was assumed that CRM skills once learned were adequate for any airplane type whether automated or not. "Crew coordination for a fixed size crew may not be independent of the model, and automation probably exerts an influence on the way the task is managed by the two pilots." (p. 177). The field study outcomes suggested that the model of aircraft and the crew coordination skills required might not be independent of each other. However, no empirical data were collected to address this hypothesis.

Consequently, Wiener and his colleagues (Wiener, Chidester, Kanki, Curry, & Gregorich, 1991) undertook a new research effort with the goal of finding empirical evidence to the dependence relationship between automation and crew coordination. The

study consisted of comparing the performance of crews during LOFT sessions in two different airplanes (i.e., DC-9-30 and MD-88, different models of the same aircraft). The data were collected through the use of video recordings, expert and crew self ratings, and questionnaires. In their first published report, Wiener et al. only presented "the purpose, rationale, and methodology of the study" (p. 121) along with some data. Results are scheduled to be released later this year or early 1993. So far, no evidence has been reported by the research team that would validate the hypothesis that automation has any influence on crew coordination. However, it has been stressed by the researchers that, at the stage of the first report, no final conclusions could be drawn from the experimental data collected.

In summary, past research efforts have shown that the implementation of automated devices in aircraft cockpits has changed the working environment for pilots. Field studies carried out by Curry (1985) and Wiener (1985b, 1989) have suggested that the clear task assignment for PF and PNF in traditional cockpits has been altered somewhat in the glass cockpit. Further studies have reported changes in communication channels. From those research efforts originated the concept that specialized crew coordination training might be required to address the particular needs of specific airplane types (i.e., traditional vs. glass cockpit aircraft). As a result, an attempt was made to collect empirical data regarding that issue. The preliminary results, however, have failed to demonstrate the need for such specialized training.

### **Statement of the Hypothesis**

The reviewed literature strongly suggests that the implementation of automated devices in the cockpit has changed the working environment for pilots. However, the literature that supports this issue has concentrated its focus only on scheduled air carriers. Nobody seems to have addressed this point for corporate aviation. With its extremely flexible demands, this segment of the industry might experience more acutely the concerns

currently associated with highly automated airliners. Therefore, it is hypothesized that crew coordination in the corporate cockpit is influenced by automation. This influence is anticipated to be seen in areas such as communication, situational awareness, or role of the pilot. Furthermore, it is hypothesized that the need for crew coordination training has become more critical due to the changes automation has generated in the pilot working environment.

## Method

### Subjects

Subjects for this study were selected from the population of American type-rated pilots in corporate aircraft most likely to be equipped with advanced automation (e.g., Challenger 601-3A, Falcon 900, Gulfstream IV). The information necessary to contact the subjects (i.e., name and address) was provided by the FAA Airmen Certification Branch in an electronic format. This list contained 3,306 names. Due to its size, it was decided to target approximately one-quarter of the sample (i.e., 880 pilots). Using a random sampling technique, 880 pilots were selected from the data base.

*CRM training.* One of the first factors according to which the subjects were grouped is whether they had gone through a crew coordination training program (see Table 1). However, no distinction was made on the quality of the program even though from the open-ended question it was learned that some subjects went through a well structured training program, whereas others had just had in-house awareness-type training. According to the FAA, this latter type of "instruction alone may not fundamentally alter crew member attitudes and behavior over the long term" (DoT, 1989, p. 4).

Table 1

*CRM Training — Distribution by Groups*

<u>Group</u>	<u>N</u>	<u>Percentage (%)</u>
Yes	374	88.8
No	47	11.2
<b>Total</b>	<b>421</b>	<b>100.0</b>

**Gender.** Only 3 female subjects completed the questionnaire and therefore counted for 0.7% of the respondents. The other 418 questionnaires (99.3%) were completed by male pilots. Due to this large disproportion gender was not considered as a variable during the analysis.

**Age.** The sample of pilots that completed questionnaires varied in age from 24 to 71 years of age (mean of 45.0 years old). In order to ease the analysis the pilots were divided into three age groups of approximately the same size:  $X \leq 40$ ,  $40 < X \leq 50$ , and  $50 < X$ . Table 2 below shows the distribution by groups. The choice of 40 and 50 were not based on any physiological, psychological, or any other reasons. Those figures were selected so that each group represents at least 20% of the whole population without encompassing more than 45% of it.

Table 2

*Age — Distribution by Groups*

<b>Group</b>	<b>N</b>	<b>Percentage (%)</b>
X $\leq$ 40	124	29.5
40<X $\leq$ 50	189	44.9
50<X	108	25.6
<b>Total</b>	<b>421</b>	<b>100.0</b>

**Total flight time.** The subjects reported total flight time varying from 800 to 34,000 hours (mean of 9,773 hours). Once again subjects were divided into three groups of approximately the same size:  $X \leq 7,500$ ,  $7,500 < X \leq 12,500$ , and  $12,500 < X$ . The figures 7,500 and 12,500 were chosen based on the same criteria mentioned above for the age variable. Table 3 presents the distribution of the subjects by groups.

Table 3

*Total Flight Time — Distribution by Groups*

<b>Group</b>	<b>N</b>	<b>Percentage (%)</b>
X≤7,500	141	33.5
7,500<X≤12,500	187	44.4
12,500<X	87	20.7
Missing Data	6	1.4
<b>Total</b>	<b>421</b>	<b>100.0</b>

*Last year flight time.* The amount of time flown in the previous year was also chosen as a variable. The method already used twice previously was again selected to divide the subjects into three groups:  $X \leq 300$ ,  $300 < X \leq 400$ ,  $400 < X$  (see Table 4).

Table 4

*Last Year Flight Time — Distribution by Groups*

<b>Group</b>	<b>N</b>	<b>Percentage (%)</b>
X≤300	116	27.6
300<X≤400	161	38.2
400<X	144	34.2
<b>Total</b>	<b>421</b>	<b>100.0</b>

Hours reported by the pilots varied from a low of 85 hours to a maximum of 800 hours (mean of 390.0 hours).

*Aircraft category.* The last major distinction was based on the aircraft pilots flew. Three aircraft were considered by the researcher to represent the state of the art in automation in today's corporate airplanes. Those three aircraft were not selected arbitrarily.

Through the literature and contacts with corporate aviation professionals, the researcher came to realize that those aircraft could be considered in the corporate environment as the most advanced aircraft in terms of automation. Nevertheless the researcher would like to emphasize that this selection represents his own choice and might not necessarily represents a unanimous opinion. Those aircraft are, in alphabetical order, the Challenger 601-3A (CL-601) manufactured by Canadair of Canada, the Falcon 900 (DA-900) manufactured by Dassault Aviation of France, and the Gulfstream IV (G-IV) manufactured by Gulfstream Aerospace of the U.S. Pilots flying at least one of those three aircraft were referred to as group A pilots, the rest of the population constituted group B (see Table 5). The purpose in grouping pilots like this was to find out if significant differences existed between what looked like two "levels" of automation in the responses collected. If such differences were to be established, this would provide incentives for further research into how crew coordination is influenced by different "levels" of automation. The first step in that research effort would be to carefully define those levels.

Table 5

*Aircraft Category—Distribution by Groups*

<b>Group</b>	<b>N</b>	<b>Percentage (%)</b>
A	231	54.9
B	190	45.1
<b>Total</b>	<b>421</b>	<b>100.0</b>



## Instrument

The instrument used for this study consisted in a section of a larger questionnaire developed for the purpose of identifying the effects of automation on corporate pilots. The development of this questionnaire was based in part on questionnaires already designed by other researchers (Curry, 1985; McClumpha et al., 1991, Wiener, 1985b, 1989) who carried out field studies in the air carrier environment. However, some changes were incorporated to address specific issues of the corporate environment. The final version of the questionnaire contained 61 questions: 46 Likert scale and 15 open-ended. Of those, eight Likert scale and two open-ended questions were dedicated to crew coordination:

### *Likert scale questions:*

8. Automation has made the first officer's willingness to speak up  
scale: Very Difficult – Extremely Easy
9. Automation makes knowing what the other crew member is doing in high workload situations  
scale: Impossible – Extremely Easy
10. Automation makes crew supervision  
scale: Impossible – Extremely Easy
11. Automation has made situational awareness  
scale: Impossible – Extremely Easy
12. Automation makes verbal communication between crew members  
scale: Completely Unnecessary – Absolutely Required
13. Automation makes crew coordination  
scale: Completely Unnecessary – Absolutely Required
14. Effect of automation on the division of responsibilities between crew members  
scale: No Effect – Completely Changed
15. Automation has made crew coordination training  
scale: Totally Unnecessary – Absolutely Necessary

### *Open-ended questions:*

- 5B. How has automation affected crew coordination?
- 6B. If you received any crew coordination training, please specify where. Which topics were covered? Did the training address the automation issue (if so, how)? What did you think of this training?

In addition to the questions, other data were also requested. The initial three pages of the questionnaire were devoted to that purpose. The first page was to collect personal information on the subjects (e.g., name, address). That page also contained a confidentiality statement guaranteeing anonymity to the subjects. The second page was used to remind participants that only pilots with advanced technology aircraft experience should answer the questionnaire. The following statement appeared on that page in large bold font: *Automation refers to advanced automated aircraft equipped with EFIS and FMS supplemented by additional automated features.* The third page served the purpose of collecting information on subjects' flight experience and other relevant information (e.g., age, gender, computer familiarization). On that page, subjects were also asked if they ever had any crew coordination training. Those three pages (along with the rest of the questionnaire) are reproduced in Appendix A.

Along with the questionnaire, two cover letters were sent to the subjects. The first one was written by Dr. John A. Wise (Principal Investigator of the large-scale study) and the second was written by Dr. H. Clayton Foushee (FAA Chief Scientist and Technical Advisor for Human Factors). The first cover letter explained the context in which the research was carried out and also emphasized the fact that only pilots with advanced automated experience were to answer the questionnaire. The second letter stated the objective of the study and explained the involvement of the FAA in this research effort (Appendix B).

## **Design**

The design approach used was a self-report descriptive research method. According to Gay (1987) "descriptive research involves collecting data in order to test hypotheses ... concerning the current status of subject of study" (p. 189). This method was, therefore, the most appropriate to collect the type of data necessary to test our research hypothesis. For this study, five main independent variables were selected: CRM

training (Yes, No), age ( $X \leq 40$ ,  $40 < X \leq 50$ ,  $X > 50$ ), total flight time ( $X \leq 7500$ ,  $7500 < X \leq 12500$ ,  $X > 12500$ ), last year flight time ( $X \leq 300$ ,  $300 < X \leq 400$ ,  $X > 400$ ), and aircraft category (A, B).

The first step of the statistical analysis consisted in obtaining descriptive statistics for each of the 8 questions pertaining to crew coordination and then separately for each variables aforementioned. An analysis of variance (ANOVA) followed. The level of significance was set up to 95%, meaning that a margin of 5% was of all the main effects found could be attributed to sampling variability. This choice of analysis was motivated by two reasons. The first reason was the fact that the focus of the analysis was to determine significant differences in means of rating of opinions. Those means have some validity because special cares were devoted to the selection of each anchor of every Likert scale questions. As a consequence, the choice of this method made it easier to interpret the results and determine which factor played a role in the significant differences established. The second reason for choosing the ANOVA method was that a previous study (McClumpha et al., 1991) also used that type of analysis. Therefore this selection provided, if need be, an easy way to compare the results of the two studies.

This analysis was divided into two steps. For each of those steps, only between comparisons were made. The first step consisted in testing each of the first five variables for main effects. For each overall significant difference established a second step was undertaken toward a more detailed look at the data collected. It consisted in testing the same variable for every subgroup of the other four variables. This provided a clearer understanding of the initial main effect. Imagine that during the first step, the variable aircraft category is found to generate significant difference among the pilots of the whole population. The second step would consist in testing this variable on the two subgroups of the variable CRM training (i.e., Yes and No), the three subgroups of the variable age (i.e.,  $X \leq 40$ ,  $40 < X \leq 50$ , and  $50 < X$ ), the three subgroups of total flight time (i.e.,  $X \leq 7,500$ ,

7,500<X≤12,500, and 12,500<X), and the three subgroups of the variable last year flight time (i.e., X≤300, 300<X≤400, and 400<X).

## Procedure

The questionnaire used was developed by an Embry-Riddle research team. The first attempts were made in late October 1991. The development of this questionnaire was based upon previous questionnaires designed for field studies carried out in the U.S. (Curry, 1985; Wiener, 1985b, 1989) and in the U.K. (McClumpha et al., 1991). In those questionnaires, few questions specifically addressed the issue of crew coordination. That is why findings from the 1988 NASA workshop (Norman and Orlady, 1988) were also incorporated in the present questionnaire. During the development phase, it was felt that a seven-point scale for the Likert questions would be better than the five-point scale normally used, thus, providing more variability for the answers. Moreover, special attention was devoted to the selection of the anchors used for the scales. For each question, the anchors represented an extreme opinion (e.g., Question 10: *Impossible vs. Extremely Easy*). By doing that, the whole spectrum of possible answers was made available to the subjects.

A pilot study, was carried out to determine the validity and reliability of the questionnaire. Because this questionnaire was based on previous work designed for the scheduled air carrier environment, a special effort was made to ensure that the instrument developed was appropriate for the corporate environment. To reach this goal, telephone interviews were conducted. Due to the large number of questions in the questionnaire, only a portion of the questionnaire (e.g., crew coordination section: questions 8 through 15) was used during each interview; a different portion would be used every time a new interview was done. Another step in the pilot study consisted of asking people to complete the questionnaire and suggest corrections or any relevant issues not addressed. Several versions were pilot-tested this way. Wiener, who was a consultant for the large scale study, also reviewed the questionnaire and provided his comments. Additionally, faculty

members of Embry-Riddle's flight staff, personnel from Gulfstream, Honeywell, Collins, and chief pilots from corporate operations participated in this pilot study. It was determined that 15 to 30 minutes were needed to completely fill out the questionnaire.

Modifications resulted from the administration of this pilot test. It was found that some subjects circled one of the anchor instead of a number, thus, making the scale a nine-point scale. Parentheses, grouping the anchor and its corresponding scale number, were therefore used to remedy that problem and some directions were added on top of each page of the questionnaire. Another observation taken into account as a result of the pilot study was that 15 open-ended questions were too many and might lower the return rate. As a result, it was decided that only seven of those 15 questions would be mentioned on every questionnaire. Three questions were considered more important than the others and therefore were mentioned every time. The remaining 12 were divided into three groups referred to as group A, group B, and group C. One third of the questionnaire had the group A questions, another had the group B questions, and the third had the questions from group C. The two open-ended questions pertaining to crew coordination were part of the second set (i.e., group B questionnaire). This questionnaire may be referred to in Appendix A.

While pilot-testing the questionnaire, a request was made to the FAA to provide us with a database of pilots type-rated in the following aircraft: BAe 1000, BAe 125-800 A&B, Beech Starship 2, Beechjet 400A, Challenger 601-3A, Citation III (650), Falcon 900, Gulfstream IV, Lear (those were not provided due to too many types included under the same name). Those aircraft were the ones most likely to be equipped with new technology systems. This list encompassed models of aircraft that might not qualify for the study if still outfitted with the original equipment (e.g., Falcon 20). However, some of those aircraft have been retrofitted with automated systems, and, therefore, were mentioned in the list. The FAA provided an electronic copy of that population. Of the 3,306 entries of this database, 880 were randomly selected.

The next step consisted of mailing the questionnaires. Computer labels were generated for each subject. Each out-going envelope contained three questionnaires (one of each type, i.e., A, B, and C), three self-addressed envelopes, and two cover letters. Three questionnaires were included in each out-going mailing since it is not necessary to be type-rated in those airplanes to fly one as a First Officer. Therefore, the subjects who received the envelope were asked to fill out one copy of the questionnaire and give the other two to pilots they knew also flew glass cockpit aircraft. A month after mailing the questionnaires, a reminder postcard was sent out to the subjects of the sample (see Appendix C) to prompt those who were qualified to answer but had not yet completed the questionnaire to do so.

Depending on the type of questions (i.e., Likert or open-ended) different methods were used to enter the data into the computer. A simple word processor was used to type the open-ended responses. On the other hand, a small program was developed (in HyperCard® version 2.1) to ease the entry of the Likert scale questions and minimize the entry errors. With 385 returned questionnaires (85% of the total return) some preliminary statistics were done to identify trends and select areas where more detailed analysis would be needed.

When the deadline was reached, 438 questionnaires were received. However, eight of those had to be disregarded because the aircraft mentioned were not adequately equipped for the study. Those 430 questionnaires corresponded to a 48.9% return rate.

Of the 430 questionnaires received, an additional nine were deleted from the database. It was felt that pilots who had flown very little during the past year did not have the adequate recent experience needed to fill out the questionnaire. A minimum of 12 hours is required to maintain one's instrument rating current. Based on that, pilot with 20 flight hours or less in the past year were deleted from the database. This finally resulted in a 421 entry database.

## **Results**

Two types of results will be presented here. The first ones will be those concerning the eight Likert scale questions. Each one will be treated separately. Descriptive as well as ANOVA results will be given. However, the ANOVA results will only be mentioned when at least one of the five variables tested (i.e., CRM training, age, total flight, time, last year flight time, and aircraft category) has been found to have a main effect on the way respondents expressed their opinion.

The second type of results of this analysis consists in summarizing the answers generated by the two open-ended questions (i.e., 5B and 6B). Once again each question will be considered individually. This will finally be completed by additional remarks regarding comments (related to crew coordination) generated by other open-ended questions of the full size study.

### **Likert Scale Questions**

Except for question 14, all Likert scale questions had two anchors reflecting an extreme negative change on one side, and an extreme positive change on the other side. For those questions, a score of four represented a neutral answer (i.e., middle point between positive and negative) while a one or a seven indicated an extreme opinion.

For question 14, the scale also measured the amount of change, however, without providing a positive or negative orientation. Therefore, it did not have a neutral answer. A score of one represented the status quo while a score of seven indicated maximum changes. For this scale, a score of four then reflected moderate changes.

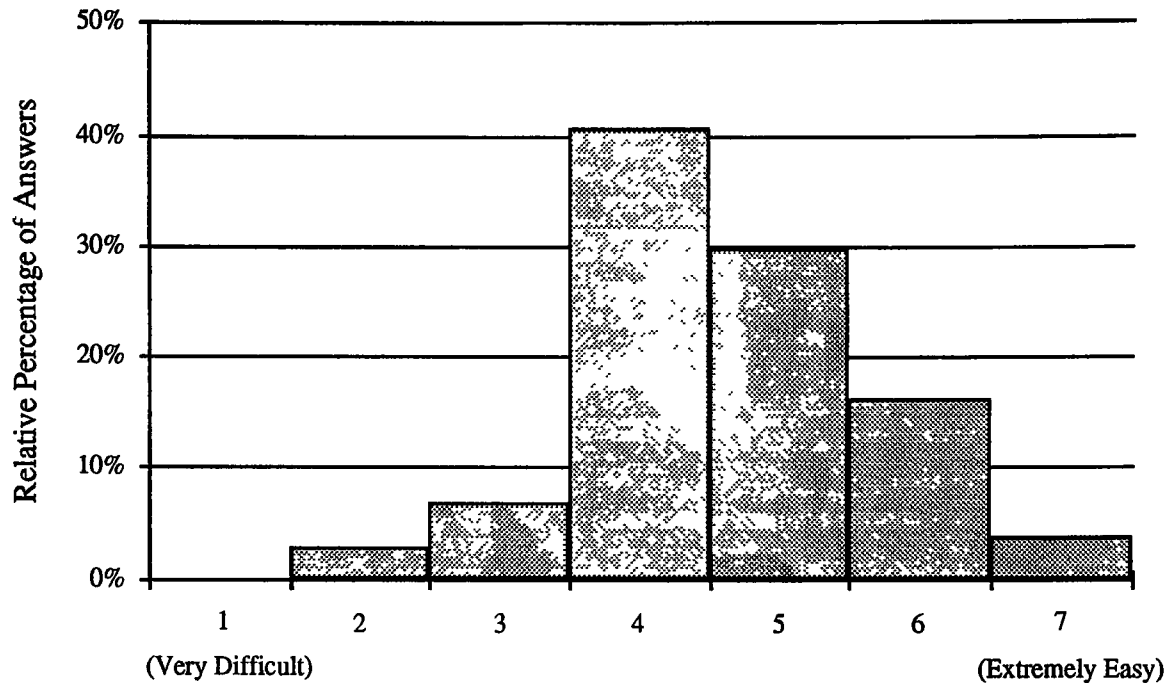
For each of the Likert scale questions, the answers given by the respondents are presented and illustrated by bar graphs. In order to clarify this presentation, no figures are added onto the graphs. For more detailed information refer to appendix D where the different frequency counts are reported.

*Question 8: Automation has made the first officer's willingness to speak up (very difficult – extremely easy).* As mentioned earlier, communication is a key element of good CRM. Several aircraft accident investigations which cited a lack of crew coordination identified communication between crew members as being inadequate. The 1977 collision of two Boeing 747s in Tenerife illustrated this problem. Two frequent causes of poor communication are poor listening and lack of assertiveness. Poor listening often characterizes captains, while a lack of assertiveness is typical for first officers. However, as Norman and Orlady (1988) report, "automated systems have changed the typical communication patterns within the cockpit" (p. 110). Question 8 was asked to find out if the changes introduced by automation have some impact on the first officer's assertiveness.

The data collected tend to indicate that advanced technology increases the willingness of the first officer to speak up ( $M=4.61$ ,  $SD=1.04$ ). Less than 10% of the respondents voiced an opinion reflecting more difficulty, while almost 50% clearly expressed some ease for copilots to be assertive (see figure 3).

Those results might be a consequence of the changes in task structure mentioned during the 1988 NASA/FAA/Industry workshop (Norman & Orlady, 1988). The working group on crew coordination further detailed this change when they mentioned that "in more automated system, PNF must provide a type of backup which requires greater active participation in flight control and less system monitoring" (p. 108). This change in task structure seems to have made it easier for first officers, especially when PNF, to be assertive due to the fact that a more "active participation" is asked of them.





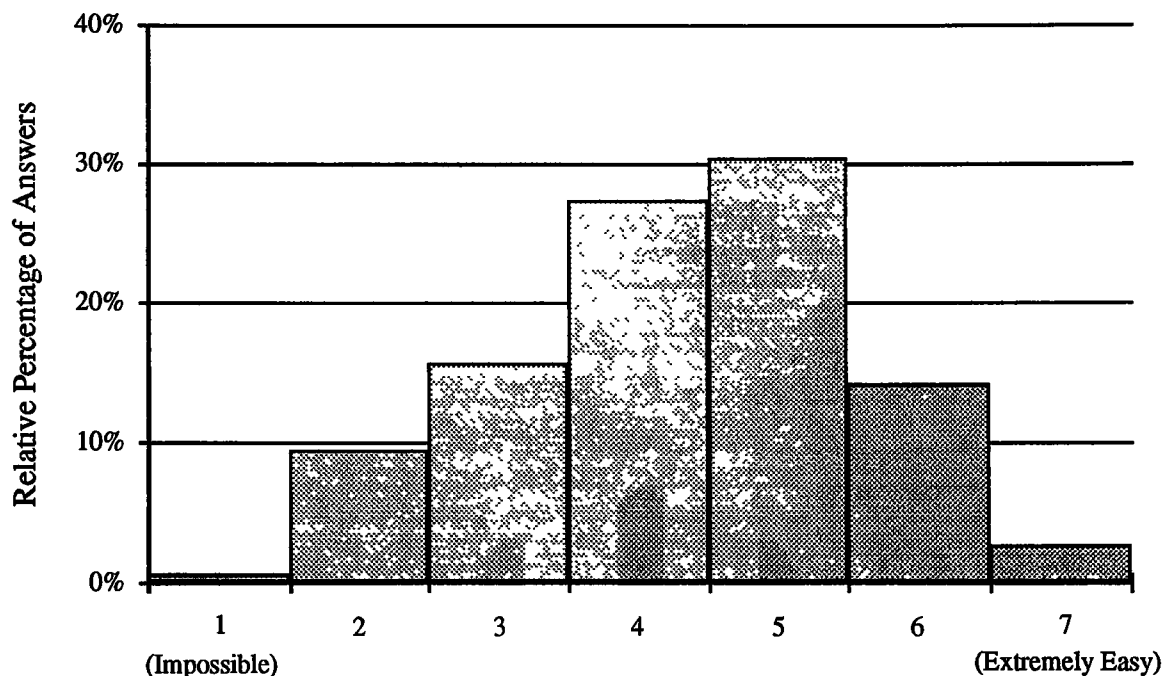
*Figure 3. Overall Data Distribution – Question 8: "Automation has made the first officer's willingness to speak up:"*

*Question 9: Automation makes knowing what the other crew member is doing in high workload situation (impossible – extremely easy).* Knowing what the other crew member is doing is also a characteristic of good crew coordination. In order to reach this goal there is a need for effective communication, verbal as well as non-verbal. However, with advanced technology cockpit design has significantly changed affecting thus both types of communication. Brown et al. (1991) explains how such change impact mutual understanding between crew members.

In the traditional cockpit, one knows what the other crew members are up to by what they are pressing, pulling, or looking at. In the modern glass cockpit, with reconfigurable and multifunction displays and controls and an emphasis on entering information into the computer, it can be more difficult to know the meaning and context of crew member's actions. (p. 401)

This very point stresses out the importance of non-verbal communication especially in glass cockpit aircraft. Yet during high workload situation this type of communication is sometime reduced. This might prevent the mutual understanding between pilots. This question was asked to determine if such was the case.

The mean rating of opinions ( $M=4.31$ ,  $SD=1.26$ ) remained close to neutrality with, however, a tendency toward a certain ease provided by automation toward mutual understanding. More than 25% of the respondents have expressed an opinion lower than four, indicating therefore a certain discomfort in knowing, in high workload situation, what the other crew member is doing (see figure 4).



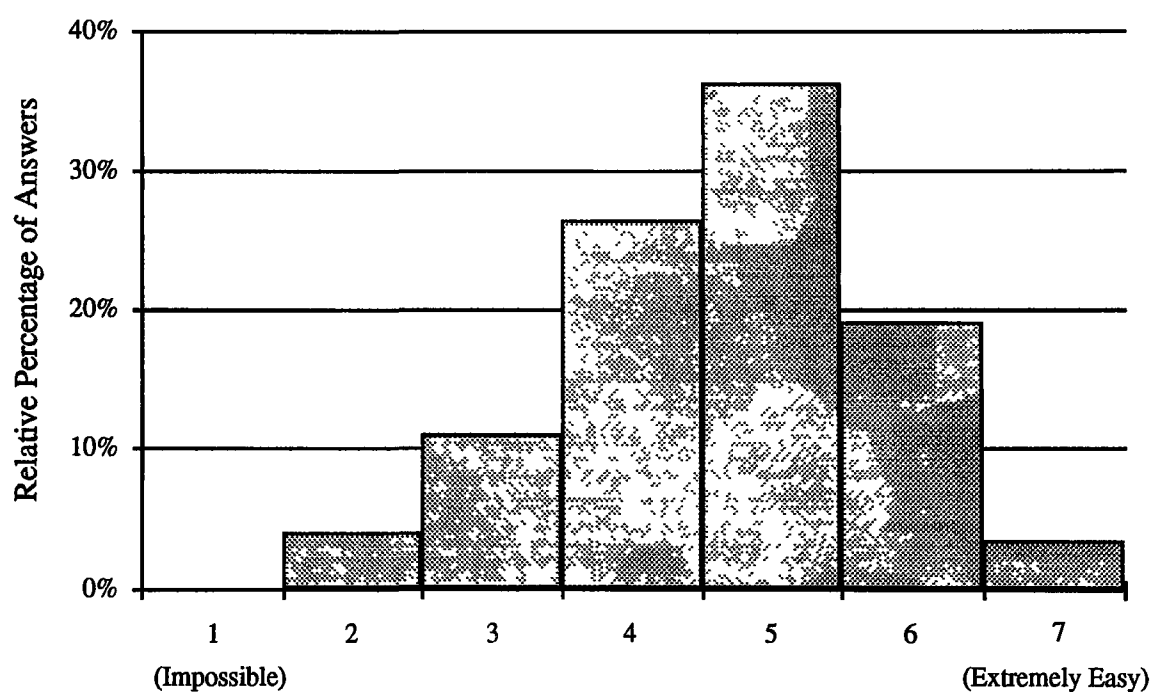
*Figure 4.* Overall Data Distribution – Question 9: "Automation makes knowing what the other crewmember is doing in high workload situations:"

***Question 10: Automation makes crew supervision (impossible – extremely easy).***

This question is along the line of the previous one, however, it address the issue of crew supervision in a more general manner. Wiener (1989) tested two statements concerning crew coordination in his last field study. One of those targeted this particular issue (i.e., "In the B-757, it is easier for the captain to supervise the first officer than in the other planes" [p. 193]). He reported that the answers collected contained "more than the usual number of 'neutral' or 'undecided' responses in the center of the scale, and slightly more disagreement than agreement with the probe" (p. 121). He then suggested that there might

exist some supervision problem in automated cockpit. The purpose of question 10 was, therefore, to determine if the same issue could be a concern within the corporate environment.

The pilots who answered expressed stronger opinions for this question than for the previous two (see figure 5). Their responses seem to indicate that for them automation eases the supervision of the other crew members ( $M=4.66$ ,  $SD=1.12$ ). Almost 60% of the population took a stand toward the ease of supervision.



*Figure 5.* Overall Data Distribution – Question 10: "Automation makes crew supervision:"

Those results are similar to the ones found for question 9, but they differ from Wiener's findings. They are, nevertheless, confirmed by the answers collected for the open-ended question 5B. Here is an example that illustrates this situation:

- "Little effect on crew coordination. Sometime it seems there is less to say because it is more obvious what the other pilot is doing or looking at." (0346)

*Question 11: Automation has made situational awareness (impossible – extremely easy).* Even though situational awareness is an "ill-defined phenomenon" (Sarter &

Woods, 1991), it is nonetheless a very important issue on which automation might have some impact. Wiener (1989) reported that some pilots have "expressed the view that automation had gone too far, that they felt they were often 'out of the loop', probably meaning that they tended to lose situational awareness" (p. 170). Brown et al. (1991) went even further in saying that "if crew members individually sense a loss of control and situational awareness, their collective assessment of events and their ability to react effectively in a coordinated fashion to rare, but inevitable, problems will be undermined" (p. 401). Because situational awareness is of such a critical importance it was felt that question 11 needed to be asked.

The answers given to this question show an overall strong rating of opinion (see figure 6). Unlike the concern recorded during Wiener's field study, the respondents expressed here the view that automation has made it easier for the pilots to be aware of their situation ( $M=5.20$ ,  $SD=1.29$ ). This trend was confirmed by the answer given to the open-ended questions (see additional comments). Several times the moving map display was cited as a feature enabling the crew to keep track of where they were. This same device was also reported as being beneficial for pilots in finding data entry errors in the flight plans. The answers presented below illustrate this finding.

- "Because of the excellent Nav display (G-IV), I feel I can spend more time in terminal area looking for traffic and still maintain better situational awareness than in less sophisticated aircraft." (0214)
- "The ability of the FMS to promote a more positive situational awareness through a more thorough understanding of your surroundings. In the event of an emergency you know where the nearest airports and nav aids are located." (0260)
- "The ability to see the orientation of the a/c to the final approach course, or other navigation features (i.e., the various 'map' modes) makes maintaining good situational awareness somewhat easier." (0383)
- "It has improved coordination because it requires the pilot flying to talk to and verify what the pilot not flying [PNF] has set up and programmed. It has also put more responsibility on the PNF which leads to more communication and better overall situational awareness." (0073)

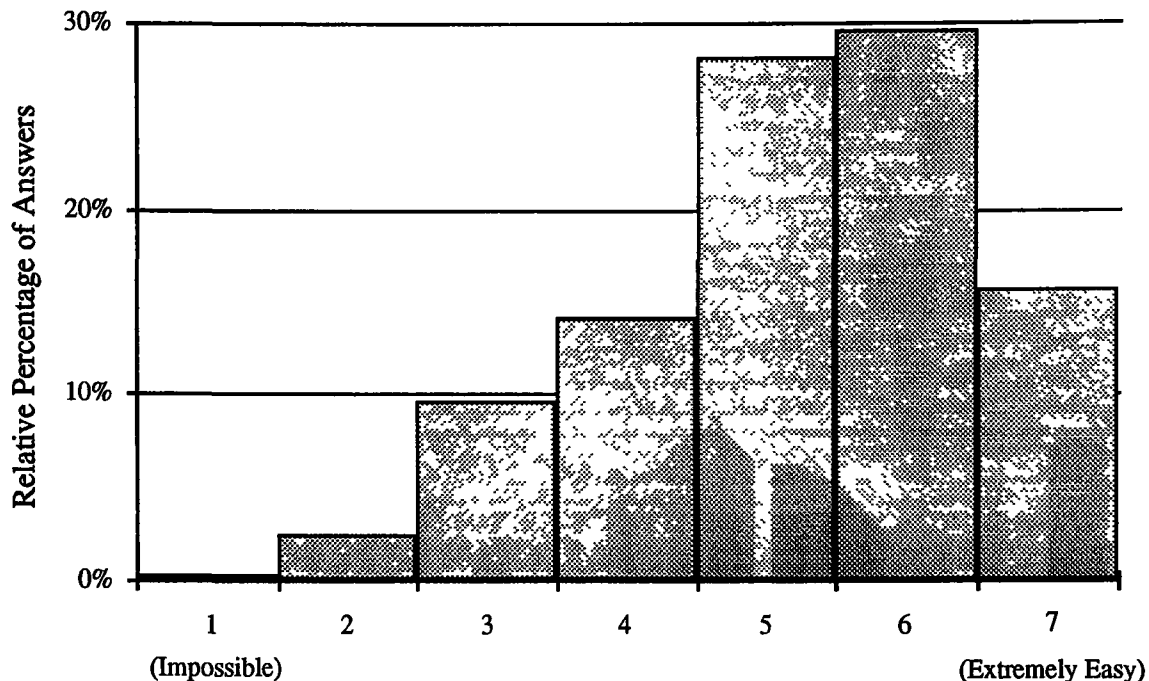
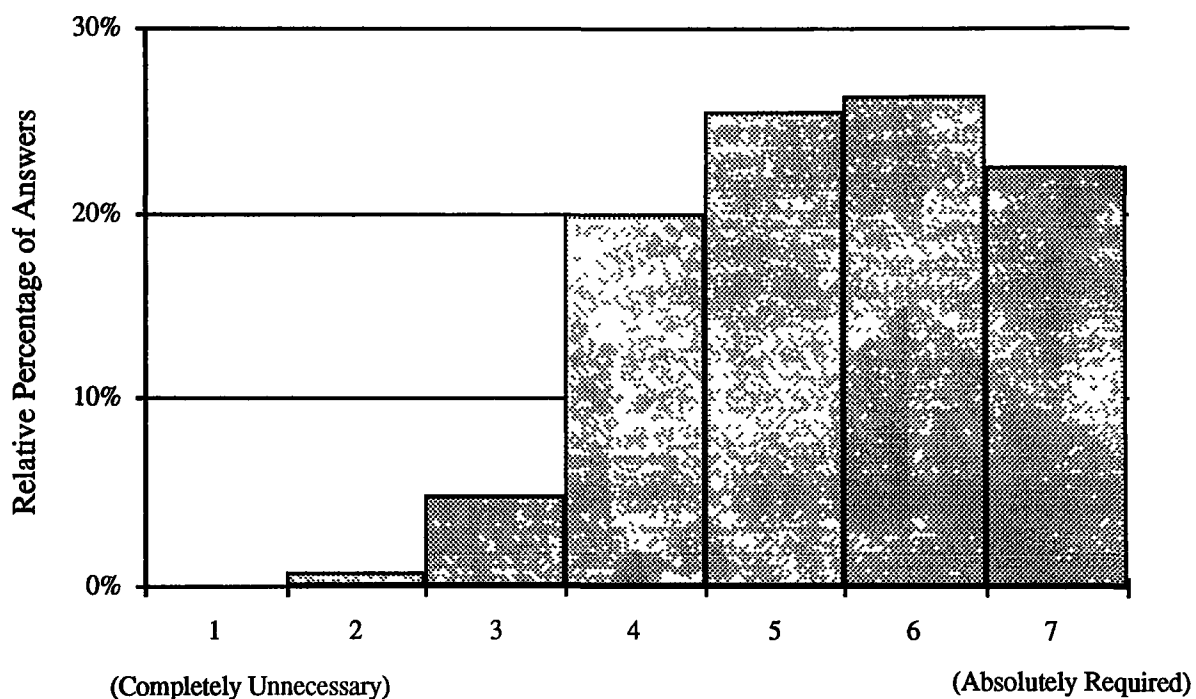


Figure 6. Overall Data Distribution – Question 11: "Automation has made situational awareness:"

*Question 12: Automation makes verbal communication between crew members (completely unnecessary – absolutely required).* Communication is a prerequisite for good crew coordination. For Lassiter and his colleagues "the ability to communicate effectively is a valuable team skill that must be mastered by all crew members to ensure an optimal level of teamwork, team performance, and safety" (1990, p.1373). They even went further and added that "poor communication is a leading cause of aircraft mishaps" (p.1373). This combined with the fact that in glass cockpits the number of non-verbal cues that can be used by crew members to communicate have been reduced gives even more importance to verbal communication. Therefore, the focus of this question was put on verbal communication.

Like the previous one, this question generated marked answers (see figure 7). Almost three-fourth of the respondents mentioned an opinion of five or more. Overall, it seems that automation has increased the need for verbal communication between crew members ( $M=5.40$ ,  $SD=1.21$ ). This outcome confirms what the researcher expected. As

mentioned in the introduction chapter and for question 9, pilots can now access many different systems using the same automated device. Therefore, if one of the pilots changes the status of one system, the other crew member does not necessarily know which system is affected by the changes. Without appropriate verbal communication between crew members, situational awareness could deteriorate rapidly. Effective crew coordination cannot be maintain without such verbal communication.

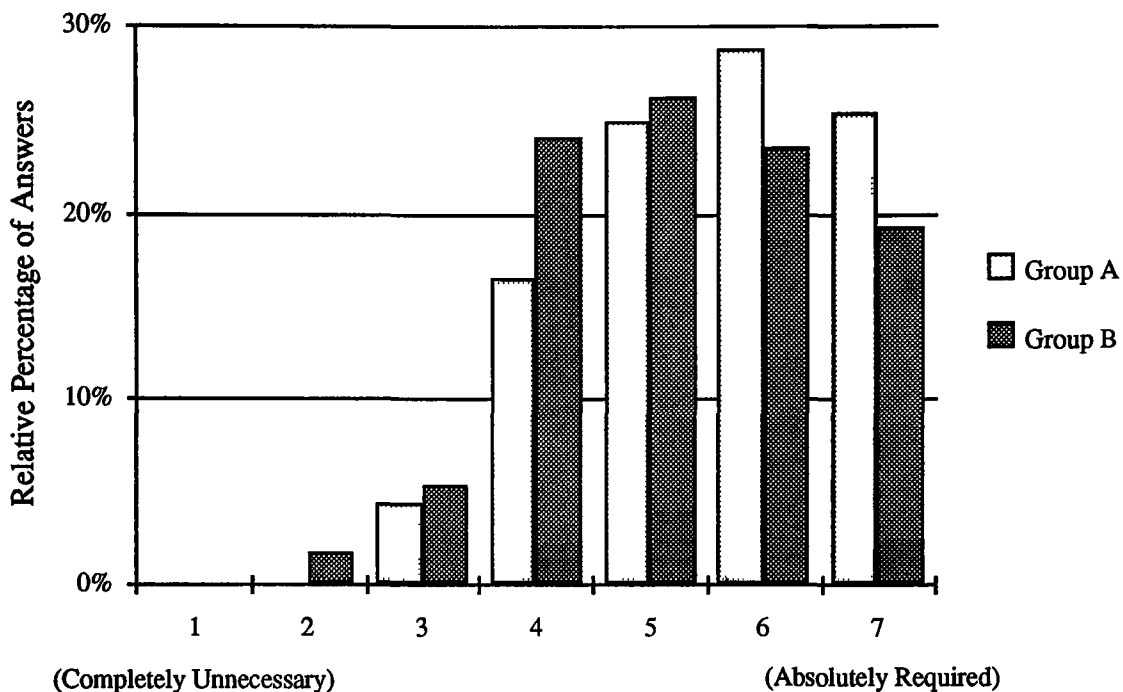


*Figure 7. Overall Data Distribution – Question 12: "Automation makes verbal communication between crewmembers."*

CRM training, age, total flight time, and last year flight time were tested for overall main effects but no significant difference was established for any of those variables.

However, the variable aircraft category was found to have a significant influence on how pilots rated their opinions with regard to the issue of verbal communication (see figure 8).

Pilots flying group A aircraft ( $M=5.54$ ) expressed stronger opinions than those flying aircraft from the other group ( $M=5.23$ ) ( $F(1, 414)=7.14, p=0.008$ ). The more detailed analysis highlighted the groups that played a role in the existence of this main effect.



**Figure 8.** Data Distribution by Aircraft Categories – Question 12: "Automation makes verbal communication between crewmembers."

The overall main effect of this variable seemed to be based on portions of the sample. Those included pilots with CRM training, middle aged pilots (i.e., 40 to 50 years old), pilots with a maximum of 7,500 total flight hours, and pilots who flew more than 400 hours the previous year.

When testing the aircraft category variable among pilots who had been through CRM training, some significant differences were found. Pilots flying CL-601, DA-900, and/or G-IV ( $M=5.56$ ) gave answers significantly higher on the Likert-scale than pilots who flew neither of those aircraft ( $M=5.24$ ) ( $F(1,368)=6.23, p=0.01$ ). No such difference was found among the group of pilots who never had any CRM training.

Pilots of medium-age were the only age group to display significant differences between the two aircraft categories. Once again the group A pilots ( $M=5.57$ ) who rated the requirement for verbal communication higher (group B,  $M=5.06$ ) ( $F(1,185)=9.29, p=0.003$ ). The same trend was established among pilots with 7,500 total flight hours or

less (group A,  $M=5.69$ ; group B,  $5.26$ ;  $F(1,138)=4.61$ ,  $p=0.03$ ). The other total flight time groups did not show such a difference.

One more time the variable aircraft category was identified as having a main effect. It was this time among pilots who had flown more than 400 hours during the previous year. Pilots flying CL-601, DA-900, and/or G-IV ( $M=5.58$ ) provided answers significantly higher on the Likert-scale than group B pilots ( $M=5.15$ ) ( $F(1,141)=4.49$ ,  $p=0.04$ ). None of the other groups within the last year flight time variable displayed such a significant difference.

*Question 13: Automation makes crew coordination (completely unnecessary – absolutely required).* Like question 10, this one is also based on Wiener's study (1989). Wiener's question targeted the level of difficulty to implement crew coordination in the cockpit of the B-757. The result showed that a majority of respondents disagreed with the statement that crew coordination was more difficult in that aircraft. Wiener further reported that "most of those interviewed expressed the view that crew coordination was no more difficult, but was *more essential* [italics added] in the automated cockpit" (p. 121). This statement from Wiener's study prompted question 13 regarding the need for crew coordination in corporate advanced technology aircraft.

Among the eight questions described in this study, question 13 generated the strongest answers (see figure 9). The overall mean ( $M=5.79$ ,  $SD=1.10$ ) displays how much pilots thought CRM was required. More than 86% of the respondents expressed that there was a need for it. Of those, more than 38% indicated that with automation crew coordination has become absolutely required. This question and question 15 were the only ones for which answer 7 received more agreement than all any other possible answer.



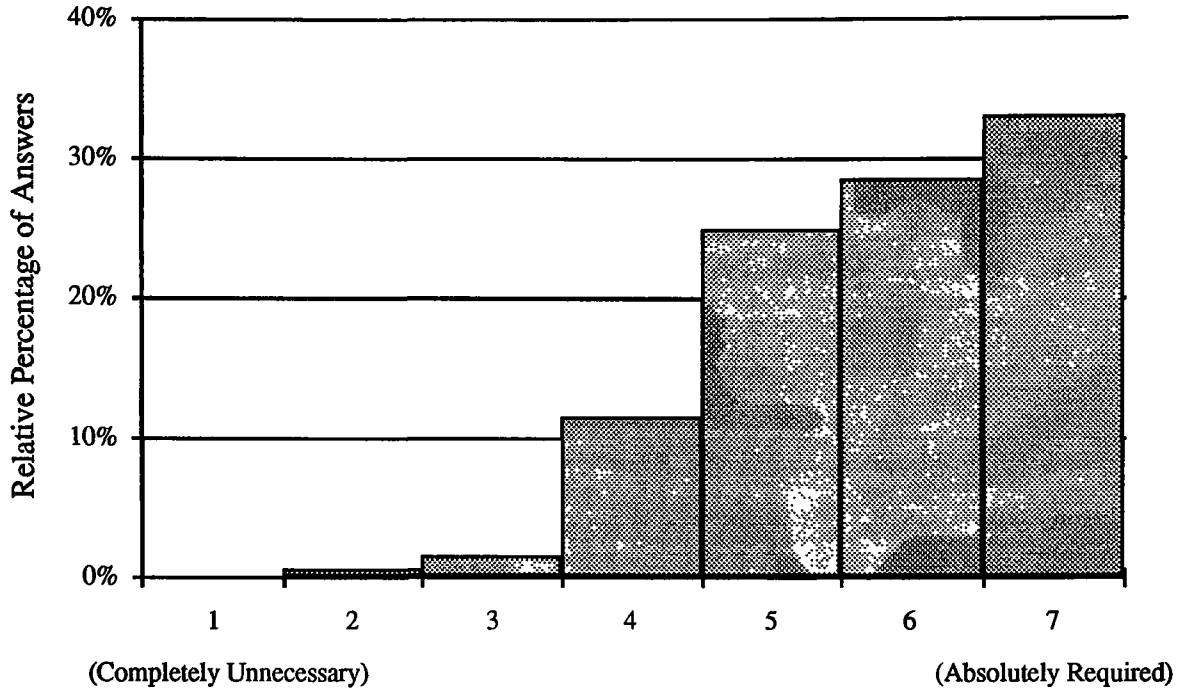


Figure 9. Overall Data Distribution – Question 13: "Automation makes crew coordination:"

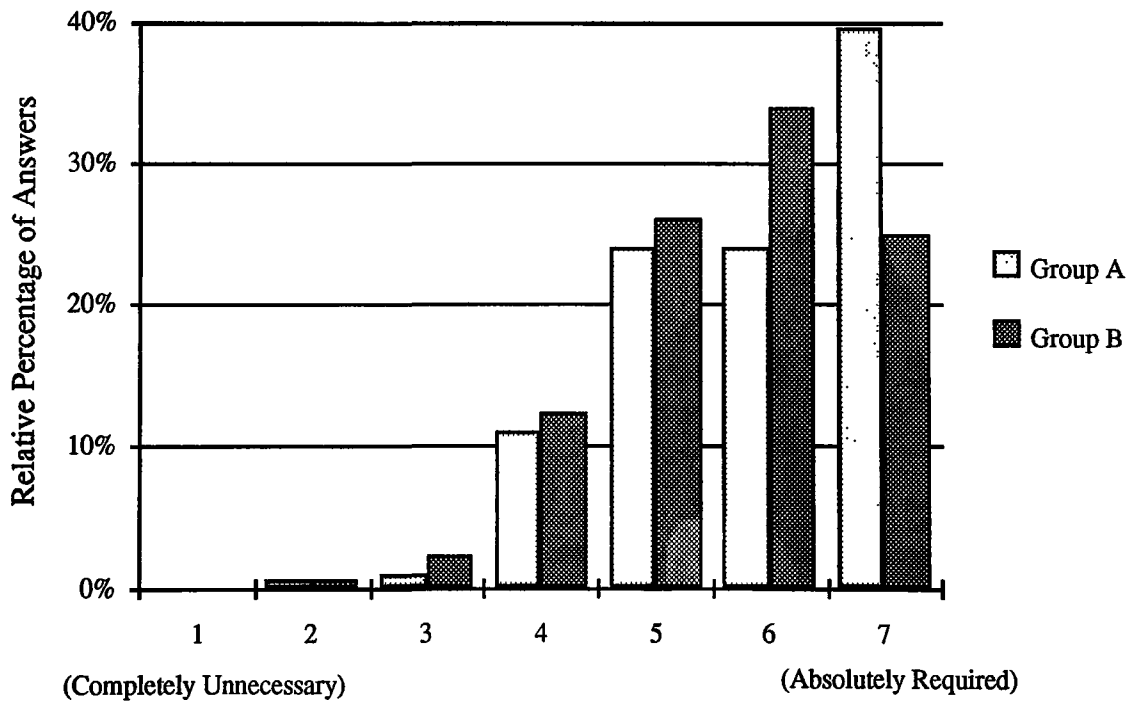


Figure 10. Data Distribution by Aircraft Categories – Question 13: "Automation makes crew coordination:"

The obtained results confirms the statement made by Wiener. Like for the previous questions, the variables CRM training, age, total flight time, and last year flight time were tested for main effects but did not present any. However, once again aircraft category was found to be the source of significant difference on the way pilots answered this question (see figure 10). Pilots of CL-601, DA-900, and/or G-IV ( $M=5.90$ ) rated their opinion significantly higher than pilots of other aircraft ( $M=5.66$ ) ( $F(1,415)=4.80, p=0.03$ ).

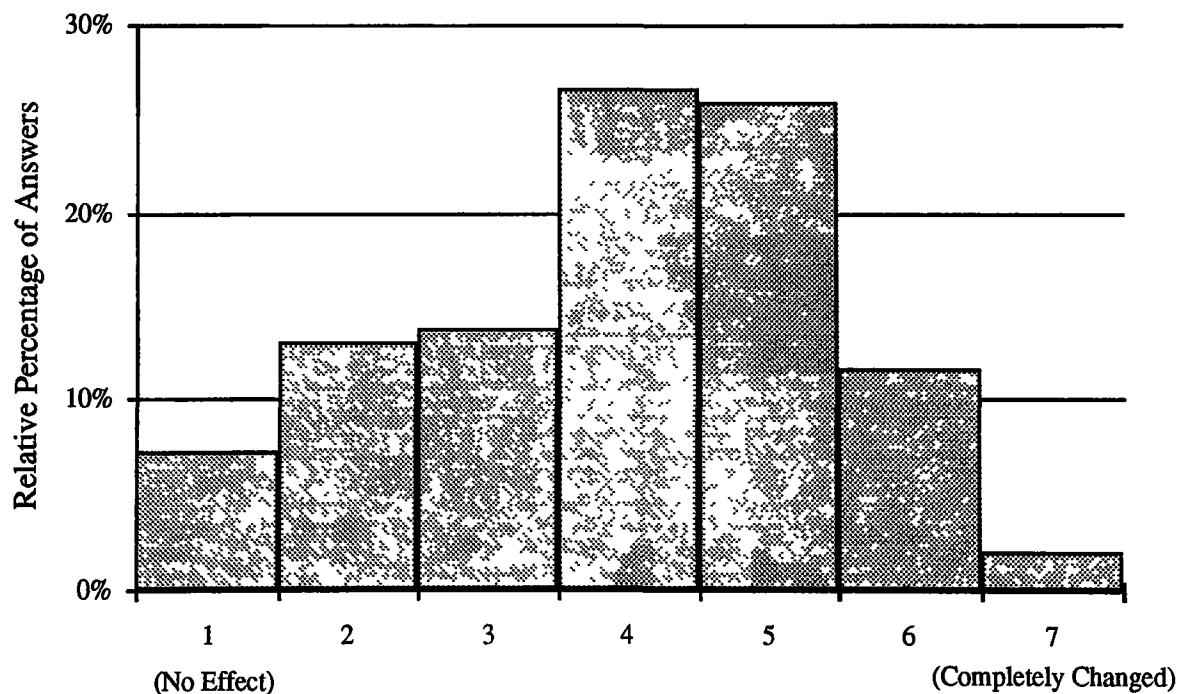
The detailed analysis which followed highlighted the subgroups of the other four variables that contributed to this main effect. Three of the four subgroups identified for question 12 are once again contributors. Those three subgroups are (1) those pilots who went at least once through CRM training, (2) the middle age pilots (i.e., 40-50 yr.), and (3) pilots with 7,500 hours or less of total flight time. A fourth subgroup was also identified. This time instead of being the pilots who flew the most during the previous year, it was the pilots who flew the least (i.e.,  $\leq 300$  hr.).

Among pilots who had crew coordination training, a significant difference in rating of opinion was found between pilots of group A aircraft ( $M=5.90$ ) and pilots of group B aircraft ( $M=5.63$ ) ( $F(1,369)=5.32, p=0.02$ ). The main effect of the variable aircraft category with the same trend (i.e., group A pilots expressing stronger opinions than group B pilots) was also found among middle age pilots (group A,  $M=5.83$ ; group B,  $M=5.53$ ;  $F(1,186)=6.21, p=0.01$ ). This significant difference was also established for pilots who had the lowest total flight time (group A,  $M=5.96$ ; group B,  $M=5.59$ ;  $F(1,138)=4.12, p=0.04$ ). Finally among the pilots who flew 300 hours or less the previous year, those flying group A aircraft ( $M=6.13$ ) once again rated their opinion higher than those flying group B aircraft ( $M=5.70$ ) ( $F(1,112)=6.20, p=0.01$ ).

**Question 14:** *Effect of automation on the division of responsibilities between crew members (no effect –completely changed).* This question is issued from the "pseudo" dilemma presented by Norman and Orlady (1988) when they addressed the topic of the role of pilot. Has it changed due to automation? Two opposite points of view are mentioned:

one considers the legal aspect of the issue while the other the operational aspect. Norman summarizes saying that "clearly, FAR 91.3 gives the pilot in command ultimate authority and in this sense, the pilot's role has not changed. But the methods which pilots use to perform their duties have been dramatically altered in the automated environment" (p. 157). Wiener (1989) further highlights the operational aspects. "There seems to be some tendency toward a breakdown of the traditional clear demarcation of 'who does what.' Although certain duties are clearly assigned to the PF and PNF, there can be a relaxation of this discipline" (p. 120).

The purpose of question 14 was to determine if some changes also existed within the corporate environment. This question, as mentioned earlier, is different from the other Likert scale questions. Its scale is the only one for which a rating of four does not represent a neutral opinion, but reflects moderate changes. Therefore the mean of 3.94 (SD=1.48) suggests that respondents felt that automation has introduced some changes in the division



*Figure 11.* Overall Data Distribution – Question 14: "Effect of automation on the division of responsibilities between crewmembers:"

of responsibilities between crew members. Almost two thirds of the population expressed an opinion varying between a three and a five (see figure 11). This finding goes along with the results presented by Wiener (1989). Moreover, it is reinforced by some open-ended responses such as:

- The first officer is now holding more of the cards in flight, although the captain does check all final inputs before accepting new information. (0166).

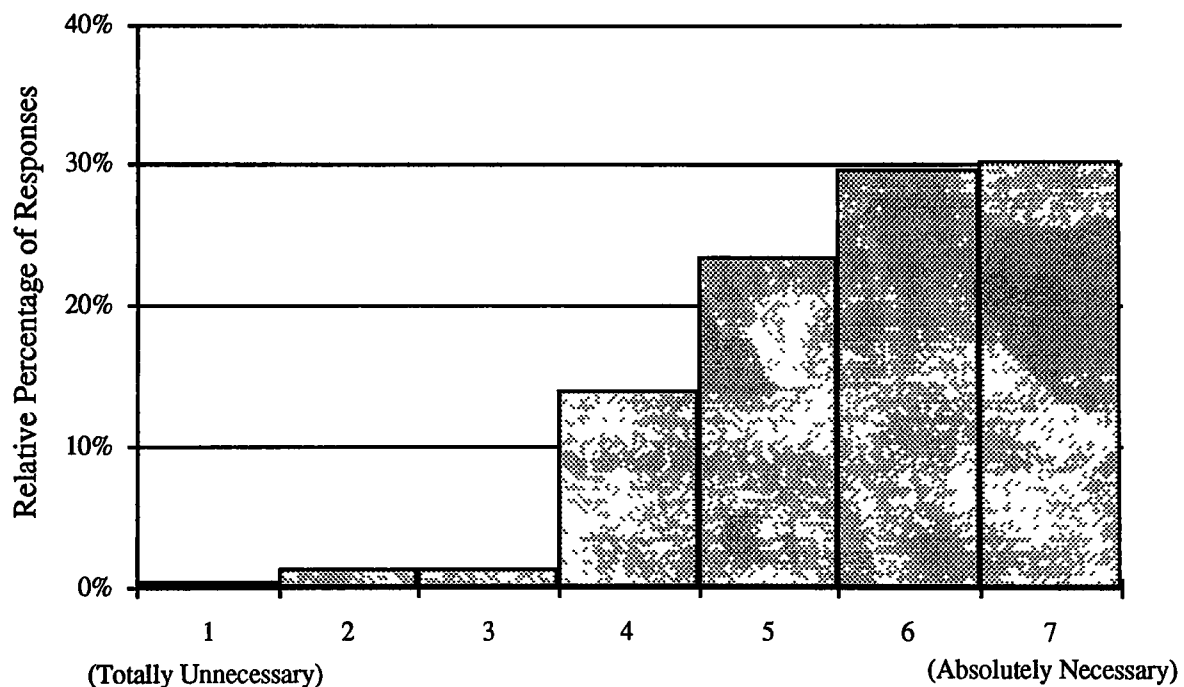
*Question 15: Automation has made crew coordination training (totally unnecessary – absolutely required).* The previous questions have addressed crew coordination as it relates to its implementation in the automated cockpit. Another issue that need to be looked at is training. Wiener (1989), considering that CRM might be the source of some problems in the advanced technology aircraft, suggested that CRM training might provide some elements of solution. However, when most of those training programs were designed, the advanced technology just starting to be implemented onboard aircraft was not taken into account. Wiener pointed out there might be a need to restructure those programs for pilots flying automated aircraft. "It may be that CRM programs, which have always been taught as if they were aircraft model-independent, should be tailored somewhat for the advanced technology aircraft" (p. 121). More recently a research team (Wiener et al., 1991) addressed, among many others, the issue of crew coordination training as it relates to automation. In the questionnaire used, one of the probes tested targeted the helpfulness of the CRM training. With question 15 the purpose was to look at the adequacy of CRM training and more specifically if the implementation of automation had affected the need for such training.

After question 13, this is the question that generated the strongest answers ( $M=5.69$ ,  $SD=1.17$ ). Less than 17% of the respondent expressed an opinion of four or lower, while almost 60% of the same population chose to answer 6 or 7, thus stating their opinion that crew coordination training is really necessary (see figure 12).

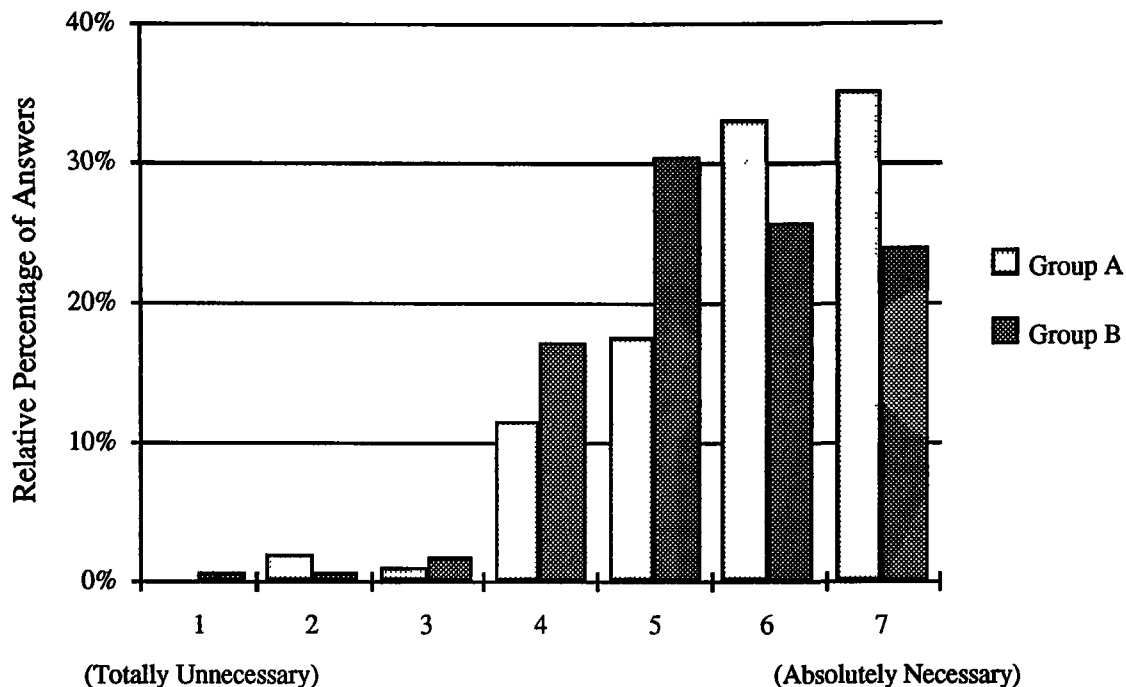
The first four variables tested did not present any main effect. The only variable which had any overall influence on pilot answers was aircraft category (see figure 13). The

same trend found for question 12 and 13 was also established for this question. Pilots of CL-601, DA-900, and/or G-IV ( $M=5.85$ ) rated their opinion significantly higher than pilots of other airplanes ( $M=5.50$ ) ( $F(1,412)=9.54, p=0.002$ ).

The detailed analysis highlighted the exact same main effects found for question 12 regarding the variable aircraft category. When testing the aircraft category variable among pilots who had been through CRM training, some significant differences were found. Pilot flying CL-601, DA-900, and/or G-IV ( $M=5.86$ ) gave answers significantly higher than pilots who had flown neither of those aircraft ( $M=5.24$ ) ( $F(1,366)=7.65, p=0.006$ ). No such difference was found among the group of pilots who never had any crew coordination training.



*Figure 12.* Overall Data Distribution – Question 15: "Automation has made crew coordination training:"



*Figure 13.* Data Distribution by Aircraft Categories – Question 15: "Automation has made crew coordination training:"

Middle age pilots were the only age groups to display significant differences between the two aircraft categories. Once again it was the group A pilots ( $M=5.94$ ) who rated higher the requirement for CRM training (group B,  $M=5.45$ ) ( $F(1,184)=9.19$ ,  $p=0.003$ ). The same trend was established among pilots with 7,500 total flight hours or less (group A,  $M=5.84$ ; group B, 5.44;  $F(1,136)=4.02$ ,  $p=0.05$ ). The other total flight time groups did not show such a difference.

One more time the variable aircraft category was identified as main effect. It was this time among pilots who had flown more than 400 hours during the previous year. Pilots flying CL-601, DA-900, and/or G-IV ( $M=5.82$ ) provided answers significantly higher than group B pilots ( $M=5.35$ ) ( $F(1,140)=6.40$ ,  $p=0.01$ ). None of the other groups of the variable last year flight time displayed any such main effect.

## Open-Ended Questions

Beside the eight Likert scale questions, there were also two open-ended questions providing valuable insight (1) on how crew coordination is affected by automation and (2) on the usefulness of CRM training. For each of these two questions the answers given were categorized in order to facilitate the presentation of the information collected. Those categories were nevertheless arbitrarily chosen based on expressions found in the responses, that is terms like "no change", "improves", or "excellent". The reader should therefore be careful not to overemphasize the importance of the present classification. A few representative comments are included in the following paragraphs to illustrate certain opinions. All the answers to the open-ended questions 5B and 6B are reproduced in appendices E and F respectively. Finally, a few general remarks are made that summarize some of the answers given to other open-ended questions of the large scale study that dealt with the issue of crew coordination. These answers may be referred to in appendix G.

*Question 5B: How has automation affected crew coordination?* Several of the respondents answered that question in terms of quality of crew coordination. Among those answers three main categories can be established: those expressing some kind of improvement (the most common answer), those which indicated no change, and finally those mentioning a degradation or a decrease in crew coordination (see table 6).

Table 6

*Classification of the Responses Given to Question 5B: "How has automation affected crew coordination?"*

<b>Categories</b>	<b>Number</b>
Improves	42
No Change	29
Decreases	9
Need for CRM	35
Other	5

However, a non negligible number of answers addressed a different aspect of the question: the needs or requirements for CRM in automated cockpits. At first it would seem that this question generated two types of answers. Nevertheless after a closer look one main topic stands out.

A large majority of subjects, whether they answered one way or the other, expressed the opinion that with automation some changes have occurred, putting some emphasis on communication. Among those who indicated an improvement in crew coordination, some mentioned that it was due to better communication taking place in the cockpit. Based on the same issue of communication, other respondents expressed a decrease in CRM quality. This apparent contradiction can, however, be explained very easily. The "higher" requirements put on communication by automation were not met by the members of those crews, leading therefore to lower level of crew coordination. The communication issue was also addressed by the respondents who expressed opinions regarding the need for CRM in automated cockpit. To illustrate those different points of view, a few characteristic answers are mentioned below.

- "It [crew coordination] has increased our reliance on working together and cooperating as a team. The advanced technology forces us to ask questions when we don't know something. The only way to manage this complexity is by communicating what you want, and ensuring all crewmembers are in the loop." (0251)
- "Crew coordination has increased because communication levels are higher." (0408)
- "It is too easy for copilot to quickly enter something in the FMS and even easier to not tell the captain what he did – and vice versa – the fingers are faster than the eyes." (0158)
- "Some problems with crewmembers doing FMS work without informing the other crewman. This is fairly rare." (0205)
- "Need very good coordination and communication. Neither person can just afford to sit still and shut up (an old phrase). The ability of either crewmember to greatly help or, more importantly, to cause confusion or chaos has improved the most. An EFIS, FMS equipped aircraft is truly a two person job, and needs to be treated as such." (0030)
- "Crewmembers must be acutely aware of what the other crewmember has programmed into the FMS. Good verbal exchange of information between crewmembers is essential for safe and efficient operation of the aircraft." (0399)



Several other issues besides communication were addressed by the respondents, however, not with the same intensity. Some of the comments reflect concerns already mentioned in the Likert scale questions (e.g., supervision of crew member, division of responsibility). Issues like complacency, system understanding and monitoring, information overload, difference in skill proficiency between pilots, as well as specific ATC consideration were among the concerns expressed by the pilots.

Finally, age was also mentioned. Even though the variable age was not found to have any main effects for the Likert scale questions, some answers provided to this question parallel the findings of the U.K. field study (McClumpha et al., 1991). A few times, pilots mentioned that older pilots had more difficulty than younger pilots with the automated system. The sample of answer provided below illustrate this issue.

- "If a young pilot is flying with an older pilot, the young pilot should be sure to use verbal reinforcement of all the things they are doing. While this verbal backup is useful all the time, no matter what the crew makeup is, I've noticed the younger pilot flying is more aware of what's going on." (0054)
- "... Old bold pilots who fight automation can induce stress and increase workload by (1) not understand[ing] how or why something is done forcing other pilot to do both jobs at times and (2) using a lower level of automation and thus possibly not knowing the current status of some items." (0163)

**Question 6B:** *If you received any coordination training, please specify where.*

*Which topics were covered? Did the training address the automation issue (if so, how)?*

*What did you think of this training?* The second open-ended question was, in fact, a series of questions. The purpose in requesting this information was to get a better understanding on the type of CRM training corporate pilots receive.

The training institutions most frequently mentioned were Flight Safety International®, SimuFlite®, and United Airlines®. The majority of training program cited were formal CRM training, however, sometimes they corresponded to recurrent training in which some crew coordination elements were incorporated. The following responses clearly illustrate this double standard.

- "All of our pilots have attended cockpit resource management (CRM) training. Communication, awareness, health, personalities are some of the subjects that are covered. Automation was not discussed. We think the training is excellent and plan to continue attending CRM in the future." (0284)
- "First received crew resource management through an in-house program in 1982. Topics were communication, checklists, teamwork, assertiveness, and command. Our training did not address automation. I liked the training." (0251)
- "No formal CRM training, recurrent training through the years from SimuFlite and FlightSafety provided some information, No automation issues ever addressed (not enough time in a 3 day recurrent) All my training has been obtained through self-education and discipline." (0101)
- "The only formal crew coordination training we have received has been of our initial and recurrent training at Flight Safety, Gulfstream, and Canadair. Time constraints do not allow the curriculum to include enough of the resource management training needed to deal with the problem. We deal with problem areas as they arise by pilot meetings and training in house." (0357)

The second request of question 6B concerned the topics that were addressed during CRM training. Those who answered this question, mentioned most often communication. Situational awareness was also cited several times. Other topics like error chain, personality, command were also mentioned but not so frequently. Concerning the issue of automation few respondents had gone through a training program that addressed automation. This part of question 6B was there to find out if Wiener's suggestion to tailor CRM programs to advanced technology aircraft had already any practical application. This does not seem to be the case so far. This question generated a few comments regarding the need to address automation in CRM training.

- "Initial and recurrent training through SimuFlite and FlightSafety. Did not specifically address the automation issue in relation to crew coordination, however, operation training and actual usage requires a degree of crew coordination. Training pertaining to automation was at FlightSafety and was fair." (0226)
- "United Airlines CRM school for 4 days in Denver. Excellent training on a 1 time basis. The 2nd time at this school would not be as effective. This school is the baseball bat between the eyes. Did not cover automation as it is not necessary. 2nd school was 3 days by an outside consultant. Very good, it fine tuned what we learned at United. Again no automation training, still don't think it was necessary for these schools." (0242)
- "We all attended Scientific Methods CRM but I do not recall automation being emphasized. It should be addressed and we will pursue that issue." (0365)

The final request of question 6B concerned the opinion of the respondent on the quality of the training received. A classification of the answers into five categories is presented below in table 7. The overall trend reflects a certain satisfaction with the training. Very few felt that their training was "inadequate" or "marginal/just fair". Almost 45% of those who expressed an opinion rated their training as "very good" or "excellent/outstanding".

Overall, question 6B indicated that the population of corporate pilots flying automated aircraft presents a wide diversity in regards to the CRM training received. This variety goes from no such training to pilots who went through several CRM training programs.

Table 7

*Classification of Responses Given to Question 6B: "If you received any crew coordination training, please specify where. Which topics were covered? Did the training address the automation issue (if so, how)? What did you think of this training?"*

<u>Categories</u>	<u>Number</u>
Inadequate	2
Marginal/Fair	8
Good/OK	19
Very Good	10
<u>Excellent/Outstanding</u>	<u>13</u>

**Additional comments.** Other comments pertaining to crew coordination were also found in the answers to open-ended questions 1 and 2 (i.e., "Briefly describe an operational problem – involving the automated features of your aircraft that could have had a negative safety consequence. How could this error have been avoided?" and "Were there any instances which the automated features 'saved the day' or had a positive safety consequence?"). For question 1, pilots cited general concerns either about crew

coordination or regarding problems of communication. The following responses are a sample representing those concerns.

- "Crew coordination seems to be the one area of concern. One member selecting a feature and the other deselecting the same feature, or one crew member changing a procedure without telling other crew member." (0089)
- "Generally speaking a high degree of crew coordination training is necessary to prevent both pilots having their heads-down in the cockpit at the same time." (0378)
- "... I feel that even though there were no errors (such as altitude deviations) that situational awareness and crew coordination were severely hampered." (0362)

Even though situational awareness was, in the last answer, reported as "severely hampered" it was cited several other times as being improved by automation in question 2 (i.e., "Were there any instances in which the automated features "saved the day" or had a positive safety consequence?"). Increased situational awareness was the third most frequent answer to this question. A few of those answers are presented below.

- "The benefit of having map display, for example, greatly improves situational awareness." (0102)
- "The ability of the FMS to promote a more positive situational awareness through a more thorough understanding of your surroundings. In the event of an emergency you know where the nearest airports and nav aids are located." (0260)
- "The ability to see the orientation of the aircraft to the final approach course, or other navigation features (i.e., the various "map" modes) makes maintaining good situational awareness somewhat easier." (0383)

## **Conclusions and Recommendations**

### **Conclusions**

The purpose of this study was to investigate how cockpit automation has affected crew coordination within the corporate environment. This study was designed based on previous research carried out in the airline industry, but it was restructured to address corporate aviation issues. The conclusions that are presented here thus refer to the corporate environment. Some conclusions, nevertheless, parallel situations already recognized by scheduled air carriers, therefore showing that some issues are not unique to a specific group within the aviation industry.

Among the eight Likert scale questions of this study, three used the "completely unnecessary – absolutely required" scale to measure the need for crew coordination in general, training for such a discipline, and verbal communication in automated cockpits. Those questions generated the strongest answers (mean greater than five). In addition, for these questions, the variable "aircraft category" was a source of significant differences. Pilots of CL-601, DA-900, and G-IV were found to express stronger needs than pilots of other aircraft. Those three aircraft do not represent a scientifically recognized "level" of higher automation than the other airplanes, however, they are recognized as such by most corporate pilots. This difference leads to speculations whether, as the "level" of automation increases, the need for crew coordination increases as well. This statement should not, however, be seen as more than a speculation for two reasons: First, the concept of "level" of automation is not clearly defined. Second, this study is based on comments which do not have any statistical significance. Despite these caveats, it is believed that this issue deserves to be looked at more carefully.

Another remark that can be made concerning CRM and the corresponding training, and verbal communication, is that their importance was reinforced by the responses given to the open-ended questions. Many times, open-ended answers emphasized the importance of training and verbal communication if good crew coordination was to be a reality in the automate cockpit.

A particular aspect of communication also addressed by this study has been the first officer's assertiveness. The answers generated by the Likert scale question did not reflect an opinion. Automation seems to have contributed somewhat to ease the willingness of the first officer to speak up. However, in fact the issue still remains a concern. This was expressed several times by the respondents. A common remark was that it was too easy to make changes in a system setting without verbally updating the other crew member about the changes made. This was sometimes completed by a comment indicating that when it happened one of the crew members was taken "out of the loop." This same issue was also reported by Wiener (1989).

It would be easy from the above to infer that automation contributes to a decrease in situational awareness. The case mentioned above represents only one aspect of this issue. When asked about the impact of automation on situational awareness, corporate pilots mentioned an overall positive influence. Question 11 and the open-ended questions presented the same results. The new displays have enabled the pilots to keep up with the navigation more easily. And on screen checklists are of great use when in high workload situation.

Two more issues were specifically addressed by this study: crew supervision and the division of responsibilities. Concerning crew supervision, Wiener (1989) concluded that "it is more difficult for the captain to monitor the work of the first officer, and to understand what he is doing, and vice versa" (p.178). No such conclusion could be reached here. On the contrary, the population of pilots who answered the two Likert scale questions (i.e., 9 and 10) that dealt with this issue expressed a slight improvement

provided by automation in the supervision of other crew member and knowing what he/she was doing. The data collected in open-ended questions did not contradict this trend.

The results regarding the division of responsibility do not differ from Wiener's conclusions (1989) or that of Norman and Orlady (1988). For Wiener, "the modern cockpit seems to produce a redistribution [of] authority from the captain to the first officer" (p.178). The same opinion was found in the responses to the open-ended questions. The results of question 14 go along the same line when they point out that some changes in the division of responsibilities have taken place in the automated cockpit.

In summary, the above results have led the researcher to accept the initial hypothesis and conclude that, within the corporate environment, crew coordination is influenced by automation. This statement, however, needs to be moderated by the fact that this study was based on pilot opinions only. The reader is therefore reminded not to attribute any statistically significant value to the conclusions made here. The purpose of this study was to provide some basis for further research. To that end, the paragraphs below provide a (non-exhaustive) list of recommendations.

### **Recommendations**

To those who would like to further study this topic of crew coordination as it relates to automation in the particular environment of corporate aviation the following recommendations are made.

1. Only a few aspects of crew coordination have been looked at in this study and the focus stayed at a general level. The first recommendation is then to target other issues (e.g., decision making, stress management) and/or limit the study to one specific topic such as communication or situational awareness.
2. Five variables were tested for main effects. Only one was the source of significant differences. It would be interesting to look at other variables (e.g., gender, experience with automated system).

3. In the paragraphs above a speculation was made concerning the "level" of automation. This issue would need to be looked at more carefully in order to find out a method to clearly measure the level of automation. This could then be used as a variable in a study similar to the present one. In such a study non automated aircraft could also be included as representing the lowest level of automation.
4. A potential reason why crew coordination had no main effect is that the subjects of this study displayed a wide variability in quality of CRM training. Categorizing pilots according to the quality of the CRM training could provide an additional variable to look at the population of corporate pilots.
5. Finally, this study revealed that the occurrence of "two-captain" crews were relatively frequent. In regard with crew coordination, this raises another concern. To the researcher's knowledge this situation is never taken into account by CRM training programs. This might call for a special module addressing this issue.



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**Appendix A**  
**Questionnaire Sample**

**PERSONAL INFORMATION** (please print):

Name (Surname) \_\_\_\_\_ (First) \_\_\_\_\_

Mailing Address (Street) \_\_\_\_\_

Address (Cont.) \_\_\_\_\_

(City) \_\_\_\_\_ (State) \_\_\_\_\_ (Zip) \_\_\_\_\_

Phone (Daytime) \_\_\_\_\_ (Fax) \_\_\_\_\_

**CONFIDENTIALITY STATEMENT**

All personal information on this form will be stored separately from the rest of the questionnaire. The information on this sheet will *only* be available to the *Principal Investigator* and will be stored in a separate database, which will later be destroyed. This information will only be used to: (1) remind those people who have not responded, and (2) as a database for a potential follow-up questionnaire. In order to assure the anonymity of your responses, you may even mail this sheet separately from the data sheets if you wish. If you send them both in the enclosed envelope, the personal information (i.e., this form) will immediately be separated from the remainder of the data and will be processed by two different research assistants.

# NOTE

*In the following statements:*

***Automation***  
refers to advanced  
automated aircraft  
equipped with  
**EFIS and FMS**  
supplemented by  
additional automated  
features.



**FLIGHT EXPERIENCE**Your age: \_\_\_\_ Gender (circle): *M F* Years flying for compensation or hire: \_\_\_\_

Total flight hours (approx.): \_\_\_\_

Initial training (circle all that apply): *Military FAR 141 FAR 61 Other: \_\_\_\_\_*When (month, year) did you *first* transition to an advanced automated aircraft: \_\_\_\_\_Have you ever had any crew coordination training (circle): *Yes No***Corporate Experience:**

Corporate flight hours (approx.): \_\_\_\_ Years of corporate flying: \_\_\_\_

Flight hours within last year (approx.): \_\_\_\_

Three aircraft you have most frequently flown within the last year:

Aircraft type	Position (check all that apply)						Hours in type		If FMS equipped, which make & model?
	Chief Pilot	Captain	F/O	S/O	Check Airman	Instructor	Total	Past year	

List any other *advanced automated aircraft* that you have flown (military, airlines, etc.):

Aircraft type	Position (check all that apply)						Hours in type		Automated features:
	Chief Pilot	Captain	F/O	S/O	Check Airman	Instructor	Total	Past year	

Other Experience (please specify): \_\_\_\_\_

Other flight hours (approx.): \_\_\_\_\_

**COMPUTER FAMILIARIZATION**If you use a computer at *home* or at *work*, please circle the type(s) and your level of expertise:*None IBM IBM compatible Macintosh Apple II Other: \_\_\_\_\_*

(Novice 1) (2) (3) (4) (5) (6) (7 Expert)

*Next page please . . .*

## Attitudes Towards Corporate Automation

Referring to the following statements, please circle the number that best represents your feeling. All the statements below refer to *advanced automated aircraft (minimum EFIS with FMS supplemented by additional automated features)*. Answer quickly — your first impression is often your best.

### Training

1. My training on how to use the FMS was:  
(Totally Inadequate 1) (2) (3) (4) (5) (6) (7 Perfect)
2. My training on "why the FMS behaves the way it does" was:  
(Totally Inadequate 1) (2) (3) (4) (5) (6) (7 Perfect)
3. My training on rapid reprogramming of the FMS was:  
(Totally Inadequate 1) (2) (3) (4) (5) (6) (7 Perfect)
4. My training on when to select a lower level of automation ("click the FMS off") was:  
(Totally Inadequate 1) (2) (3) (4) (5) (6) (7 Perfect)

### Programming Procedures

5. Compared to flying hands-on, programming ATC changes into the FMS on approach is:  
(Impossible 1) (2) (3) (4) (5) (6) (7 Extremely Easy)
6. The ease of use of my FMS is:  
(Impossible 1) (2) (3) (4) (5) (6) (7 Extremely Easy)
7. When ATC requires changes during approach we:  
(Totally Inadequate 1) (2) (3) (4) (5) (6) (7 Perfect)

### Crew Coordination

8. Automation has made the first officer's willingness to speak up:  
(Very Difficult 1) (2) (3) (4) (5) (6) (7 Extremely Easy)
9. Automation makes knowing what the other crewmember is doing in high workload situations:  
(Impossible 1) (2) (3) (4) (5) (6) (7 Extremely Easy)
10. Automation makes crew supervision:  
(Impossible 1) (2) (3) (4) (5) (6) (7 Extremely Easy)
11. Automation has made situational awareness:  
(Impossible 1) (2) (3) (4) (5) (6) (7 Extremely Easy)
12. Automation makes verbal communication between crewmembers:  
(Completely Unnecessary 1) (2) (3) (4) (5) (6) (7 Absolutely Required)
13. Automation makes crew coordination:  
(Completely Unnecessary 1) (2) (3) (4) (5) (6) (7 Absolutely Required)

*Next page please . . .*

**Directions:** Please circle the number that best represents your feeling. All the statements below refer to **advanced automated aircraft** (minimum EFIS with FMS supplemented by additional automated features).

14. Effect of automation on the division of responsibilities between crewmembers:

(No Effect 1) (2) (3) (4) (5) (6) (7 Completely Changed)

15. Automation has made crew coordination training:

(Totally Unnecessary 1) (2) (3) (4) (5) (6) (7 Absolutely Necessary)

### Workload

16. Effect of automation on pilot fatigue:

(Minimizes 1) (2) (3) (4) (5) (6) (7 Maximizes)

17. Automation makes the effort required to be comfortable with "what is going on":

(Minimal 1) (2) (3) (4) (5) (6) (7 Maximum)

18. Automation makes workload during *preflight*:

(Extremely Low 1) (2) (3) (4) (5) (6) (7 Dangerously High)

19. Automation makes workload during *takeoff/climb*:

(Extremely Low 1) (2) (3) (4) (5) (6) (7 Dangerously High)

20. Automation makes workload during *cruise*:

(Extremely Low 1) (2) (3) (4) (5) (6) (7 Dangerously High)

21. Automation makes workload during *approach/landing*:

(Extremely Low 1) (2) (3) (4) (5) (6) (7 Dangerously High)

### Understanding

22. I always know which mode the FMS is in.

(Completely Disagree 1) (2) (3) (4) (5) (6) (7 Completely Agree)

23. The use of the FMS makes the *number* of crew errors:

(Extremely Low 1) (2) (3) (4) (5) (6) (7 Dangerously High)

24. The use of the FMS makes the *severity* of crew errors:

(Trivial 1) (2) (3) (4) (5) (6) (7 Life Threatening)

### Skill Loss/Retention

25. Effect of automation on my ability to mentally keep up with what is going on:

(Completely Degrades 1) (2) (3) (4) (5) (6) (7 Completely Improves)

26. Effect of automation on my hands-on flying skills:

(Completely Degrades 1) (2) (3) (4) (5) (6) (7 Completely Improves)

*Next page please . . .*

**Directions:** Please circle the number that best represents your feeling. All the statements below refer to **advanced automated aircraft** (minimum EFIS with FMS supplemented by additional automated features).

27. Effect of automation on complacency:

(Eliminates 1) (2) (3) (4) (5) (6) (7 Maximizes)

28. Hand flying part of every trip keeps my proficiency up.

(Completely Disagree 1) (2) (3) (4) (5) (6) (7 Completely Agree)

### Cockpit Design

29. The physical layout of the controls and displays in the automated aircraft I fly is:

(Awful 1) (2) (3) (4) (5) (6) (7 Perfect)

30. The mental demands to interpret digital information relative to traditional gauges are:

(Extremely Low 1) (2) (3) (4) (5) (6) (7 Extremely High)

31. The trustworthiness of the automated systems in my aircraft is:

(Completely Untrustworthy 1) (2) (3) (4) (5) (6) (7 Perfect)

32. The problems caused by the different layouts of alphanumeric keypads are:

(Nonexistent 1) (2) (3) (4) (5) (6) (7 Always Occurring)

### General Attitudes

33. Cockpit automation has made flying:

(Impossible 1) (2) (3) (4) (5) (6) (7 Extremely Easy)

34. Automation makes detecting aircraft system faults:

(Impossible 1) (2) (3) (4) (5) (6) (7 Extremely Easy)

35. Automation makes me feel:

(Totally Out of Control 1) (2) (3) (4) (5) (6) (7 Completely in Control)

36. Automation makes pilot stress:

(Unbearable 1) (2) (3) (4) (5) (6) (7 Nonexistent)

37. Effect of automation on flight safety:

(Inherently Dangerous 1) (2) (3) (4) (5) (6) (7 Free of Risk)

38. I am looking forward to the next generation of automated equipment.

(Completely Disagree 1) (2) (3) (4) (5) (6) (7 Completely Agree)

39. What percentage of the FMS functions that you were trained to utilize *do you actually use* during a normal flight?

(0%) (20%) (40%) (60%) (80%) (100%)

*Next page please . . .*

**Directions:** Please circle the number that best represents your feeling. All the statements below refer to **advanced automated aircraft** (minimum EFIS with FMS supplemented by additional automated features).

40. What percentage of the FMS functions that you were trained to utilize *do you feel confident using?*

(0%) (20%) (40%) (60%) (80%) (100%)

41. During takeoff/departure in an *automated* aircraft, the percentage of time I scan for other traffic is:

(0%) (20%) (40%) (60%) (80%) (100%)

42. During cruise in an *automated* aircraft, the percentage of time I scan for other traffic is:

(0%) (20%) (40%) (60%) (80%) (100%)

43. During approach/landing in an *automated* aircraft, the percentage of time I scan for other traffic is:

(0%) (20%) (40%) (60%) (80%) (100%)

44. During takeoff/departure in a *non-automated* aircraft, the percentage of time I scan for other traffic is:

(0%) (20%) (40%) (60%) (80%) (100%)

45. During cruise in a *non-automated* aircraft, the percentage of time I scan for other traffic is:

(0%) (20%) (40%) (60%) (80%) (100%)

46. During approach/landing in a *non-automated* aircraft, the percentage of time I scan for other traffic is:

(0%) (20%) (40%) (60%) (80%) (100%)

*Next page please . . .*





**Appendix B**  
**Cover Letters**



## CAAR Letterhead

Dear Corporate Pilot,

The *Center for Aviation/Aerospace Research* at Embry-Riddle Aeronautical University collectively with the *Center for Applied Human Factors in Aviation* have been awarded a two-year contract to investigate the effects of automation in the corporate cockpit. We believe this work will help identify the nature, variety, and magnitude of automation-induced problems experienced in advanced corporate cockpits. The goal of our research is to provide flight personnel, system designers, and system evaluators with means of improving the safety and efficiency of corporate aviation.

You were identified by your type rating for such high automated aircraft. Therefore, we are kindly asking for your participation in our research efforts, as your expertise on this topic will be extremely valuable. Enclosed are several copies of a questionnaire that we have developed and extensively tested to specifically address the automation-related issues in the corporate aviation environment. We included the additional copies so that you could give them to other members of your flight department who fly these advanced aircraft but may not be type rated. However, keep in mind that all pilots who complete this survey **must** have had experience with *advanced automated aircraft* (EFIS and FMS supplemented by other automated features).

Be as brief or detailed as you like (during our pretest, it took between 15 and 30 minutes to complete the questionnaire). Please feel free to make additional comments and/or suggestions if you think relevant issues were not addressed.

Since we need to report the final results by August 1992, we kindly request that you return the completed questionnaire in the envelope provided by April 15th, 1992. We can assure you that *all contributors* will be guaranteed *complete anonymity*.

If you have any questions, please contact me at (904) 226-6384 or FAX (904) 226-7050.

Sincerely,

John A. Wise, Ph.D.  
Principal Investigator

encl.

FAA Cover Letter

Signed by Foushee

**Appendix C**  
**Reminder Postcard**



**Corporate Aviation Automation Program  
Center for Aviation/Aerospace Research**  
Embry-Riddle Aeronautical University  
600 S. Clyde Morris Blvd.  
Daytona Beach, FL 32114-9970

Nonprofit Organization  
U.S. POSTAGE  
PAID  
Daytona Beach, FL  
PERMIT NO. 313

Dear Corporate Pilot,

A month ago we sent you a few questionnaires for our research investigating the effects of automation in the corporate cockpit. We need your feedback on this topic, as your expertise will contribute to improving the safety and efficiency of corporate aviation. If you have already filled yours out and returned it, we thank you. If not, we would appreciate if you could complete the questionnaire and/or pass the others along to someone else who fly these advanced aircraft but may not be type rated or otherwise received a questionnaire. Your immediate response will be deeply appreciated. We need your comments today!

Thank you for your cooperation.

Project Staff

**Appendix D**  
**Frequency Counts for the Likert Scale Questions**

## Frequency Counts for Question 8

	<b>Count</b>	<b>Percent</b>
<b>1</b>	0	0.00%
<b>2</b>	11	2.69%
<b>3</b>	28	6.85%
<b>4</b>	166	40.59%
<b>5</b>	122	29.83%
<b>6</b>	67	16.38%
<b>7</b>	15	3.67%

## Frequency Counts for Question 9

	<b>Count</b>	<b>Percent</b>
<b>1</b>	2	0.48%
<b>2</b>	39	9.35%
<b>3</b>	65	15.59%
<b>4</b>	114	27.34%
<b>5</b>	127	30.46%
<b>6</b>	59	14.15%
<b>7</b>	11	2.64%

## Frequency Counts for Question 10

	<b>Count</b>	<b>Percent</b>
<b>1</b>	0	0.00%
<b>2</b>	16	3.86%
<b>3</b>	45	10.84%
<b>4</b>	110	26.51%
<b>5</b>	151	36.39%
<b>6</b>	79	19.04%
<b>7</b>	14	3.37%

## Frequency Counts for Question 11

	<b>Count</b>	<b>Percent</b>
<b>1</b>	1	0.24%
<b>2</b>	10	2.39%
<b>3</b>	40	9.57%
<b>4</b>	59	14.11%
<b>5</b>	118	28.23%
<b>6</b>	124	29.67%
<b>7</b>	66	15.79%

## Frequency Counts for Question 12

	<b>Count</b>	<b>Percent</b>
<b>1</b>	0	0.00%
<b>2</b>	3	0.72%
<b>3</b>	20	4.81%
<b>4</b>	83	19.95%
<b>5</b>	106	25.48%
<b>6</b>	110	26.44%
<b>7</b>	94	22.60%

## Frequency Counts for Question 12 by Aircraft Categories

	<b>Count</b>		<b>Percent</b>	
	<b>Group A</b>	<b>Group B</b>	<b>Group A</b>	<b>Group B</b>
<b>1</b>	0	0	0.00%	0.00%
<b>2</b>	0	3	0.00%	1.60%
<b>3</b>	10	10	4.37%	5.35%
<b>4</b>	38	45	16.59%	24.06%
<b>5</b>	57	49	24.89%	26.20%
<b>6</b>	66	44	28.82%	23.53%
<b>7</b>	58	36	25.33%	19.25%

## Frequency Counts for Question 13

	<b>Count</b>	<b>Percent</b>
<b>1</b>	0	0.00%
<b>2</b>	2	0.48%
<b>3</b>	6	1.44%
<b>4</b>	48	11.51%
<b>5</b>	104	24.94%
<b>6</b>	119	28.54%
<b>7</b>	138	33.09%

## Frequency Counts for Question 13 by Aircraft Categories

	<b>Count</b>		<b>Percent</b>	
	<b>Group A</b>	<b>Group B</b>	<b>Group A</b>	<b>Group B</b>
<b>1</b>	0	0	0.00%	0.00%
<b>2</b>	1	1	0.44%	0.53%
<b>3</b>	2	4	0.87%	2.13%
<b>4</b>	25	23	10.92%	12.23%
<b>5</b>	55	49	24.02%	26.06%
<b>6</b>	55	64	24.02%	34.04%
<b>7</b>	91	47	39.74%	25.00%

## Frequency Counts for Question 14

	<b>Count</b>	<b>Percent</b>
<b>1</b>	30	7.21%
<b>2</b>	54	12.98%
<b>3</b>	57	13.70%
<b>4</b>	111	26.68%
<b>5</b>	108	25.96%
<b>6</b>	48	11.54%
<b>7</b>	8	1.92%

## Frequency Counts for Question 15

	<b>Count</b>	<b>Percent</b>
<b>1</b>	1	0.24%
<b>2</b>	5	1.21%
<b>3</b>	5	1.21%
<b>4</b>	58	14.01%
<b>5</b>	97	23.43%
<b>6</b>	123	29.71%
<b>7</b>	125	30.19%

## Frequency Counts for Question 15 by Aircraft Categories

	<b>Count</b>		<b>Percent</b>	
	<b>Group A</b>	<b>Group B</b>	<b>Group A</b>	<b>Group B</b>
<b>1</b>	0	1	0.00%	0.53%
<b>2</b>	4	1	1.76%	0.53%
<b>3</b>	2	3	0.88%	1.60%
<b>4</b>	26	32	11.45%	17.11%
<b>5</b>	40	57	17.62%	30.48%
<b>6</b>	75	48	33.04%	25.67%
<b>7</b>	80	45	35.24%	24.06%



**Appendix E**

**Responses Given to Open-Ended Question 5B**

*How has automation affected crew coordination?*

- Special considerations unique to ATC (0001).
- Actually, about the same (0003)
- Made it more precise and very well defined (0005).
- Definite improvement! The 18 years in single seat fighters taught me to stay ahead as much as possible (0013).
- Crew coordination has to increase because the copilot has to make the changes on the FMS and tell the Captain what he has done (0014).
- Improved. I watch my partner much closer. Especially new copilots (0016).
- Definite decreased. Different FO's have different FMS skill levels. I find FO's saying, "I can do this for you if you want" and I make a yes or a no, instead of as in the past, asking for what I want (0020).
- Neutral (0021).
- After initial familiarization, automation has increased coordination. However, proper crew coordination and cockpit management have always been a strong point in this department (0023).
- Improved it (0024).
- Forced a much higher level of cockpit crew coordination (0025).
- Need very good coordination and communication. Neither person can just afford to sit still and shut up (an old phrase). The ability of either crewmember to greatly help or, more importantly, to cause confusion or chaos has improved the most. An EFIS, FMS equipped aircraft is truly a two person job, and needs to be treated as such (0030).
- Yes very much. Operationally emphasis needs to be placed on crew coordination (0036).
- Somewhat more communication/coordination required. It seemed like immensely more in the early learning stages (0040).
- I find myself spending more time monitoring the equipment and less time on good resource management as I do in a conventional cockpit (0048).
- Positively = once all crew understand system (0050).
- It has created a greater awareness for the need for crew coordination. Complacency caused by complete dependency on FMS LNAV could be disastrous in my opinion. Therefore, with this "new" system, I tend to be more aware of crew coordination needs (0053).

- If a young pilot is flying with an older pilot, the young pilot should be sure to use verbal reinforcement of all the things they are doing. While this verbal backup is useful all the time, no matter what the crew makeup is, I've noticed the younger pilot flying is more aware of what's going on (0054).
- Generally, it allows for better crew-coordination. If used properly, it frees the crew to be able to communicate more efficiently (0064).
- The type of aircraft the automation equipment is installed requires more teamwork because of size (0071).
- It has improved coordination because it requires the pilot flying to talk to and verify what the pilot not flying [PNF] has set up and programmed. It has also put more responsibility on the PNF which leads to more communication and better overall situational awareness (0073).
- None (0077).
- When operating in DUAL X-LOAD; requires less verbal communication; visa-versa (0081).
- Improved it (0090).
- Very little effect (0097).
- Unfortunately, crew coordination (in the formal sense) is next to non-existent in our department. Luckily, the major system that we use (Global GNS-X) is "friendly" enough to use and to catch mistakes (0101).
- No change (0104).
- For autothrottles, it changes actions during the takeoffs and landings. It causes the crew to need to take more mutual understanding of plan (0115).
- I believe the most significant area is in the use of checklists on the multi-function display. When using this, the pilot flying can always see where the other pilot is and what has been accomplished without talking back and forth. This is especially useful in busy terminal control areas where communications with approach/departure is hectic (0116).
- Slightly decreased crew coordination due to overload of information presented and accidental errors during keyboard input (0118).
- We fly co-captains all trained in CRM. So, we have excellent crew coordination already. However, I have found cockpit interaction increases and must when flying equipment (0120).
- About the same – very important (0122).

- It has made this much easier in that the cockpit displays make the pilot flying's interactions much more apparent when verbal communication is not practical (0124).
- No much affect (0126).
- It can take quite a good amount, and ••• distracting time to familiarize a recently checkout co-pilot. They are obviously curious and wanting to learn, but sometimes due to time and situational restraints you have to program it yourself. (0131).
- (Slightly different things to look for, but not very much change in basic crew coordination. (0132).
- Not much change (0144).
- Made it easier (0147).
- Made CRM an absolute necessity (0152).
- See comments (additional info) (0153).
- Generally improved the "personal" feelings between pilots. As our comfort level grew, so did the overall "crew/teamwork" feelings. (0155).
- It is too easy for copilot to quickly enter something in the FMS and even easier to not tell the captain what he did – and vice versa – the fingers are faster than the eyes. (0158).
- Crew coordination has improved since the F/O or pilot not flying can affect the flight both positively and negatively if the wrong data is entered at the wrong time. Coordination seems better with other crewmembers who readily accept and understand advanced cockpit practices. Old bold pilots who fight automation can induce stress and increase workload by (1) not understand[ing] how or why something is done forcing other pilot to do both jobs at times and (2) using a lower level of automation and thus possibly not knowing the current status of some items (0163).
- Makes crew coordination easier. Crew coordination is a bit different with automated systems. (0164).
- The first officer is now holding more of the cards in flight, although the captain does check all final inputs before accepting new information. (0166).
- Made it easier to verify other crew members situation. (0167).
- Resulted in less cockpit conversation and allows more time for checklists and next phase planning (0168).
- Very well (0171).
- No, not as long as both pilots keep a keen sense of our responsibility. (0174).
- About the same. (0179).

- Increased (0183).
- Only to the point of who will actually do the button pushing and when. (0190).
- Made it better; gives the crew quicker references to position, altitude, speed, etc. (0192).
- Too easy for the PNF to reprogram, thinking he is helping and taking the PF out of the loop. So, automation requires higher levels of coordination especially since the boxes cross talk (0194).
- I am not sure it has changed it much (0202).
- Some problems with crewmembers doing FMS work without informing the other crewman. This is fairly rare (0205).
- Able to provide much more information, therefore more precise language is required (0206).
- We have to be very careful that the proper info and modes are in operation at any given period in flight (0207).
- Not to any great degree (0208).
- It's about the same (0210).
- Improved crew coordination; but our flight department spends much time and effort in this area for constant improvement (0213).
- Improved (0218).
- Somewhat improved, I only have about 300 hours over a two year period with this equipment, if that were 300 per year it would be more effective and efficient now (0224).
- No effect (0225).
- Crew coordination has not been affected as much as crew efficiency which has improved. (0226).
- Made the coordination more important to have good information available (0230).
- It is very important when a crewmember makes a change everyone should be informed. It is too easy for a change to go unnoticed (0231).
- It has increased our coordination, we must work together and talk to each other more to correctly program the FMS (0238).
- Eased the workload on both crewmembers (0241).

- I think automation mandates crew coordination. However, we have all been to 2 Cockpit Resource Management seminars and I think they more than anything have shown us the value of good crew coordination (0242).
- Not changed it (0244).
- Makes it easier to show F/O what you are doing if ATC gives you a change in plan. (0246).
- It has increased our reliance on working together and cooperating as a team. The advanced technology forces us to ask questions when we don't know something. The only way to manage this complexity is by communicating what you want, and ensuring all crewmembers are in the loop (0251).
- Because of the vast amount of data available with FMS/EFIS it has probably helped crew coordination (0255).
- Increased communications between crew members (0257).
- I think it has made crew coordination easier and mandatory (0262).
- No effect (0266).
- Forcing to work as a crew and team (0270).
- Not significantly (0271).
- no effect (0274).
- Overall it has improved (0276).
- No change (0278).
- Automated features has had no effect on crew coordination in our flight department (0279).
- Reinforced our realization that crew coordination is critical, particularly in busy airspace (0283).
- I am convinced there has been a major turn around in our crew coordination for the better, since all of us have been using EFIS and FMS equipped aircraft. Coordination is a must and that is way we have presented it to our pilots (0284).
- Improved due to dual Nav/Fuel functions and ability to track dual approach aids (0286).
- Same but more accurate knowing what both pilots are doing (0288).
- Heightened awareness of other crew members "alertness" and response time (0299).

- Increased because each pilot knows what is loaded in the others FMS (0302).
- Very little, basic duties remain the same for each crewmember (0303).
- Increased by providing easy ways for pilots to divide duties (0307).
- Not any great degree, however, it is easier to have access to an abundance of available information (0321).
- None (0322).
- It has required a greater amount of communication between crew members (0323).
- The KNS 660 reduces navigation chores and allows concentration on flying and systems monitoring (0333).
- We have a very definite left seat and right seat job description (we fly with 2 captains) (0345).
- Little effect on crew coordination. Sometime it seems there is less to say because it is more obvious what the other pilot is doing or looking at (0346).
- Since we run our FMSs in "dual" configuration. Meaning what is put into one is automatically put into the other, it makes it extremely important to be precise and communicate what you are going to do if it is the least bit out of the ordinary (0348).
- Attention to detail is critical. An open dialog between pilots must be maintained to keep each other informed in any aircraft but especially in an automated aircraft. We have recorded our checklist and procedures to factor in the operational changes brought on by EFIS and FMS usage (0357).
- Put more responsibilities on the F/O to be part of the crew and to keep up with the situation (0359).
- Yes, inevitably one person is programming when they should be doing something else (such as monitoring) (0362).
- Has emphasized the need for clear concise coordination to align displays (0365).
- It has provided the crew with the maximum amount of information available, reducing crew interactions (0367).
- Initially decreased - as things "sorted out" there was an increase in awareness for need to better coordinate (0369).
- Has strengthened crew coordination considerably. Much more challenge and response coordination on selecting functions, such as heading, courses, navigation, approach, altitude, and speeds, especially on arrival and departures when pilot is busy flying (0373).

- It allows us both to very easily see what the status is = OAT, fuel flow, time to destination, current wind, etc. (0375).
- Properly used, it forces better crew coordination (0378).
- Not at all (0382).
- It requires even more crew coordination just to make sure both crew members are "in the loop." Since, in my opinion, automation breeds complacency, the effort required to resist is enormous (0386).
- I think it has helped to standardize all phases of flight in our operation (0392).
- Crewmembers must be acutely aware of what the other crewmember has programmed into the FMS. Good verbal exchange of information between crewmembers is essential for safe and efficient operation of the aircraft (0399).
- The copilot monitors the procedure in progress to alert the captain of any deviation from the charts. The major problem is when one of the crewmembers knows more than the other and tends to rely heavily on him and doesn't learn himself (0405).
- Crew coordination has increased because communication levels are higher (0408)
- It hasn't, but I feel that with proper programming, crew coordination problems have been relieved (0414).
- Increased requirements slightly. (Changes to FMS program not so readily discernible to flying crewmember as older systems.) If programming pilot doesn't pass the changes verbally to the "flyer," it could lead to confusion and possible serious consequences (0415).
- Accidental fumbling with switches and buttons. Confusion with displays and reader information (0417).
- The first 10 hours it interfered, but now thanks to a procedure in place within the department, coordination is back at the baseline (0419).
- It increased the need for crew coordination (0421).
- Yes- must keep each other aware of configuration changes of the FMS (0423).
- With new equipment, it has increased it due to (the need to) watch the other crew member (to insure) he does not misinterpret all of the information that is available and get confused. Once familiar with it, you still have to back up but it takes a lot less time (0427).
- Yes, because of the various displays and configurations available (GNS-1000/SPZ-8000) pilot flying must be specific in his requests of PNF in mode/program selections on MFD/FMS, etc. (0428).



- It has decreased workload and simplified the basic flying portion of my job so I can afford more time spent at crew coordination (0439).
- Detracts during reroutings by air traffic control (0443).
- In some cases; to prevent misprogramming, the automated features are used independently by each pilot (0452).
- Enhanced it (0453).
- Has a good effect (0454).
- No change. We've always demanded good crew coordination (0458).
- It is easy for one crew member to enter a change without thinking to tell the other. Can cause some confusion. Crew coordination education beyond that required for a "manual" aircraft is imperative (0459).

## **Appendix F**

### **Responses Given to Open-Ended Question 6B**

*If you received any crew coordination training, please specify where. Which topics were covered? Did the training address the automation issue (if so, how)? What did you think of this training?*

- FSI. CRM course (0001).
- Flight Safety (0002).
- Flight Safety (Pitt) All topics mentioned. Excellent training (0005).
- F.S.I. communication and psychology of leadership mostly emphasized. Did not address automation. A good start but left a lot to be desired (0013).
- Cockpit resource management. No address on automation. Helpful training overall (0016).
- Yes, we had [John Doe] come into our operation for a one day automation seminar (0020).
- CRM training through Northwest Aerospace [John Doe]. Automation issue was addressed (with a reminder to "turn it off" when it seems to increase rather than decrease workload) (0021).
- United grid-- no automation. FSI-- no automation (0023).
- I've had CRM twice. The training did not address FMS management per its use. CRM is very good. What needs to be address is the ever looking pair of eyes. Workloads vary and who plugs in what and when is still in question (0024).
- Initial and Annual recurrent. Covered automation in regards to splitting workloads (0025).
- Very little - Flight Safety offers some but most of our crewmembers resist. "Old school" attitude. Training is available we just don't use it (0036).
- United Airlines 1987 Denver. Aero Studies Limited 1991 Minneapolis. Neither really addressed automation other than to mention it in passing (0040).
- United Airlines/Scientific methods "Cockpit Resource Management" (0048).
- United Airlines cockpit resource and Flight Safety Savannah. Excellent (0050).
- U.S. Air Force for several years prior to 1974. American Airlines training facility, KDFW 1981-89. Flight Safety International at KICT and KSAV 1980-1991. SimuFlite at KDFW 1990. (Automation was not covered). The training was not adequate — it barely skinned the surface (0053).
- Classes at Flight Safety and Eastern Airlines (CRM). Very little was discussed concerning automation issues. Overall, the training is very useful - especially for young/old crew combinations (0054).

- I've gone through a couple of CRM courses where the subject of automation was dealt with. Emphasis was placed on crew-communication, the need for someone to be flying the airplane, getting things set-up ahead of time, etc. (0064).
- Training was contracted and executed in house and was complete to my satisfaction (0071).
- 1) Flight Safety cockpit resource management course. 2) Company sponsored CRM course (0073).
- Flight Safety International. No, FMS or EFIS were not specifically taught (0077).
- Crew coordination training while using an EFIS/FMS equipped aircraft has not been provided (0081).
- Yes, at Flight Safety in Dallas, TX. approx. one month ago. Topics involved communications, personalities, etc. But not automation to any degree. Excellent training. (0090).
- Training at Flight Safety/Houston CI-601-3A simulator includes the FMS/EFIS equipment, and is included in the general operation of the aircraft (simulator). (0097).
- No formal CRM training, recurrent training through the years from SimuFlite and FlightSafety provided some information, No automation issues ever addressed (not enough time in a 3 day recurrent) All my training has been obtained through self-education and discipline. (0101).
- FlightSafety — good training — send for the manual (0104).
- FSI and SimuFlite. Communications, decision-making, error chain. Did not address automation. I thought the training was excellent. We will be getting more as time goes on (0115).
- No (0116).
- FlightSafety Int. crew coordination lectures and audio-visual. Quality: fair to good (0118).
- Scientific Methods — Very good school. Did not discuss automation (0120).
- Cockpit Resource Management (FlightSafety) numerous briefings FSF – USC Safety school (0122).
- (1) SimuFlite, Inc. at Dallas, TX. Flight deck management course. (2) Scientific methods cockpit resource management course at Atlanta, GA. Both course were very good but did little to address FMS specifically (0124).
- FlightSafety. (0126).

- FlightSafety crew coordination seminar 1990. Accident review and cause mainly. I do not recall them addressing automation. Any training along these lines are helpful and thought provoking. (0131).
- SimuFlite – communication between crew members assignment of tasks. No training in automated systems. (0132).
- Standard FSI initial and recurrent training. EFIS/FMS training OK. (0144).
- FSI Wichita, KS. Very good course in crew coordination and cockpit resource management. (0147).
- We have had CRM training at both SimuFlite and FlightSafety – Training was good – did address automation. (0152).
- EFIS = OK. FMS = very marginal (0153).
- Cockpit resource management Scientific Methods, Inc. This was of questionable value to our type of "small pilot group." As we live with only 24 pilots. The program as presented did very little for us. We know, and see, each other every day; not once in a career as the airlines have. (0155).
- not formally trained (0163).
- None (0164).
- Most of the crew coordination training I have received has had to do with concise and clear communication, and emergency crew coordination. Any professional pilot, airline or other, should be required to attend a class in crew coordination (0166).
- Very basic (at FlightSafety only and at airline). No instruction offered by avionics manufacturer (Collins & Bendix) even though requested. (0167).
- None (0168).
- SimuFlite ••• crew training but doesn't cover automation nor does FlightSafety. (0171).
- (1) FlightSafety, Inc. (2) CRM. (3) No (4) FlightSafety CRM course very good! (0174).
- FlightSafety, Toledo and Montreal. Clear understanding of each other's activity. Necessity of communication. Command priorities. (0179).
- SimuFlite, FlightSafety did not include automation. SimuFlite – good to excellent. FlightSafety – poor to good. (0183).
- Crew coordination training during initial ground simulator training at FlightSafety , Wichita, KS. Type rated in simulator without having flown the aircraft. Simulator had a different EFIS system than our aircraft. Minimal automation training on our system by

flight safety and EFIS/FMS marker. Recommend more time spent on specific EFIS/FMS system. (0190).

- FlightSafety and internal company programs. EFIS, Global and INS operation. touched lightly on automation issue. Training needs emphasis (0192).
- 1983 UAL CPM, ATL. Autocratic thinking, improved communication, "synergy." Too early for automation training. Very helpful still affects the way I run a cockpit (0194).
- FlightSafety not adequate (0195).
- United's CRM program did not address automation except in very general fashion (0205).
- In house training based on the Myers-Briggs preferences model. United Airlines training was also conducted, however I did not receive that training. For our in house training, automation was addressed (0206).
- Cockpit Resource Management – Briggs (0207).
- FlightSafety Internal, SimuFlite. Cockpit resource management United Airlines. (0213).
- FlightSafety Wichita, KS. (0218).
- FlightSafety – button pushing knob twisting basically, automation was addressed but I think could be covered better with 2-3 hour on an EFIS simulator, not necessary in the aircraft I think the training was adequate for safe operation of the equipment. (0224).
- Initial and recurrent training through SimuFlite and FlightSafety. Did not specifically address the automation issue in relation to crew coordination, however, operation training and actual usage requires a degree of crew coordination. Training pertaining to automation was at FlightSafety and was fair (0226).
- Yes. The week long United Airlines CRM course. It did not address automation. It was excellent training (0230).
- Received CRM from FlightSafety. An excellent course. However, automation was not covered (0231).
- Yes. 1. SimuFlite. 2. FlightSafety. 3. U.S. Navy. Topics: situational awareness, stress, use of checklists, communication skills, managing people. All were excellent. No training on automation was provided (0238).
- Cockpit resource management – FlightSafety Int'l West Palm Beach, Florida. Flight deck management – White Plains, NY. Human factors safety course – Las Vegas, NV (HAI). Automation issues briefly talked about. Training of any sort always good (0241).
- United Airlines CRM school for 4 days in Denver. Excellent training on a 1 time basis. The 2nd time at this school would not be as effective. This school is the baseball bat

between the eyes. Did not cover automation as it is not necessary. 2nd school was 3 days by an outside consultant. Very good, it fine tuned what we learned at United. Again no automation training, still don't think it was necessary for these schools (0242).

- FlightSafety. It includes automation. Good training (0244).
- I received crew coordination training at FlightSafety and often ground schools. But the automation issue was not dealt with. It was valuable training when combined with simulator sessions (0246).
- First received crew resource management through an in-house program in 1982. Topics were communication, checklists, teamwork, assertiveness, and command. Our training did not address automation. I liked the training (0251).
- Short course in "Cockpit Resource Management" Flight Safety, June '91. Topics covered were crew coordination, error chain, etc. I thought the training was excellent but it did not address the automation issue (0255).
- With CRM from Mass. A twelve month program completed in 1989. It did not address automation (0257).
- United Airlines cockpit resource management training — Denver. All topics covered — but pretty much geared to airline cockpits. Did not address automation and I did not like the 4 day course (0262).
- FSI CRM (0270).
- At Flight Safety - did not address the automation issue (0271).
- USAF, Flight Safety International, SimuFlight (0274).
- The only training I have had has been on the job (0276).
- We subscribe to Flight Safety International for all of our training and they stress the crew concept continuously (0279).
- USAF, Flight Safety and SimuFlite. All covered the need for crew coordination and steps to achieve it but none covered crew coordination in an automated cockpit ( to be fair, Air Force cockpits I flew in were manual) (0283).
- All of our pilots have attended cockpit resource management (CRM) training. Communication, awareness, health, personalities are some of the subjects that are covered. Automation was not discussed. We think the training is excellent and plan to continue attending CRM in the future (0284).
- Flight Safety - crew concept, error chain, situational awareness - too brief of a course, not enough PF, PNF training (0286).
- Flight Safety (0288).

- None (0299).
- United Airlines CRM, NATCO CRM - Neither had much to say on automation emphasis on synergy - taking charge in emergency plus normal CRM - all OK but needs the right instructor (0302).
- Training at Flight Safety and Simuflight - all aspects of cockpit resource management were covered in reference to automation, very little was discussed except for the operation of the FMS, EFIS, and AFIS (0303).
- Flight Safety International (0304).
- FSI -at normal recurrency training (0307).
- United Airlines, Scientific Methods. Training was done without any special reference to automation, but training was exceptional!! (0321).
- Initial and recurrent Cockpit Resource Management training at FSI, automation was not addressed (0322).
- Flight Safety International crew coordination training in the simulators (0323).
- Flight Safety CRM — Excellent. continues emphasis on the "human factor" is a must in aviation and all levels (0324).
- Flight Safety and SimuFlite. Did not address automation. SimuFlite training was well done (0333).
- SimuFlite and Flight Safety. The bottom line for the left seat pilot to be free to FLY THE AIRPLANE and the right seat pilot does nearly everything else (0345).
- Cockpit Resource Management – United Airlines at Denver How each crew members style is represented an a matrix 1-1 through 9-9. The workshops were conducted to learn your own style and how to improve it and work with other people's style. Also Myers-Briggs training in-house with specialist automation was not especially addressed in either training (0346).
- All our initial and recurrent training is done at flight safety with two company crew members. Crew coordination is usually addressed. We have also had CRM training. I think it is very important (0348).
- The only formal crew coordination training we have received has been of our initial and recurrent training at Flight Safety, Gulfstream, and Canadair. Time constraints do not allow the curriculum to include enough of the resource management training needed to deal with the problem. We deal with problem areas as they arise by pilot meetings and training in house (0357).
- Flight Safety CRM course (0362).



- We all attended Scientific Methods CRM but I do not recall automation being emphasized. It should be addressed and we will pursue that issue (0365).
- Flight Safety - 1980 Just started to be more of a need for crew coordination (0367).
- United Airlines - Scientific Methods CRM, Flight Safety standard courses (0369).
- Flight Safety simulator, but it was minimal and only as far as the crew was conscientious to pursue (0373).
- My earlier remarks referenced to initial training when systems were first on the market and especially with the earlier literature from the manufactures- not complete enough- but now the training supplied by organizations such as Flight Safety Intl. is outstanding (0378).
- Great diversity (0381).
- Received in Air Force [C-141], prior to automated cockpits – but the principles don't change. . . . . Communicate, Communicate, Communicate!!! (0386).
- U.S. Air and FSI. It is a must in today's cockpits (0392).
- SimuFlite (1986) didn't cover automation. At my place of employment, each year for the last 2 years, no one seems to have an approach for covering automation (0394).
- FSI- situational awareness, communication. Training was helpful but no cure-all. Did not cover automation specifically (0396).
- Flight Safety at Teterboro. Basically just an introductory program, how to program, how system is designed, and how to use system operationally. Very, very basic (0399).
- Flight Safety-TEB. The automation issue was addressed but just cursory. Having flown this system for four years, I know more than most of the instructors (0405).
- In house, but conducted by Simuflight. Was a two day course and covered many subjects. Training was very good (0408).
- Flight Safety International program- it was very good (0413).
- Various cockpit resource management courses through Flight Safety International. A good training course (0414).
- SimuFlite, USAF, Air National Guard, Flight Safety. Division of responsibilities, standard practices and callouts, situational awareness, command techniques, etc. Training was both good and desirable (0415).
- Flight Safety: Cockpit Resource Management. No automation specifically mentioned. Good stuff (0419).

- **Flight Safety.** Situational awareness, cockpit management, cockpit safety management, human factors, stress and distractions. Training did not address automation. The training was valuable and helpful (0421).
- **Yes- situational awareness and decision making.** Yes- primarily emphasized the use of FMS and automation to maintain situational awareness and reduce workload, i.e. if you have a tool, then use it (0423).
- **Flight Safety- both as student and instructor.** Very basic training- try to stimulate persons awareness. Very limited on automation issue. Thought it was very good for initial training (0427).
- **CRM, scientific methods.** They covered the human aspects of flying as a crew. I thought the training offered good insights on avoiding human errors through the team approach. They did not cover automation (0439).
- **Flight Safety Inc.** OK (0443).
- **Flight Safety.** CRM (0449).
- **Part 121 and large turbojet operations** requires some coordination training. However I did not receive any formal training with my transition to automated aircraft. A great fouling. I think, in general, that training for advanced automated corporate aircraft is inadequate (0452).
- **Flight Safety Int'l.** United Airlines/Scientific Methods Cockpit Resource Mgmt. Northwest Aero Studies, Professional Cockpit Mgmt. Univ Southern Cal, Effective Cockpit Communications, Professional Cockpit Mgmt (0458).
- **I have had CRM and FDM courses** given by both Simuflight and Flight Safety. Little emphasis was given to automation. It was mostly on personalities and the effect they can have on teamwork. There was a lot of attention given to advocacy and asserting ones position (0459).

**Appendix G**

**Other Open-Ended Responses Related to Crew Coordination**

### Responses given to question 1

*Briefly describe an operational problem – that you personally know of – involving the automated features of your aircraft that could have had a negative safety consequence. How could the error have been avoided?*

- The need for extensive crew coordination is paramount. Although our system has many backup safety features, complacency can easily lead to disaster (0036).
- Crew coordination seems to be the one area of concern. One member selecting a feature and the other deselecting the same feature, or one crew member changing a procedure without telling other crew member (0089).
- Two pilots operating dual FMS systems without communicating inputs to each other (0128).
- Incidents involved mis-programmed FMS or (more frequently) misunderstanding between crew members as to what was programmed (0130).
- Crew coordination is very important when ATC changes (route changes) are received. It should be clear who will make the changes on the FMS and then that pilot must be sure to transfer the information to the other side so both pilots are "flying" the same route (0141).
- A standard flight plan stored in FMS was not the one filed. Due to an in-flight crew change (one pilot) I did not know change in routing FMS was flying other than clearance (0165).
- Better crew coordination and cross checking to ensure correct data input (0169).
- . . . being sure the other crew member does not change what is selected at the wrong time. Effective crew coordination is a must during these situations. (0177).
- Programming both sides of FMS — Capt. and F.O. not coordinating changes between the two (0217).
- Better crew coordination and division of attention (0218).
- First officer programming changes into the FMS without first letting me know that he's going to do that (0271).
- At times we are told present heading for traffic, etc. and we fly off our planned route. Should have some type of visual warning device to back up pilot(s) when off of planned route. This is probably a crew coordination problem more than anything else (0276).
- After programming clearance into FMS, crewmember deleted intersections on jet airways to minimize screen clutter. Course was altered from clearance. Crewmember should have advised me before making changes in route (0322).

- With dual FMSs, crew coordination and specific division of responsibility is critical (0325).
- FMS when in "initiated transfer" having one pilot send info to the other when it is inaccurate or not what the pilot flying wanted to look at. It could be avoided by communication between crew members or flying in "single operation" (0346).
- . . . . I feel that even though there were no errors (such as altitude deviations) that situational awareness and crew coordination were severely hampered (0362).
- Transitioning from FMS mode to VHF mode was a problem early in the EFIS/FMS cockpits until definite coordination procedures were established. Even today, on occasion it's still a problem (0370).
- Generally speaking a high degree of crew coordination training is necessary to prevent both pilots having their heads-down in the cockpit at the same time (0378).
- If the operator inadvertently enters an inappropriate location identifier as the departure point, the system responds as though you actually are departing from the incorrect point. Better crew coordination during programming would help (0384).
- With two crew there is always one to fly the airplane and one to "push buttons." A problem could arise when both pilots become fixated on watching the MFD and not paying attention to other more important matters. "Crew coordination" (0424).
- Improved crew coordination and more comprehensive training on automated features [is needed] (0452).

### **Responses given to question 2**

*Were there any instances in which the automated features "saved the day" or had a positive safety consequence?*

- Everyday, situational awareness is much improved by automation (0025).
- Situational awareness with regard to position and wx in relation to flight plan route vastly improved (0027).
- It allows excellent "situational awareness" (0037).
- The benefit of having map display, for example, greatly improves situational awareness (0102).
- Increased situational awareness "where am I" is always a benefit (0103).

- Holding patterns are extremely easy to enter and exit. Position awareness is very high (0109).
- Situational awareness (0117).
- Automation should improve situational awareness as one has time to "think ahead" particularly on an approach which might involve tricky winds and poor runway conditions/potential missed approach, etc. (0130).
- Situational awareness is always improved if the system is used properly (0136).
- Nearly always aid in situational awareness. Especially, when arriving an unfamiliar airport visually (0140).
- The multi function display is always helpful for situational awareness (0166).
- Ability on most MFDs to show final ADC (?) course relative to aircraft position improves situational awareness (0175).
- Day in and day out we utilize FMS pointer on HSI for bearing to airport during vector to ILS (also distance on UNS) for strong situational awareness. EFIS display of wind direction/velocity is great for approaches and to indicate possible shear conditions without INS wind calls (0181).
- As a result of the confidence of where you are and where you are going you can give greater attention to the outside situation (0209).
- Because of the excellent Nav display (G-IV), I feel I can spend more time in terminal area looking for traffic and still maintain better situational awareness than in less sophisticated aircraft (0214).
- If positioned properly, situational awareness is heightened tremendously! (0228).
- Increased situational awareness (0234).
- Situational awareness has improved with the FMS (0238).
- The ability of the FMS to promote a more positive situational awareness through a more thorough understanding of your surroundings. In the event of an emergency you know where the nearest airports and nav aids are located (0260).
- First, it makes us more aware of fuel burn and range. It also requires us to review routing before leaving the chocks, which to me, provides a better overview for situational awareness (0289).
- Situational awareness improves (0296).
- Improved situational awareness always and every day (0321).

- Electronic Map Display greatly contribute to situational awareness in terminal area vector "dance" (0337).
- The map display available now certainly gives you additional situation awareness (0356).
- G-IV nav displays showing current route and location of airports and nav aids gives both crewmembers greater situational awareness (0379).
- The ability to see the orientation of the a/c to the final approach course, or other navigation features (i.e., the various "map" modes) makes maintaining good situational awareness somewhat easier (0383).