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Pilot Opinions on High Level Flight Deck Automation Issues: Toward the Development of a Design Philosophy

Yvette J. Tenney, William H. Rogers, and Richard W. Pew

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Table of Contents

Page

List of Figures

List of Tables

ABSTRACT

There has been much concern in recent years about the rapid increase in automation on commercial flight decks. Part of the concern is that automation is introduced without an explicit guiding philosophy about its usability and its impact on overall flight crew-flight deck performance and aircraft safety. Several surveys of commercial airline pilots have addressed flight deck automation issues. However, most have solicited opinions specific to automation implemented on particular aircraft. This paper describes a survey that was aimed at gathering pilot opinions about high level, automation philosophy issues. It was administered to 132 pilots of advanced automation aircraft. The respondents included 46 Airbus A-320 pilots (representing Northwest, United, and America West), 47 Boeing 747-400 pilots (representing Northwest and United), and 39 Douglas MD-11 pilots (representing American and Delta).

The survey was composed of four major sections. The first section asked pilots to rate different automation components that exist on the latest commercial aircraft regarding their obtrusiveness and the attention and effort required to use them. The second section addressed general "automation philosophy" issues, such as: What attributes make automation "good?" What attributes make it "trustworthy?" Has increased automation increased or decreased physical and mental workload? The third section focused on issues related to levels and amount of automation, such as: On the continuum from unaided pilot performance to completely automated functions, where should flight deck systems lie—in different situations and for different functions? What are the advantages and disadvantages of different levels of automation? The fourth section addressed several design issues specific to a next-generation high speed civil transport aircraft.

The results indicate that pilots of advanced aircraft like their automation, use it, and would welcome more. However, they also believe that automation has disadvantages, especially fully autonomous automation. They want their automation to be simple and reliable and to produce predictable results. Furthermore, in response to questions about the extent to which they felt in control of the aircraft versus controlling the automation itself, they revealed that simple and reliable is, in some ways, related to how little attention they need to pay to it. If there is a necessity to interact with automation extensively, such as with systems requiring intensive data input or components that must be constantly monitored, it is more likely to be perceived as obtrusive and pilots' attention will be focused on the automation instead of the underlying function. This phenomenon may be an unavoidable penalty for human-centered automation when contrasted with autonomous systems and highlights the importance of effective interface design.

Although we began this survey with the objective of trying to understand the contrast between human-centered and full automation, we come away from it with a slightly different perspective. To be against human-centered automation is to be against apple pie. The issues instead are to understand, from the pilots point of view, how far they want to go in introducing automation and what features need to be present to maintain situation awareness, to assure human control of the integrity of flight and to promote safety and airline cost-effectiveness. The answer provided in this survey is that the greatest promise for further gains with the fewest disadvantages is obtained in moving from manual systems to shared-performance systems, as contrasted with moving from shared-performance systems to autonomous systems.

Although pilots generally indicated they would like more of all types of automation, the biggest needs for higher levels of automation were in pre-flight; communication, systems management, and task management functions; planning as well as response tasks; and high workload situations. There is an irony and a challenge in the implications of these findings. On the one hand pilots would like new automation to be simple and reliable, but they need it to support the most complex part of the job—managing and planning tasks, especially in high workload situations.

INTRODUCTION

There has been much concern in recent years about the rapid increase in automation on commercial flight decks. The results of pilot surveys have raised flags over such issues as increased heads down time, degradation of flying skills, workload extremes, and the requirement to manage unanticipated situations (e.g., McClumpha, James, Green, & Belyavin, 1991; Sarter & Woods, 1991; Wiener, 1989). The factors underlying these findings have been explored by researchers and industry experts (e.g., ATA, 1989; Kantowitz, & Sorkin, 1987; Norman, 1986; Regal & Braune, 1992; Wiener & Curry, 1980). Part of the concern is that automation has been introduced without an explicit guiding philosophy about its usability and its impact on overall flight crew-flight deck performance and aircraft safety. "The fundamental concern," according to the Air Transport Association of America, "is the lack of a scientifically-based philosophy of automation that describes the circumstances under which tasks are appropriately allocated to the machine and/or the pilot" (ATA, 1989). To address this need, the ATA has created a "National Plan to Enhance Aviation Safety through Human Factors Improvements." In a similar vein, NASA has initiated an Aviation Safety/Automation Program that has made the development of a flight deck automation philosophy a high priority (Billings, 1991; Norman & Orlady, 1989).

The challenge in developing an automation philosophy has been well described by Riley (1989):

> In the past, automation decisions could be made by assigning to human or machine whatever task each was better able to perform. Now, this criterion is often difficult to apply. Furthermore, designers must consider such issues as the operator's loss of situation awareness due to relying too heavily on automation, conflicts between the operator's decisions and the machine's decisions, or tendencies of the operator to override or defeat the automation due to lack of trust in it, p.124.

Of particular relevance to these issues is the growing literature on the cognitive processes involved in the management of complex multi-task systems (see Adams, Tenney, and Pew, 1994, for a review). With it, has come an appreciation of the difficulties faced by the operator:

> The distinctive characteristic of the complex semi-automated environment is that the operator is confronted with a number of tasks at once. No matter: the operator's behavior must still be goal directed. In order to switch in and out of tasks so as to maintain the integrity of the system or mission as a whole, the operator must subordinate each of the individual tasks and the overall ensemble to his or her understanding of the goals of the system or mission as a whole. Given that the opportunity, urgency, and particulars of completing any given task must be in constant flux with the stream of events, this is no small requirement. (Adams, Tenney, & Pew, 1994, p. 35).

One implication of this research is that automation should be "human-centered" (Billings, 1991; Rouse, Geddes, & Curry, 1987; Wiener, 1989). At a minimum, it must provide a coherent task breakdown, maintain focus on higher-level goals, minimize distractions, and offer strong contextual support following interruptions (Adams, Tenney, & Pew, 1994).

Another way to interpret this literature, however, is that humans, with their propensities for error and cognitive limitations, should be taken out of the loop altogether. Why trust any function to a human when a machine can be programmed to do it better? These two views, the human-centered and its opposite, the full-automation view, are two candidate design philosophies that have been discussed in the human factors literature (Billings, 1991; Norman & Orlady, 1989; Regal & Braune, 1992; Rouse, Geddes, & Curry, 1987).

To date, there has been little support among researchers for the full-automation philosophy, for both technical and political reasons (Regal & Braune, 1992). The human centered-view, by contrast, has many proponents (e.g., Billings, 1991; Norman & Orlady, 1989; Regal & Braune, 1992; Wilson & Fadden, 1991). It is founded on the premise that "the flight crew will be an integral component of safe and efficient commercial flight for the foreseeable future because human skills, knowledge, and flexibility are required in the operation of complex systems in an unpredictable and dynamic environment" (Palmer, Rogers, Press, Latorella, & Abbott, 1995). As a consequence, the crew must be kept involved in and informed about all aspects of the flight situation that they would need to know about if they were to fly manually and must always have the option to do so.

Billings (1991) has described the principles of human-centered automation as follows. The basic premise is: "The pilot bears the ultimate responsibility for the safety of any flight operation" (Billings, 1991). An axiom of this premise is: "The human operator must be in command." Corollaries to this axiom include:

> To command effectively, the human operator must be involved. To be involved, the human operator must be informed. The human operator must be able to monitor the automated systems. Automated systems must therefore be predictable. The automated systems must be able to monitor the human operator. Each element of the system must have knowledge of the others' intent (Billings, 1991, p. 12).

The goal, in this view, is to create automation that supports human strengths and compensates for human weaknesses, while leaving ultimate control in the hands of the human (Billings, 1991; Regal & Braune, 1992). The concept of providing different levels of automation for flight control—from highly automated control through a flight management computer, to moderately automated control through a mode control panel, to basically manual control through a wheel and column and throttle—was an initial step in this direction. Today, there are many systems, either on the flight deck or on the drawing board, that would qualify as human-centered, in the sense of easing information processing, enhancing situation awareness, and preventing mistakes. Examples include graphic map displays, integrated caution and warning systems, decision aids, electronic checklists, and electronic libraries.

Although the human-centered approach may sound good in theory, in practice there are many unresolved questions. How much knowledge should a pilot be expected to have? Are there times and situations where advising the human and waiting for a decision would be riskier than having the machine take direct action? Is it conceivable that in the future there will be aspects of flight that are so well understood that they can be programmed to be completely reliable and risk-free without the need for human monitoring? These issues are not just limited to flight decks. They are issues whenever automation is seen as "simplifying" large complex systems. They point, once again, to the need for careful guidelines: "A well thought-out philosophy will help designers achieve the most effective balance between fully automated and human-centered automation systems" (Regal & Braune, 1992).

The purpose of this study was to contribute to the development of a design philosophy for new, advanced flight decks by gathering data on pilots' views on automation philosophy as well as on some of the many concepts and definitions that will be needed to formulate meaningful guidelines: for example, what it means for automation to be trustworthy, how to define levels and types of automation, and how to characterize good and bad automation experiences. This information was collected by administering a survey concerned with high-level automation issues to commercial airline pilots.

The Survey

The present survey was administered to captains and first-officers of the Boeing 747-400, Douglas MD-11, and Airbus A-320 aircraft. These aircraft were selected because, when the survey was administered, they were the newest flight decks of each manufacturer that had been in service long enough to have a sufficient number of experienced respondents. The Airbus A-320 went into revenue service in 1988, the Boeing B747-400 in 1989, and the Douglas MD-11 in 1991. An advantage of using all three was that they provided the opportunity to compare responses along a technological dimension. The Airbus A-320 is considered to be the most highly automated. For example, it is a fly-by-wire aircraft and has envelope protection features that cannot be overridden. Boeing, is perceived to be the least automated of the three. For example, its envelope protection system advises, but does not restrict, the pilot. Douglas, in turn, is considered to lie somewhere in between the other two. (However, systems management on the MD-11 is the most automated of all three aircraft.) By including pilots of all three flight decks in the survey it was possible to look for differences in attitudes and opinions as a function of different automation implementations on the aircraft they fly.

Philosophy

The first issue addressed in the survey was the extent to which pilots endorsed the human-centered, as opposed to the fully automated philosophy. While researchers may be leaning strongly toward a human-centered philosophy, it was not clear to what extent the actual users and designers of the automation shared their views. Regal & Braune (1992) have warned:

> It appears that, at the present time, many individuals and groups find it easier to work on developing fully automated systems than dealing with the difficulties involved in tailoring systems to the cognitive complexities of humans. We need to understand the advantages and disadvantages of a human-centered automation approach so that it is possible to objectively choose the optimal system design, p. 3.

A human-centeredness scale, consisting of thirteen questions, was devised by combing the literature for statements that reflected either a human-centered or full-automation view and then pairing each statement with an opposing statement (see Appendix A, Q32-41 and Q46-48 and Table 1). As in previous surveys the paired statements were presented to subjects as the endpoints of a scale (McClumpha et al., 1991). Subjects could indicate strong agreement with either statement by choosing a scale point close to one of the extremities, mild agreement by choosing a point just on either side of the midpoint of the scale, or neutrality, by choosing the midpoint itself. Table 1 identifies the endpoints for each question as human-centered or fully-automated and references the sources of the ideas for the questions.

Good/Trustworthy Automation

The second issue on which pilot opinions were sought concerned the attributes that are most essential for making pilots like and trust the automation on their flight deck. Billings (1991) has proposed a set of desirable attributes for human-centered automation. As he pointed out, however, it may not be possible to give equal emphasis to all the attributes. For example, an emphasis on informativeness, by increasing the complexity of the machine, might be incompatible with maximal dependability. For that reason, it seemed worthwhile to solicit pilot opinions on those attributes that should receive top priority. Therefore, two questions were composed in which subjects were asked to rank order the ten attributes proposed by Billings and an eleventh one—"simple"—that appeared to the investigators to be curiously missing (see Appendix A, questions 51 and 52). In question 51, subjects ranked the attributes with respect to *good automation* (defined as enhancing safe, economical operation of the aircraft). In question 52 they ranked them with respect to *trustworthy* automation (defined as producing pilot acceptance and faith in its operation or output).

Table 1
Human-Centered Philosophy Questions

Q32-41; 46-48

Question No.	Opening	Human-Centered Ending	Fully- Automated Ending	Source of Idea for Question
32	Initial emphasis in training should be placed on learning about	the "basic airplane" before introducing the automation	the automation before introducing the basic airplane	Norman & Orlady, 1989, p. 184)
33	I would like to see the introduction of more automation that	assists the pilot in problem solving	automatically solves problems	Morgan Herschler, Wiener, & Salas (1995)
34	I would like to see the introduction of more automation that	evaluates and advises the flight crew on alternative plans of action	automatically executes alternative plans of actions	Morgan, Herschler, Wiener, & Salas (1995)
35	It is likely that situational information about A/C systems given by automation in the future	will always require confirmation	can always be accepted as fact	Pew (1988)
36	It is likely that procedural info. concerning A/C systems given by automation in the future	will always require confirmation	can always be accepted as fact	Pew (1988)
37	It is likely that the pilot in the future will	still be responsible for flying the aircraft	not be responsible for flying the aircraft	Billings (1991, p. 12, 57, 80) Jordan (1963, p. 162)
38	In the future	there will still be system failures that require deviations from standard procedures	we can expect that every system failure will have a prescribed procedure to follow	Regal & Braune (1992, p.4)
39	The biggest obstacle to total flight safety is	system design	pilot performance	Pew (1988)
40	In pilot training in the future, principles of navigation and aviation are likely to receive	just as much emphasis	less emphasis	Norman & Orlady (1989)
41	In most cases, an automatic system should	warn the crew of envelope exceedence, but not restrict pilots' control	prevent the aircraft from exceeding its performance envelope	Billings (1991, p. 29, 86)
46	Decision aids should emphasize	situation information	response information	Morgan, Herschler, Wiener, & Salas (1995)
47	Decision aids should provide the flight crew with	a list of alternatives	one alternative	Morgan, Herschler, Wiener, & Salas (1995)
48	Decision aids should provide the flight crew with	recommendations	commands	Morgan, Herschler, Wiener, & Salas (1995)

Physical and Mental Workload

The third issue concerned the nature of workload on the advanced flight deck. Previous surveys have produced somewhat contradictory results. Some studies have reported workload problems, particularly workload extremes, while others have not. Wiener (1989), found that automation increased workload at the busiest times, but this result was not supported by McClumpha et al. (1991). In order to explore this issue more fully, subjects were asked to rate both physical and mental workload separately for each phase of the flight (see Appendix A, question 55).

Levels of Automation: Promise and Concerns

The fourth issue related to levels of automation, that is, the degree to which functions or tasks are performed by the pilot, the automation, or some combination. The question was whether pilots could evaluate different levels of automation on the basis of their costs and benefits (see Appendix A, questions 78-80). While previous surveys have collected pilots' expectations and concerns about automation in advanced, in contrast to traditional flight decks, they have not, to our knowledge, been asked to consider the pros and cons of different levels of automation.

How many, and what kinds of levels, are meaningful to pilots? Again, the goal was to establish the psychological validity of the concept of a level, while at the same time collecting data about the trade-offs between costs and benefits associated with the different levels. The ability of subjects to assign different expectations and/or concerns to the different levels would provide evidence that the distinction between levels was real to them. On the other hand, if subjects gave statistically indistinguishable responses to the three levels, it would be difficult to argue that the levels were meaningful.

In developing this survey, our original intent was to gather data on all six levels of automation proposed by Billings (1991). Billings' automation levels not only distinguished whether the flight crew or automation, or some combination, was assigned a particular function or task, but also whether the pilot or the automation had authority over task performance, and if the automation had authority, how that authority was delegated by the pilot. Closer examination of these levels, however, revealed that some of the distinctions among levels were subtle and ambiguous. We were concerned that opinions about advantages and disadvantages of different levels, or what the ideal level was for different situations, would be unreliable given the difficulty of understanding the differences among levels.

Furthermore, as Regal & Braune (1992) have observed, different researchers have proposed different schemes. The most extensive is from Riley (1989), who has proposed seven levels along a "machine intelligence" dimension (ranging from "raw data" to "the anticipation of operator error") and twelve levels along an "autonomous" dimension (ranging from varying degrees of communication with the pilot to varying degrees of taking action with or without pilot permission or overrides). Thus it is evident that many dimensions (e.g., task performance, authority, machine intelligence) underlie different notions of automation levels.

Rather than attempting to examine the whole problem of levels, which we suspect, along with Riley (1989), will be multidimensional and complex, we opted, as a first step, to see if a meaningful distinction could be made between one intermediate level of automation, "shared pilot/automation performance," and the two extremes: "fully autonomous" and "unassisted pilot performance" (see questions 78-80 for definitions). In these questions, subjects were presented with a list of specific concerns and expectations that had appeared in the literature (ATA, 1989; McClumpha et al., 1991; Norman & Orlady, 1989, Appendix A; Parasuraman, Molloy, & Singh, 1993; Pew, 1988; Singh, Molloy, & Parasuraman, 1993; Wiener, 1989) and were asked to indicate how strongly they felt each one applied to each of the three levels of automation.

Ideal Level of Automation for Different Situations

The fifth issue addressed in the survey was pilots' satisfaction with the level of automation available on their aircraft for particular situations (See Appendix A, questions 56-77). It is common to hear concerns that aircraft are too automated or that automation has too much authority, yet pilots applaud many of the most sophisticated automated systems on their aircraft and express the need for more automated assistance in some situations. We argue that the ideal level of automation cannot be judged independently of the particular situation or context. For example, anecdotal reports from pilots suggest that they feel under-utilized during normal conditions, due to the amount of automation, but could use more automation in non-normal conditions. The question then becomes, what aspects or attributes of the situation affect the ideal level of automation from the pilot's perspective? Recent work on defining situation awareness requirements (Deutsch, Pew, Rogers, & Tenney, 1994) suggests that it is useful to decompose complex situations into simple situations that vie for the pilot's attention and to decompose those situations into a set of attributes. In the context of commercial aviation, the attributes that appear to be most important for defining situations are the environmental and system events that occur and the tasks and functions that can be carried out. In questions 56 to 77, subjects were asked to consider the following situation attributes: flight condition (i.e., normal, non-normal, emergency); phase of flight; mission function (i.e., flight control, navigation, communication, systems management, and task management); human information processing task (i.e., monitoring, processing, responding); and workload (i.e., high, medium, low) (Deutsch et al., 1994; Regal & Braune, 1992).

For each category of each situation attribute (e.g., for "high workload" in the workload attribute; for "navigation" in the mission function attribute), subjects were asked to indicate: a) the level of automation they had available on their aircraft for that item; and b) the level they would use ideally. They made each of these judgments on a five point scale, ranging from "unassisted pilot performance" to "totally automated performance." By comparing actual vs. ideal level it was possible to see in what situations differences between current and ideal levels of automation exist. Equally importantly, subjects' ability to differentiate between the different categories of a particular situation attribute would suggest that the particular ways of decomposing situations, and the scales used, were meaningful. It is important to establish the psychological validity of these categories because the formulation of automation guidelines is likely to involve this intermediate level of discourse (e.g., For the *cruise phase of flight*, or for *low workload situations*, the ideal level would be shared performance).

Amount of Automation

The sixth issue again concerned the question of whether the flight deck is over- or under-automated. Because this issue is such an important one it seemed worthwhile to approach it in different ways. This time instead of estimating ideal levels of automation for different situations, subjects were asked to rate the ideal amount of automation, where amount was defined as the total number of automated systems or components on the aircraft.

Subjects answered five questions, concerning five different types of automation. Each question had two parts. In part 'a' they rated the amount of each type of automation in their current aircraft. In part 'b' they indicated whether the ideal amount of automation would be more than, less than, or the same as in their current aircraft .

The questions differed from those in the previous section in the following ways:

1. The questions concerned amount rather than level of automation.

2. The questions asked about a different set of categories. This time subjects were asked to consider five types of automation: aircraft control, systems control, information automation, decision automation, and protective automation (see Q81-85 for definitions). These categories were derived from Billings' (1991) distinction between control, information, and management automation and were expected to have psychological validity.

3. In part 'b' subjects indicated how far they thought they were from the ideal amount of automation. This time there was no need to subtract the responses of part 'b' from 'part a' because subjects compared the actual to the ideal directly in 'b.' (Another reason for not subtracting was that the two scales were not equivalent.)

Phenomenological Experiences

The sixth and final automation issue concerned the question of how to talk about the phenomenological experience of using automation. Dimensions of experience that have been emphasized in the literature and are clearly of relevance to designers are the notion of workload (e.g., Adams, Tenney, & Pew, 1994; Gopher & Donchin, 1986; Wickens, 1992) and situation awareness (e.g., Adams, Tenney, & Pew, 1995; Endsley, 1995; Gilson, Garland, & Koonce, 1994; Sarter & Woods, 1991; Taylor, 1989; Taylor & Selcon, 1993). There is another dimension of experience, however, that has been noted persistently in the literature, but whose ramifications have not yet been explored (Billings, 1991; Hollnagel, 1991). It has to do with the feeling that one is having a direct as opposed to an indirect, or mediated experience. An example of a direct experience would be the feeling, when driving, that one can sense the bumps on a road directly, rather than through the tires. The same distinction is believed to occur in aviation. Pilots may feel that they are controlling certain aspects of the flight directly, even though they are assisted by automation. On the other hand, they may become so involved with the demands of the automation, that their attention is completely diverted from the flight. In such cases, pilots may feel that they are managing or supervising the automation rather than controlling the flight. This kind of indirect experience is believed to occur when the automation is new, cognitively demanding, or otherwise obtrusive (Hollnagel, 1991).

In order to explore this dimension, subjects were presented with a list of 31 flight deck automation systems they were likely to have encountered and were asked to rate each one on several different dimensions of experience, including situation awareness, or "knowledge of the big picture," workload, the controlling/managing dimension, distractibility, predictability, and frequency of use (see Appendix A, questions 1-31). (Slightly different scales were used for the alerting questions, 27-31).

The list was compiled based on components described by Billings (1991) and McGuire et al. (1991). It was then reviewed by two retired airline pilots. They added and subtracted items based on whether the items made sense in terms of the scales subjects would use to rate them and whether they were described in language that would be unambiguous to pilots. Some items, mostly ones that were either completely transparent or required no pilot interaction, were eliminated based on preliminary data indicating that they would produce uniform responses.

Results were analyzed to see if the dimensions clustered into sub-dimensions and to see which pieces of automation gave rise to which types of experience. The results of the questions relating to phenomenological experiences will be described in the results section, but the supporting tables summarizing the data are provided in Appendix B.

Miscellaneous

Included in the questionnaire for other purposes were some questions designed to assess preferences for specific design options. Two questions (see Appendix A, questions 42,43) related to how autopilot modes are organized. The functioning of the autoflight systems differs among aircraft types. In terms of a philosophy, it has been suggested that the autoflight modes should reflect what it is that pilots really want to control, that is, speed, lateral path and vertical path. Conventional systems typically are organized by thrust, roll, and pitch, the aircraft parameters that are directly affected by control inputs. Secondly, given that autoflight modes have become very complex and are suspected as factors in several recent accidents, a question about the predictability of mode transitions was asked. A third question addressed the use of synthetic speech (see Appendix A, question 44). Synthetic speech is seen as a technology that can facilitate presentation of information to the flight crew, particularly in high visual workload conditions, but commercial flight decks have traditionally been very conservative in regard to introduction of such technologies. A fourth question related to the overall amount of information available on the flight deck (see Appendix A, questions 45); the question has continually been raised as to whether there is too much information on today's flight decks, but to our knowledge a pilot sample has never been directly asked. Two questions address decision aids and the presentation of probabilistic information (Q49,50). As decision aids and artificial intelligence technologies continue to advance, and automation becomes more capable of probabilistic assessments, the question arises as to how certain information should be before it is presented to the pilot. Finally, seven questions (Q88-94) addressed issues related to the ongoing design of the High Speed Civil Transport (Alter & Regal, 1991; Regal & Alter, 1993; Swink & Goins, 1992). These included questions concerning the use of displayed sensor and database data to replace forward vision lost due to the elimination of forward windows, and questions concerning the best control device, that is, a side stick, wheel and column, or center stick. The results of these questions will be presented and discussed in Appendix C.[1]

METHOD

<u>Subjects</u>

Captains and First Officers actively flying Boeing B747-400, McDonnell Douglas MD-11, and Airbus A-320 aircraft for U.S. airlines were recruited for this survey. A total of 132 pilots, 47 B747-400 pilots, 39 MD-11 pilots, and 46 A-320 pilots, completed the survey. The sample included one female. The distribution of Captains and First Officers across airlines and aircraft types is shown in Table 2.

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1 Also included, for exploratory purposes, were four open-ended questions (Q 53, 54, 86, 87). The results will not be discussed in this report.

Table 2
Number of Captains and First Officers Completing the Survey by Aircraft Type and Airline

Aircraft Type	Airline	Seat	Number of Pilots
B747-400	Northwest	Captains	2
(N=47)		First Officers	17
	United	Captains	3
		First Officers	25
MD-11	American	Captains	11
(N=39)		First Officers	2
	Delta	Captains	13
		First Officers	13
A-320	Northwest	Captains	5
(N=46)		First Officers	2
	United	Captains	10
		First Officers	11
	America West	Captains	8
		First Officers	10

The mean age of pilot subjects was 45.9 with a range of 28 to 59. Subjects averaged 18.9 years of commercial flying experience, 12704 total flying hours, and 15.8 years of formal education. All subjects had experience on jet aircraft other than the one for which they were currently type rated. Classification of three of the subjects, in terms of aircraft type, was problematic because they were currently type-rated on both the Airbus A-320 and the Boeing 747-400. In those cases, subjects were assigned to the aircraft in which they indicated more flying hours.[2]

It is apparent from Table 2 that for unknown, assumably random reasons, there was an unequal distribution between Captains and First Officers. The proportion of First Officers in the groups varied as follows: Boeing 89%, Douglas 38%, and Airbus 50%. Table 3 shows the background characteristics of subjects in the three aircraft groups. These data were compiled from the biographical forms that each subject filled out. Unfortunately, due to the unequal representation of Captains and First Officers across aircraft types, differences emerged in their background

2 One subject in this category was inadvertently misclassified as Boeing instead of Airbus.

characteristics, complicating the task of comparing the aircraft groups . As can be seen in the table, Douglas pilots were, on the average nine or ten years older than the other pilots and, as a result, had more total flying hours and more hours flying as pilot in command. The analyses of variance for these characteristics were all significant: $F(2,126)=23.23$, $p<.0001$ for age, $F(2,127)=14.93$, $p<.0001$ for total flying hours, and $F(2,125)=10.94$, $p<.0001$ for hours as pilot in command. Tukey tests revealed that in all cases, the Douglas pilots differed from the other two groups ($p<.05$), which did not differ from each other ($p>.05$).

Table 3
Biographical Data for Pilots of Different Aircraft

	Boeing 747-400 (N=47)	Douglas MD-11 (N=39)	Airbus A-320 (N=46)
Age	42.6	52.3	43.8
Total Hours Flying	11,393	16,154	11,160
Total Hours as Pilot-in-Command	5,041	9,045	5,688
Years of Formal Education	16.3	15.2	15.8

As will be clear from subsequent sections, these problems prevented us from drawing conclusions about some of the comparisons that we had intended to make. The aircraft differences we were able to report with confidence met the following criteria:

1. The results for the different aircraft were in line with expectations.

2. Supplementary analyses, based on an unconfounded subset of the data (e.g., only Boeing and Airbus first officers), supported the original analysis.

Materials

A package of materials was sent to each subject. It included a cover letter explaining the general intent of the survey, a one-page background questionnaire (see Appendix A), the survey, and an envelope in which to return the survey. The survey itself consisted of 34 pages, and included four sections with a total of 94 questions (see Appendix A).

Procedure

U.S. commercial airlines were identified that operated the B747-400, MD-11, and A-320 aircraft. The airlines were called and a contact person (usually the Chief

Pilot) for each type of aircraft was requested. The Chief Pilots were called and informed about the study. Chief Pilots contacted Fleet Captains for each aircraft type, who posted flyers and/or messages where flight crews could read them. Equal numbers of Captain and First Officer volunteers were requested from each airline; the goal was to have 150 respondents, 25 Captains and 25 First Officers for each aircraft type, but as can be seen from Table 2, respondents for some airline and aircraft types were skewed in terms of number of Captains and First Officers , and the total number of subjects responding was less than desired. Volunteers signed up with Fleet Captains and a list of names and addresses was compiled and forwarded to one of the researchers, who then mailed the materials package to each subject on the list.

Volunteers were requested to return the survey within a week and were paid $150 for completing the survey. One hundred sixty surveys were sent out and 132 were returned (Surveys were accepted even if they were late). Subjects were asked to complete questions pertaining to specific automation components based on their current aircraft. They were given the name and number of one of the researchers so that they could call for clarification or explanation of any question they did not understand. Half a dozen calls were received, all requesting clarification of the automation pieces listed in questions 1-31.

RESULTS

The results for each of the major issues the questionnaire was designed to address will be discussed for the sample as a whole. Subsequently effects attributable to the aircraft currently flown will be explored.

Philosophy

In questions 32-41 and 46-48, subjects responded to thirteen questions designed to assess agreement with a human centered, as opposed to a fully autonomous viewpoint. A human-centeredness score was calculated for each subject by averaging the responses to the thirteen philosophy questions (Q32-41; 46-48). Before calculating the averages, the polarity of some of the questions was reversed, and the scores transformed accordingly, so that a five always represented the human-centered end of the scale. The polarity of the questions had been varied randomly, to avoid calling the subject's attention to the dimension of interest.

The average response to the twelve questions, across all 132 subjects, was 3.53. This score showed that subjects endorsed the human-centered view, but not as strongly as they could have. An examination of each of the separate philosophy questions showed that subjects responded on the human-centered side of the scale consistently for all but one question. (This exception will be discussed shortly). (See Figures 1a to 1m showing the frequency of responses to each question at each scale point).

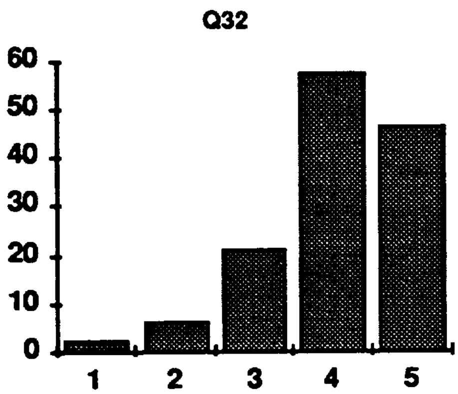

Figure 1a. Initial emphasis in training should be placed on learning about:

the automation before introducing the "basic airplane" | the "basic airplane" before introducing the automation

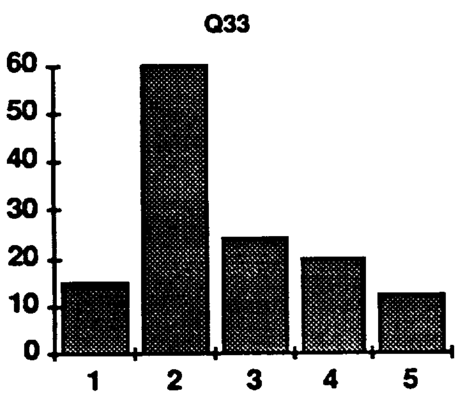

Figure 1b. I would like to see the introduction of more automation that:

assists the pilot in problem solving | automatically solves problems

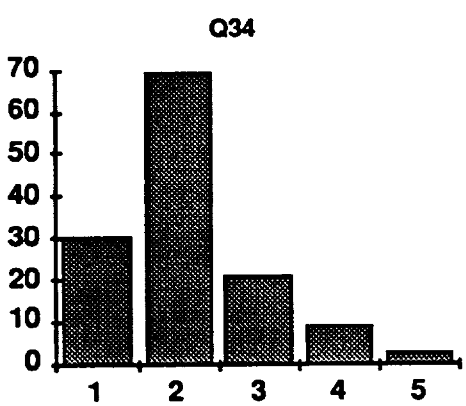

Figure 1c. I would like to see the introduction of more automation that:

evaluates and advises the flight crew on alternative plans of actions | automatically executes alternative plans of action

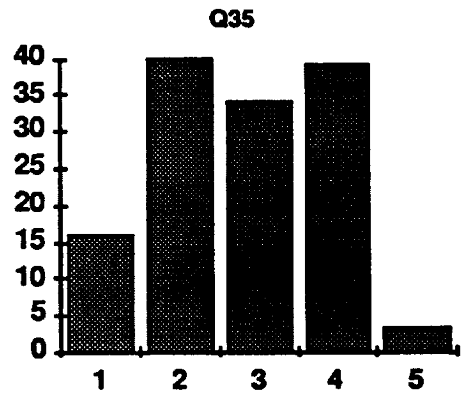

Figure 1d. It is likely that situational information about A/C systems given by automation in the future:

will always require confirmation | can always be accepted as fact

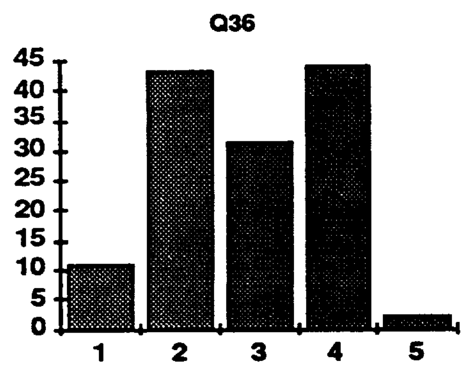

Figure 1e. It is likely that procedural information, response recommendations and commands concerning A/C systems given by automation in the future:

will always require confirmation | can always be accepted as fact

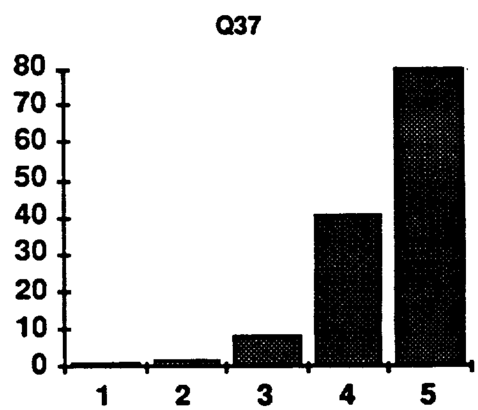

Figure 1f. It is likely that the pilot in the future will:

not be responsible for flying the aircraft | still be responsible for flying the aircraft

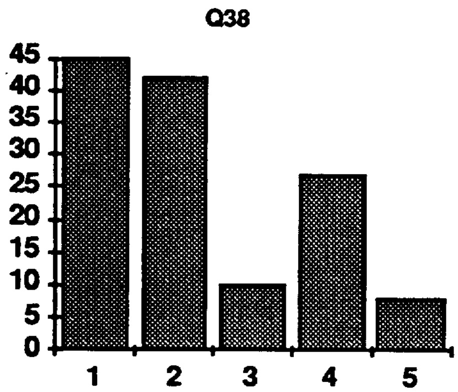

Figure 1g. In the future:

there will still be system failures that require deviations from standard procedures

we can expect that every system failure will have a prescribed procedure to follow

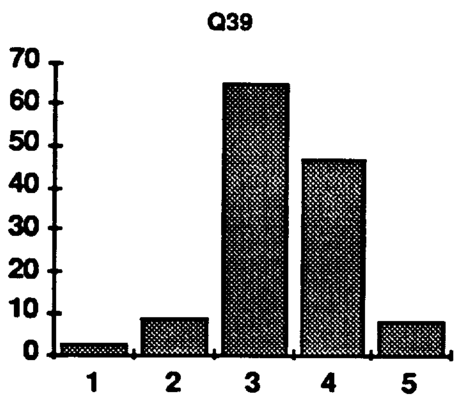

Figure 1h. The biggest obstacle to total flight safety is:

system design

pilot performance

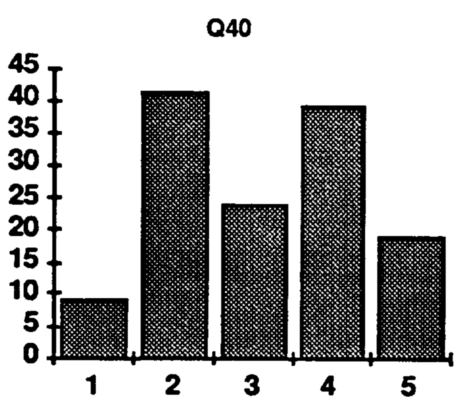

Figure 1i. In pilot training in the future, principles of navigation and aviation are likely to receive:

less emphasis

just as much emphasis

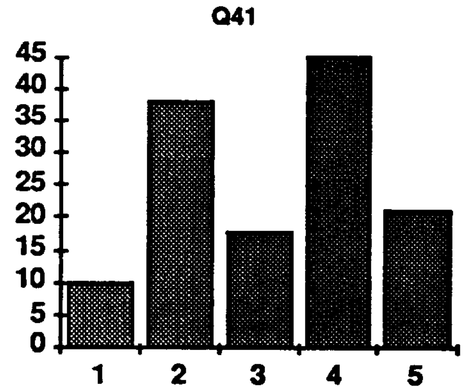

Figure 1j. In most cases, an automatic system should:

prevent the aircraft from exceeding its performance envelope

warn the crew of envelope exceedence, but not restrict pilot control

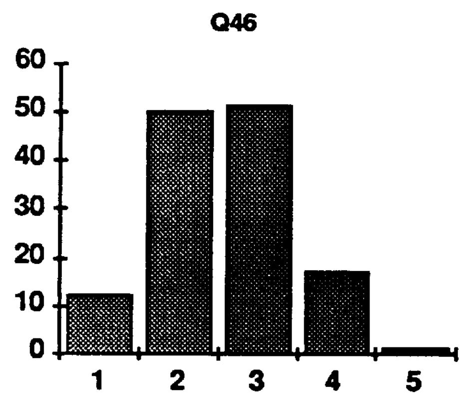

Figure 1k. Decision aids should emphasize:

situation information

response information

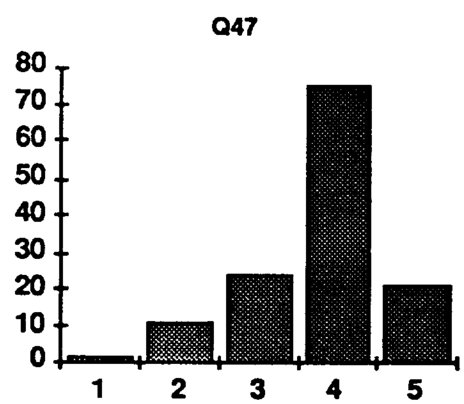

Figure 1l. Decision aids should provide the flight crew with:

one alternative

a list of alternatives

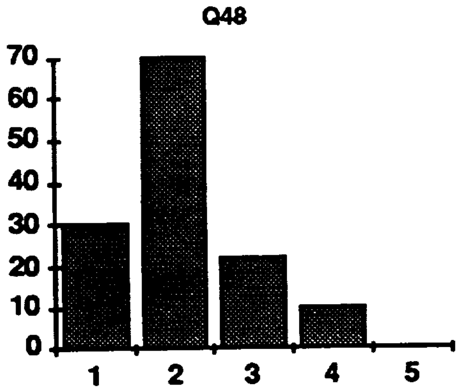

Figure 1m. Decision aids should provide the flight crew with:

recommendations commands

Question 37 (Figure 1f) elicited the strongest human-centered response. Subjects were nearly unanimous in proclaiming that the pilot will still be responsible for flying the aircraft in the future (mean =4.9). Not surprisingly, given this view, subjects also felt strongly on Q32 (Figure 1a) that beginning pilots should learn about the "basic airplane," before learning to use the automation (mean=4.05). They also showed a strong preference for automation that assists the pilot in problem solving, as compared to one that automatically solves problems (Q33, Figure 1b), another central tenet of human-centered philosophy (mean, with reversed scale,=3.86).

The only score to fall slightly to the full-automation side of the scale for the average subject was Q39 (Figure 1h). This question asked whether the greatest obstacle to total flight safety was system design or human performance. The assumption was that proponents of the human-centered view would focus on the problem of poorly designed systems while proponents of the full-automation view would point their finger at human foibles. Interestingly subjects proved to be more sympathetic to the full-automation view on this question than on any of the others, responding on the "human performance" half of the scale (mean=2.61, reversed scale). The respondents may have been influenced by the statistic that "pilot error" is responsible for two thirds of all aircraft accidents (Regal & Braune, 1992). Another interesting finding was that on the question concerning envelope protection (Q41, Figure 1j), the B-747 and MD-11 pilots responded on the human-centered side, while the A-320 pilots responded on the full-automation side. This result will be discussed in the section on Aircraft Differences.

These results provide support in the pilot community for the human-centered design philosophy that has been favored by researchers. In constructing the scale, effort was made to avoid making one of the poles sound like the "right answer." The fact that only one of the questions was close to the ceiling (Q, 37), lends credence to the measurement technique and suggests that the questions received careful consideration.

Good/Trustworthy Automation

The average ranking was calculated for each of the eleven attributes for good automation (Q51) and then for trustworthy automation (Q52). The attribute that received the most favorable average ranking in each case was then ranked #1, the next best attribute #2, and so forth. The rank orders obtained in this way are shown in Table 4.

Table 4
Rank Ordering of Attributes for Good and Trustworthy Automation

Q51-52

Attribute	Rank for Good Automation (Q51)	Rank for Trustworthy Automation (Q52)
Dependable	1	1
Predictable	2	2
Simple	3	4
Comprehensible	4	3
Informative	5	5
Subordinate	6	8
Flexible	7	10
Error-resistant	8	7
Accountable	9	6
Adaptable	10	11
Error-tolerant	11	9

Note. The ranks indicated are a rank ordering of the average ranks given for the attributes.

As can be seen in the table, the results for the two questions were highly correlated (Spearman's $R=.86$, $p<.001$). Although, Q51 had stressed safety and economy, while Q52 had emphasized pilot acceptance and use, subjects failed to make a distinction between "good" and "trustworthy" automation. Striking in both cases was the clear "back to basics" response. An examination of the first five ranks showed that pilots want automation that works (i.e., is dependable) and that they can understand (i.e., is simple, predictable, and comprehensible). All other features were considered, by their lower ranks, to be secondary. The message seems to be: Don't try anything fancy (i.e., flexible, adaptable, accountable, error-tolerant or error-resistant), just give me something I can use.

Billings (1991) has suggested that certain of the attributes on the list oppose certain others, in the sense that emphasizing one often forces a de-emphasis on the other. The following attribute pairs, he believes, bear such a relationship:

- Accountable—Subordinate
- Predictable—Adaptable
- Comprehensible—Flexible
- Dependable—Informative
- Error-resistant—Error-tolerant

The present results suggest the following prioritization for these pairs. With the exception of the first pair (accountable-subordinate), for which rankings were inconsistent across Q51 and Q 52, the rankings showed a clear preference for the left hand members of each pair.

With respect to the problem of human error, the rankings suggest that pilots want to prevent error from happening in the first place rather than trusting a machine to correct it. Towards that end, their first desire is for automation that is easy to use (ranks 1-5), their second is for error-resistant systems that will check for typical kinds of mistakes (rank 7 or 8) and their last is for automation that will try to help out after an error has occurred (rank 9 or 11).

In sum, the rankings show a preference for simple, easy to use systems over truly leading edge technologies. They lend further support to the human-centered attitudes of the pilots revealed in the philosophy questions.

Physical and Mental Workload

In Question 55, respondents were asked to rate workload for glass cockpits in comparison with conventional cockpits. Responses were made on a five point scale where 1 was "much lower than in conventional cockpits," 3 was "about the same," and 5 was "much higher." The average physical and mental workload ratings obtained for each phase of a flight are shown in Figure 2. These averages are based on 111 out of the 132 subjects. Four subjects had to be eliminated for failure to respond to all parts of the question. The additional reduction in sample size was necessary to equalize the numbers from each of the three aircraft groups so that a mixed-factors analysis of variance could be carried out, with aircraft as a between-subjects factor (Results of the aircraft analysis will be discussed in a later section). Subjects were retained in the order in which they had responded to the survey.

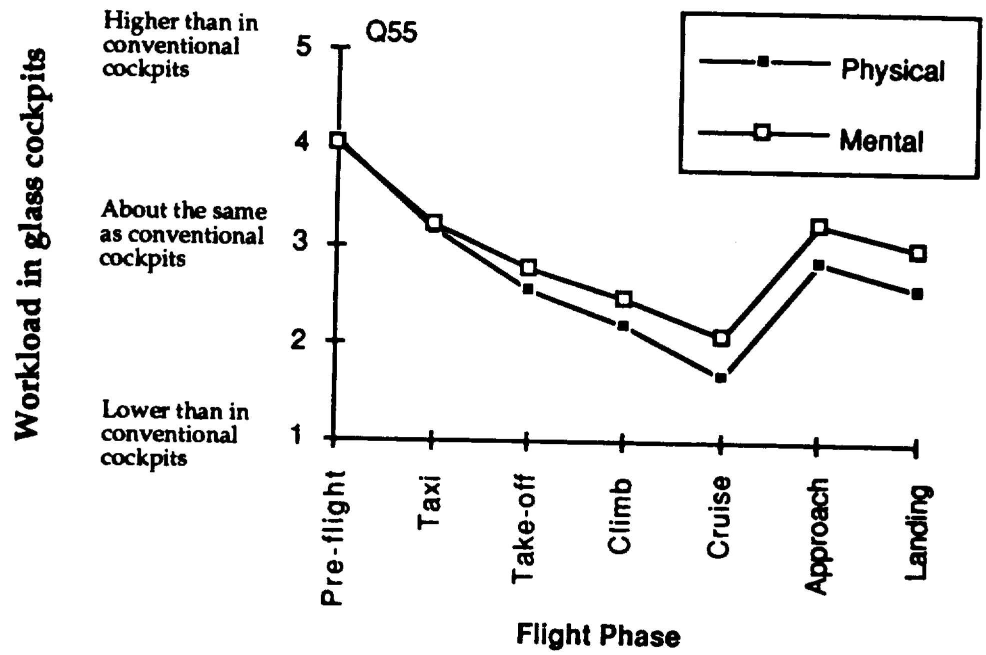

Figure 2. Physical and mental workload for different flight phases.

The results support the conventional wisdom that automation has reduced physical workload more than it has mental workload. Regarding physical workload, inspection of the portion of the curve that is below 3.0 ("about the same as in conventional cockpits") shows that physical workload was rated as being lower than in the conventional cockpit for all flight phases except two: pre-flight (4.04), which was substantially higher and taxi (3.14), which was about the same. The physical aspect of punching buttons into the computer and talking to ATC in these phases may be responsible for the high physical workload ratings for these phases. While these actions are not physically exhausting, in the usual sense of high physical workload, they do entail being physically busy. The biggest reduction in physical demands can be seen in the cruise phase (1.69), presumably reflecting the widespread use of flight control and navigation automation.

Mental workload ratings, showed the same general ups and downs across phases as physical workload. However, the difference in workload in glass cockpits in relation to conventional cockpits was more pronounced for physical workload than for mental workload.

These observations were supported by statistical analysis. A two-way repeated measures analysis of variance, with workload type (physical vs. mental workload) and flight phase as within-subject variables revealed a main effect of workload type, $F(1,110)=30.57$, $p<.0001$, a main effect of flight phase $F(6,660)=1215.6$, $p<.0001$, and a significant interaction between workload type and flight phase ($F(6,660)=5.671$, $p<.0001$.

Individual comparisons were carried out by a Tukey test (significance was assessed at the .05 level for all Tukey tests in this report). The results revealed that the rating of mental workload differences between glass and conventional cockpits were significantly different than the rating for physical workload differences for the cruise ($p<.05$) and approach ($p<.05$) phases and just missed being significantly different for landing ($p<.10$).

The Tukey test also showed the following pattern of change over flight phases: Ratings of both physical and mental workload differences between glass and conventional cockpits changed significantly from pre-flight to taxi ($p<.05$) and from taxi to take-off ($p<.05$). Physical, but not mental workload differences, changed from climb to cruise ($p<.05$), and both types of workload difference ratings changed from cruise to approach ($p<.05$).

In summary, the results showed that pilots feel that mental workload has not been reduced in the automated cockpit to the same extent that physical workload has. Both physical and mental workload were rated as markedly higher in glass cockpits than conventional cockpits for pre-flight, and slightly higher for taxi. Mental workload was rated as slightly higher or the same in glass cockpits for approach and landing.

<u>Levels of Automation: Promise and Concerns</u>

In questions 78-80, subjects indicated how much they agreed or disagreed with claims about different levels of automation. First, they rated all the possible advantages, or promises, of each level (part 'a') and then the possible disadvantages, or concerns (part 'b').

An overall "promise" and an overall "concerns" measure were obtained for each of the three levels of automation of interest by averaging the responses to each item in Q78-80a, and Q78-80b, respectively for each subject. The average measures, across subjects, are shown in Figures 3a and 3b, respectively. The number of subjects included in the analysis, after eliminating the few non-responders and equalizing the aircraft groups, was 114 and 111 out of 132 for the" promises" and "concerns" analyses, respectively.

The overall promise rating (see Figure 3a) was significantly lower for the pilot unassisted (2.68) than for the shared or fully autonomous levels, $F(2,226)=91.813$, $p<.001$. The shared and autonomous levels were rated identically overall (both 3.79). An examination of Table 5a shows that pilots felt that the autonomous level has the most promise to "alleviate fatigue," "reduce workload," "provide more precise data," "increase safety," and "increase airline cost effectiveness," but could not match the shared level for "keep me involved," "keep me informed," improve my performance," and "improve my situation awareness." Neither level could top the unassisted level for "keep me involved."

Concern ratings showed a clear differentiation of levels (see Figure 3b). Overall concern grew from 2.3 to 3.29, as automation increased, which was a significant difference, F (2,220)=96.001, p<.0001. A Tukey test showed that each of the levels differed significantly from the others. These results were highly stable: Inspection of individual items (see Table 5b) showed that all but four of the items increased regularly across levels.

Major concerns at the fully automated level were increased head-down time (4.05), complacency (3.95), and degradation of pilot skills (3.90). These items, which have to do with the pilot's ability to "stay in the loop," are related to the fear that full automation will not "keep me involved" expressed earlier in the promises section. Fourteen out of the eighteen items on the list received scores above 3.0, indicating they were of moderate to high concern at the fully automated level. The four that were of lower than moderate concern were "temperamental devices," "difficulty in learning to operate," "need for new skills," and "difficulty in detecting system errors."

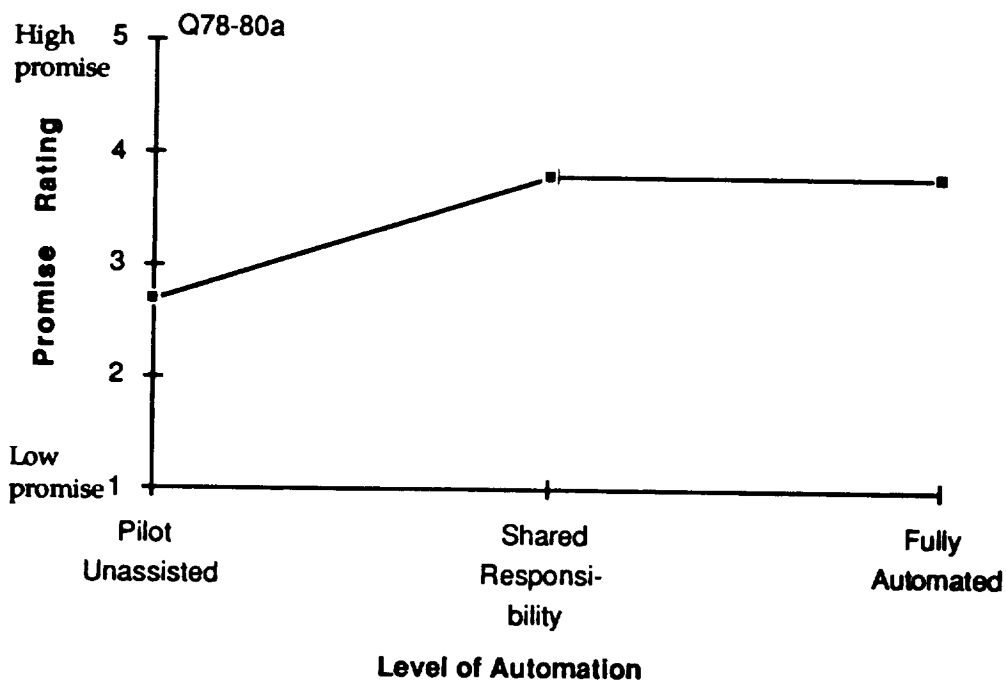

Figure 3a. The *promise* of different levels of automation.

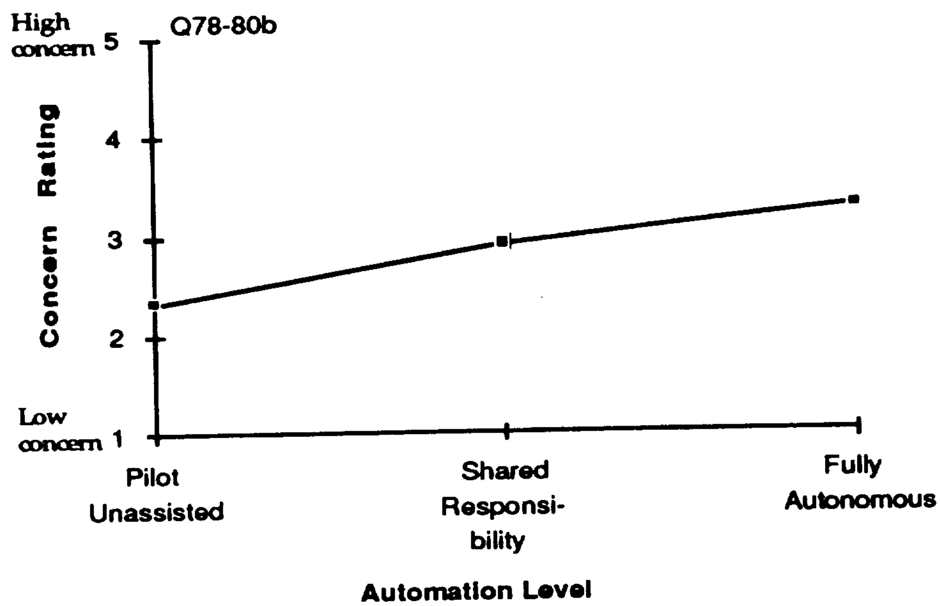

Figure 3b. *Concern* about different levels of automation.

Table 5a
Average Promise Rating at Each Level of Automation

Q78a-80a

Promise	Pilot Unassisted	Shared Control	Autonomous
keep me involved	4.24	4.14	3.15
keep me informed	3.18	4.21	3.99
improve my performance	2.87	3.89	3.56
improve my situation awareness	2.98	3.96	3.78
alleviate fatigue	2.03	3.47	3.65
reduce workload	1.88	3.42	4.08
provide more precise data	2.32	3.71	4.14
increase safety	2.25	3.82	3.90
increase airline cost effectiveness	2.42	3.58	3.68

Note. The rating scale was: 5 = agree 1= disagree "that automation at this level holds the promise to..."

Table 5b
Average Concern Rating at Each Level of Automation

Q78b-80b

Disadvantage	Pilot Unassisted	Shared Control	Autonomous
temperamental devices	1.85	2.48	2.76
display complexity	2.15	2.78	3.13
losing sight of the raw data	1.90	2.77	3.34
difficulty in learning to operate	2.05	2.54	2.95
data entry errors	2.33	3.12	3.32
software engineering errors	2.09	3.11	3.43
need for new skills	2.06	2.62	2.78
unforeseen and unintended negative consequences	2.83	2.82	3.10
workload extremes (high and low)	3.83	3.10	3.32
increase in the no. of alerting signals	2.46	3.11	3.40
loss of situation awareness	2.94	2.65	3.16
need to work around automation in unusual circumstances	2.06	2.94	3.34
increased head-down time	2.67	3.54	4.05
difficulty recovering from automation failure	1.94	2.97	3.46
degradation of pilot skills	1.85	3.11	3.90
difficulty in detecting system errors	3.12	2.73	2.71
reluctance of crew to take over from automation	1.78	2.60	3.12
complacency	2.30	3.13	3.95

Note. The rating scale was: 5 = high concern 1 = low concern "that automation at this level could lead to ..."

For shared performance, only seven out of the eighteen items were rated higher on average than "3," indicating more than moderate concern. The items that dropped from the high concern half of the scale to the low half between fully autonomous operation and shared performance were: display complexity, losing sight of raw data, unforeseen and unintended negative consequences, loss of situation awareness, need to work around the automatics in unusual circumstances, difficulty in recovering from an automation failure, and reluctance of crew to take over from automatics.

Although pilots generally had fewer concerns about flying unassisted than about flying with automation, they did see clear advantages to automation. Two concerns, workload extremes (3.83) and difficulty in detecting system errors (3.12), were seen as concerns at the unassisted level that were alleviated by the introduction of automation.

In summary, subjects showed, through their concerns and promise ratings, that they have no trouble thinking about three different levels of automation. In terms of costs and benefits, the intermediate level seemed to be the most advantageous, because it showed as much promise as the fully automated level with fewer concerns.

Ideal Level of Automation for Different Situations

In a series of questions subjects were asked to rate the maximum level (Q56-77) of automation on their current aircraft (see part 'a') and the level that they would ideally use (see 'b' part). The questions were asked for five attributes of the situation that could affect the actual and ideal levels of automation: flight condition (i.e., normal, non-normal, emergency) (Q56-58); phase of flight (Q59-66); mission function (i.e., flight control, navigation, communication, systems management, and task management) (Q67-71); human information processing task (i.e., monitoring, processing, responding) (Q72-74); and workload (i.e., high, medium, low) (75-77).

A measure of the subject's satisfaction with the level of automation in his current aircraft, with respect to the ideal, was calculated by subtracting the ideal rating from the actual rating for each question. The "actual minus ideal rating" captures the subject's satisfaction in the following way: A positive rating means that a higher level of automation is available than pilots ideally would use, a negative rating means that the highest level available is lower than they ideally would use, and a zero means that the highest level available is the same as the ideal level they would use. A negative rating indicates that perhaps higher automation levels should be considered for that particular situation.

The "actual minus ideal" ratings for each of the five situation attributes are shown in Figures 4a-4e. For these analyses, the sample was again reduced to 111 out of 132 to achieve equal numbers in the three aircraft groups. A one-way, repeated measures analysis of variance, with category as the factor (e.g., high, medium, and low for the situation attribute labeled "workload,") was carried out on the "actual minus ideal" scores for each of the situation attributes. The results showed a significant main effect of category (p<.0003 for *human information processing task*, and p<.0001 for all other situation attributes). In other words, the different perspectives afforded by each of the situation attributes helped subjects to identify situation categories for which they could use higher levels of automation in contrast to those for which the available automation level was sufficient.

The most interesting categories in each analysis were those for which pilots indicated a level of automation that departed from the ideal. For every bar in Figures 4a-4e, a t-test for repeated measures was conducted to determine if the actual level (part 'a') was *significantly* below or above the ideal (part 'b'). To correct for multiple comparisons, the probability level for the t tests in each classification scheme was multiplied by the number of t tests conducted.

The following categories were found to be significantly above the ideal in the level of automation available to aid pilots (p<.05, adjusted): normal flight (see *flight conditions*, Figure 4a), climb, cruise, descent, and landing (see *flight phase*, Figure 4b); flight control (see *mission function*, Figure 4c). This finding does not mean that the higher levels of automation should be eliminated for these situation categories, but it does indicate that lower levels should be available for pilot use. It also has implications for the likelihood that pilots will resist using higher levels of automation in some situations, and should be taken into account in training and operations.

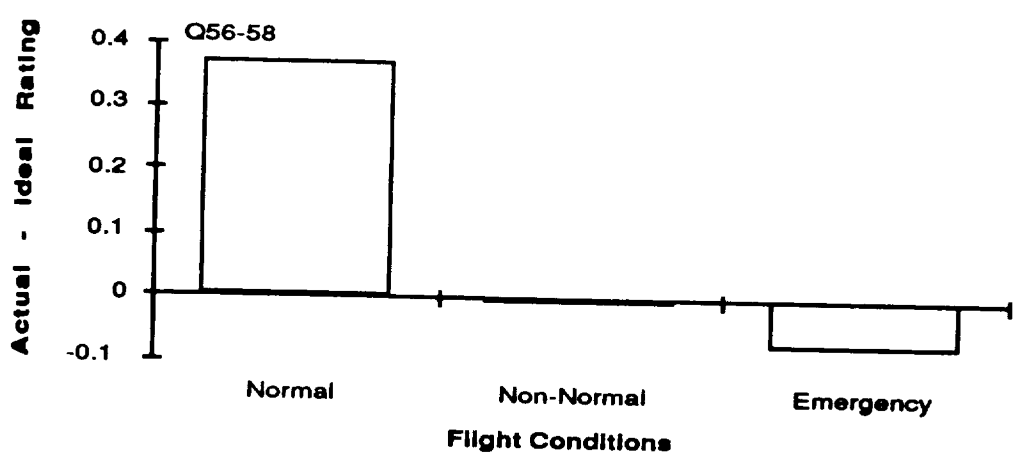

Figure 4a. Satisfaction with level of automation for different flight conditions. A positive rating means that the automation level available is higher than the respondent's ideal level.

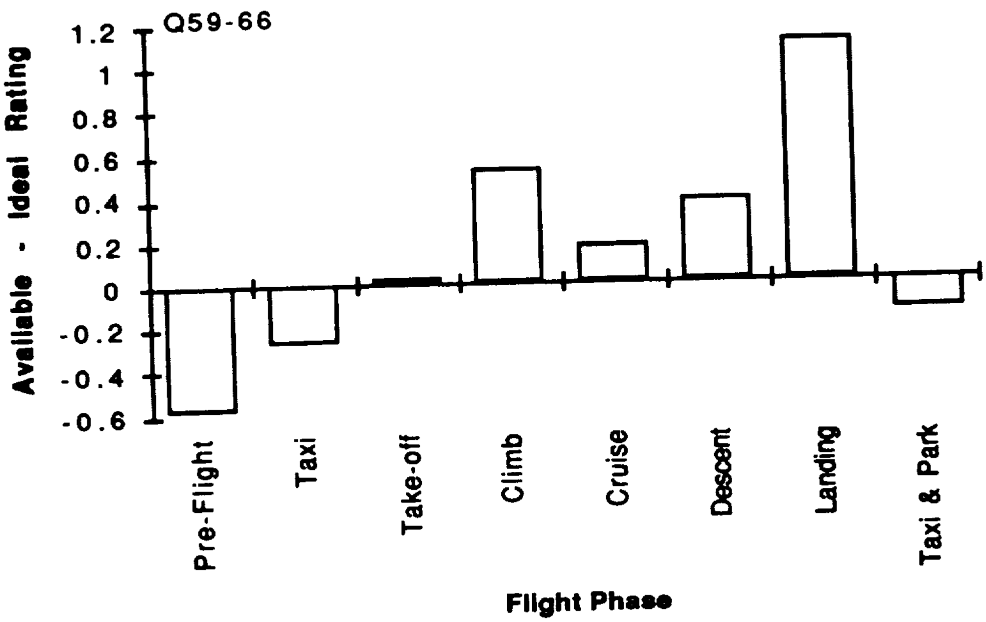

Figure 4b. Satisfaction with level of automation for different flight phases. A positive rating means that the automation level available is higher than the respondent's ideal level.

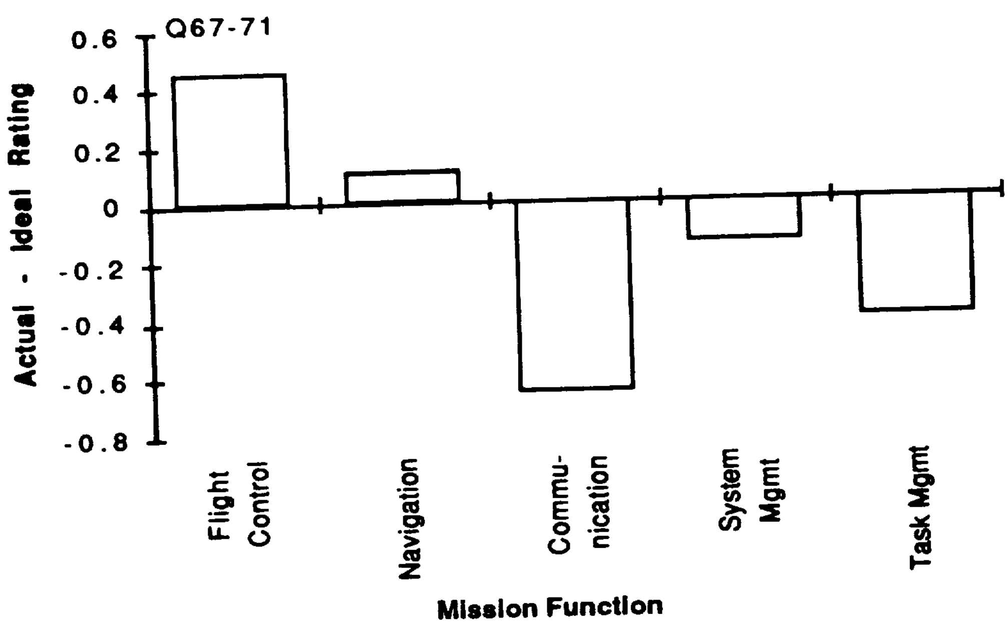

Figure 4c. Satisfaction with level of automation for different mission functions. A positive rating means that the automation level available is higher than the respondent's ideal level.

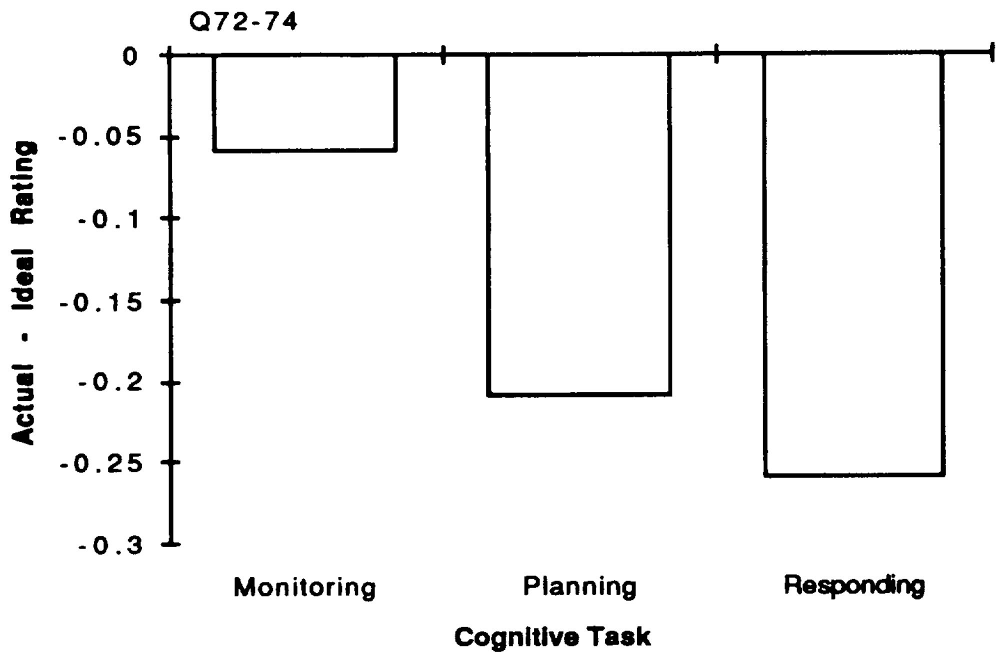

Figure 4d. Satisfaction with level of automation for different cognitive tasks. A positive rating means that the automation level available is higher than the respondent's ideal level.

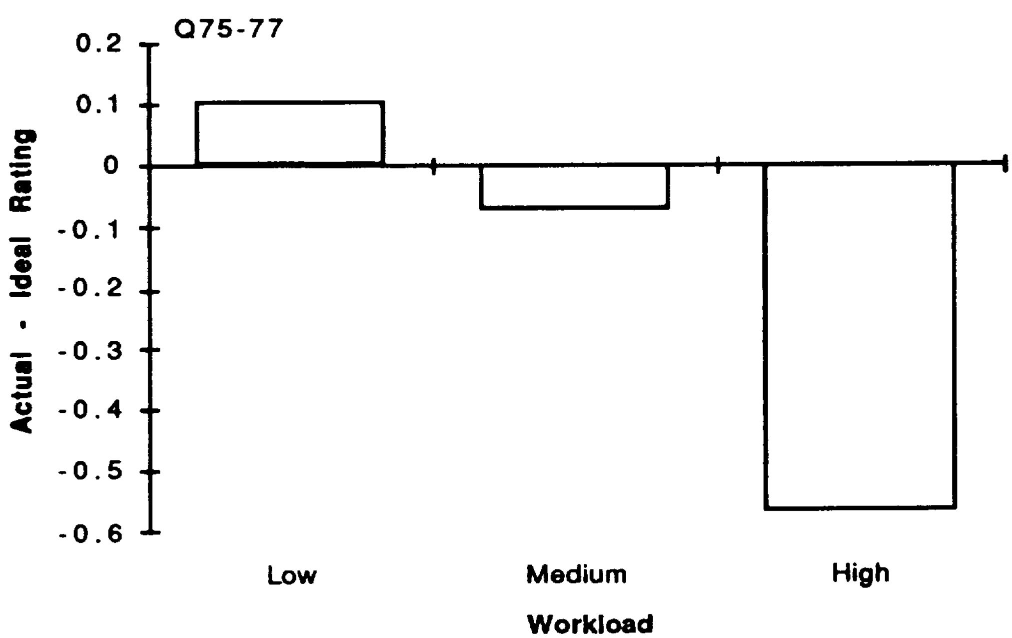

Figure 4e. Satisfaction with level of automation for different workloads. A positive rating means that the automation level available is higher than the respondent's ideal level.

The following categories were found to be significantly below the ideal in the level of automation available to aid pilots (p <.05, adjusted): preflight and taxi (see *flight phase*, Figure 4b); communication and task management (see *mission function*, Figure 4c), responding, defined as performing goal-oriented actions (see *human information processing task* Figure 4d); high workload (see *workload*, Figure 4e). This finding, of the need for more automation to deal with pre-flight and taxi, communication and task management, and high workload situations, reinforces the message of earlier sections—a plea for attention to the crew's mental workload.

Amount of Automation

In a series of questions (Q81-85), subjects were asked to rate the amount of different types of automation on their current aircraft (part 'a') and then to indicate whether ideally, they would want less, the same amount, or more automation than they currently have (part 'b'). The average ratings for the two parts of the questions are shown in Figures 5a and 5b, respectively.

The results of part 'a' (see Figure 5a) showed that subjects felt that their aircraft had at least a "moderate" amount of automation in all categories. The pilots felt they had the largest amounts of automation for aircraft control (mean of 4.34) and systems control (4.18.). Information automation, defined as automation that informs the pilots about the aircraft and systems states, operations, procedures, regulations, and location of the aircraft and relevant entities in the environment, was also considered prevalent (3.94). Pilots felt they had a lower amount of protective automation (3.52). Decision automation, defined as automation that aids the pilot in selecting alternatives and making choices, came out lowest (3.11).

An F test for repeated measures indicated that the overall difference between automation categories was significant, $F(4, 440)=59.169$, $p<.0001$. A Tukey test indicated that each of the ratings for the different automation categories differed from the others ($p<.05$), with the exception of one pair, aircraft control and systems control, which were statistically indistinguishable ($p>.05$).

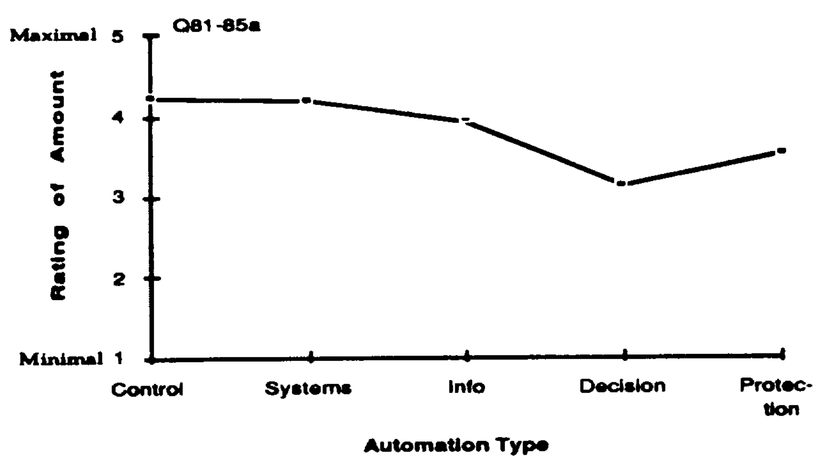

Figure 5a. Amount of different types of automation in aircraft.

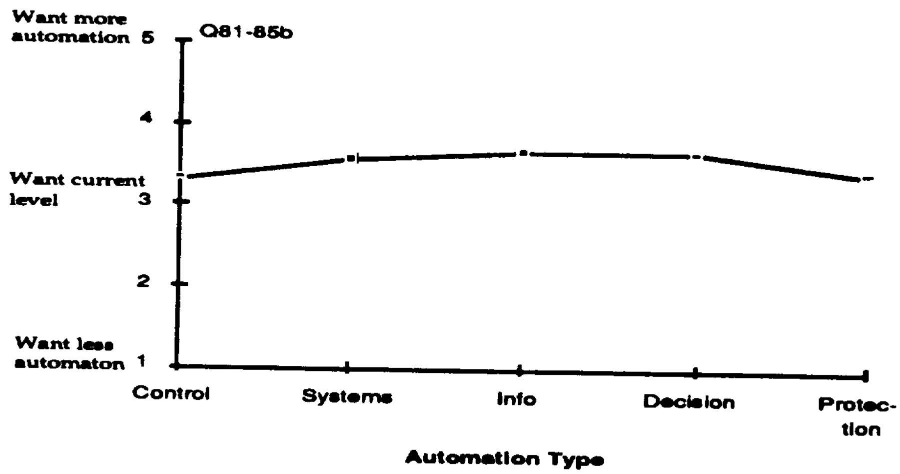

Figure 5b. **Desire for less, same amount, or more automation.**

The results for part 'b,' in which pilots indicated the ideal amount of automation with respect to their current aircraft are shown in Figure 5b. On this scale, a 3.0 indicates a belief that current levels are ideal, a score of more than 3.0 means that more automation is desired and a score below 3.0 means that less is desired. The average ratings were all slightly above 3.0, indicating that pilots would prefer, ideally, to have slightly more automation than they currently have in all categories. The two categories that came closest to the ideal were aircraft control (3.3), followed by protection (3.4) automation. Although pilots indicated in part 'a' that they did not have a large amount of protective automation on their aircraft, they evidently felt that the amount was close to ideal. The biggest needs were for more information (3.7), decision (3.6), and systems (3.6) automation.

An analysis of variance for repeated measures showed a significant effect of category, $F(4,440)=8.457$, $p<.0001$. A Tukey test confirmed that the need for information and decision automation was significantly greater ($p<.05$) than the need for more control or protective automation. The need for systems automation was also significantly greater ($p<.05$) than the need for more control automation.

Phenomenological Experiences

In questions 1-26 subjects rated different automation systems on seven dimensions (parts 'a' through 'g'). Questions 27-31 were similar, except that subjects rated different cockpit alerts on six different dimensions (parts 'a' through 'f'). Tables B1-B13 in Appendix B show the order in which the components fell on each of the dimensions, respectively. All 132 subjects were included in this analysis, but subjects were not required to answer all questions. They were requested to leave a blank if they were not familiar with the component. Overall, subjects left 6.8% of the components unrated (data showing which components were omitted will be presented in a subsequent section concerned with aircraft differences).

Ratings were averaged across subjects and automation components for each dimension queried. Before the averages were calculated, the rating scales for some of the questions (parts a, c, d, and f of Q1-26) were reversed from the way they appeared on the questionnaire, so that a '5' always indicated the desirable end of the dimension.

The average rating across all components and subjects is shown in Table 6 for each of the dimensions. It is clear from these data that subjects were favorably inclined towards the automation systems on their flight deck, though they had some reservations. On questions 1-26, they found the automation components to be unobtrusive (4.00), predictable (3.97), extremely helpful for reducing workload (3.82), and they were inclined to use them whenever appropriate (4.39). On the other hand, they were close to the midpoint when it came to the feeling that they were controlling the flight rather than managing the automation (3.25, where '5' = high controlling), and the feeling that they were focusing on the flight rather than on the automation (3.61, where '5' = attention to flight).

For questions 27-31, subjects clearly trusted the alerts (4.27) and found them compelling (4.87, see Table 6). They gave lower ratings, however, to the ease of returning to tasks after an alert (3.50), degree to which the alert can be responded to without thought (3.52), and immediacy of knowing what the problem is (3.65). While these responses were on the positive half of the scale, they were close to the borderline.

To assess whether any of the separate dimensions might have a common basis from the pilots' perspective, correlations were calculated for each of the dimensions in Q1-26 and Q27-31, respectively, paired with each of the others. The two correlation matrices are presented in Tables 7a and 7b.

For Q1-26, all but one correlation were significant (see Table 7a). The three highest correlations were for: 1) the two dimensions describing the automation (unobtrusiveness 'c' and predictability 'e', $R=.7050$, $p<.001$); 2) the two describing the pilot (situation awareness 'b' and workload reduction 'f', $R=.6698$, $p<.001$); and 3) the two describing the interaction between pilot and automation (attention on flight/automation 'a' and feeling of controlling/managing 'd', ($R=.6254$, $p<.001$). These three clusters, while not completely independent, provide a useful structure for thinking about automation experiences.

Table 6
Average Rating of Automation Components on Each Dimension

Q1-26 and Q27-31

Questions	Dimension	Average Across Components
1a-26a	attention on flight*/automation	3.61
1b-26b	understanding of the big picture	3.79
1c-26c	unobtrusiveness	4.00
1d-26d	controlling*/managing	3.25
1e-26e	predictability	3.97
1f-26f	workload reduction	3.82
1g-26g	frequency of use	4.39
27a-31a	attention-getting	4.87
27b-31b	trust in alert	4.27
27c-31c	knowing what the problem is	3.65
27d-31d	ability to respond without thought	3.52
27e-31e	ease of returning to task after alert	3.50
27f-31f	scarcity of alert occurrences	3.65

Note. Rating scales for some dimensions were reversed from the way they appeared in the questionnaire so that 5 = the favorable end of the continuum for all dimensions. A * is used to indicate the favorable end where it is not obvious from the dimension name.

Table 7a
Correlation of the a-g Components for Q1-26+

	Attention to Flight 1-26a^r	Situation Awareness 1-26b	Unobtrusive 1-26^{r}c	Feeling of Controlling 1-26d^r	Predictable 1-26e	Workload Reduction 1-26f^r	Frequency of Use 1-26g
1-26a^r	1.00	.2871**	.4651**	.6254**	.4388**	.2764**	.3229**
1-26b		1.00	.3213**	.2093*	.3637**	.6698**	.1870*
1-26c^r			1.00	.4124**	.7050**	.4709**	.5356**
1-26d^r				1.00	.3330**	.1567	.2384**
1-26e					1.00	.4121**	.4544**
1-26f^r						1.00	.2304**
1-26g							1.00

+Seven component scores (averaged across Q1-26) were entered for each subject.

^{r}The 1-5 scale was reversed from the way it appeared in the questionnaire so that '5' would uniformly represent the favorable pole.

*Significant at the .05 level. **Significant at the .01 level.

Table 7b

Correlation of the a-f Components for Q27-31+

	Attention Getting 27-31a	Trust 27-31b	Know Exactly 27-31c	Can Respond Automatically 27-31d	Easy to Resume 27-31e	Frequency of Alert 27-31f
27-31a	1.00	.3757**	.1729*	.1678	.0979	-.2022*
27-31b		1.00	.3779**	.2586**	.2523**	-.3316**
27-31c			1.00	.4578**	.3138**	-.1221
27-31d				1.00	.2582**	-.2249*
27-31e					1.00	-.2493**
27-31f						1.00

+Six component scores (averaged across Q27-31) were entered for each subject.

*Significant at the .05 level.

**Significant at the .01 level.

The high correlation found between the two questions intended to explore the direct/mediated experience (attention on flight/automation; feeling of controlling/supervising) suggests that this distinction has psychological validity. Tables B1 and B4 in Appendix B show the components listed in order of the ratings they received on these dimensions. Components at the top of the list were rated highest on allowing attention to the flight (or a feeling of controlling the flight), while those at the bottom were highest on directing attention to the automation (or a feeling of managing the automation).

An examination of the lists in Tables B1 and B4 in Appendix B substantiates that the 'a' and 'd' dimensions were highly correlated. In both cases, the types of automation at the top and bottom differed strikingly from each other. At the top of both lists, representing the extreme direct experience (attention to flight and feeling of controlling the flight) are: the hydraulic amplification of inputs, auto ground spoiler, fly-by-wire controls, and automatic rudder. As would be expected, the ratings confirm that these controls require little attention and do not detract from the flying experience. At the bottom, representing the extreme mediated experience (attention to the automation, feeling of managing the automation), by contrast, are: FMC-flight planning FMC-auto manage, FMC LNAV and VNAV, ACARS, and subsystem schematics, as well as the auto landing. With the exception of auto landing, these components either require complex pilot input as previous studies have suggested (Sarter & Woods, 1994), or are complicated enough to distract attention away from the flight.

The inclusion of auto landing in this group of highly interactive systems rather than with the other flight control systems at the top of the list is revealing. It suggests that landing with this system does not free the pilot from doing the job, at least not mentally. The lack of familiarity with the system and the fact that this flight phase is extremely critical may be factors contributing to this feeling.

The correlation between situation awareness and workload reduction also is of interest. Note that the correlation is a positive one: Components listed as resulting in higher situation awareness generally were rated high in workload reduction (see Tables B2 and B6 in Appendix B). This finding is very encouraging since one might expect situation awareness to incur a workload penalty—that is, it takes effort and attention to develop and maintain situation awareness. The fact that automation components generally seem to increase situation awareness without increasing workload is a somewhat unexpected benefit. There are notable exceptions however. The FMC and TCAS traffic display were rated as providing high situation awareness, but also were rated as high in workload (see Tables B2 and B6 in Appendix B). The improved situation awareness with these components does come with a penalty. The automatic rudder and hydraulic amplification of inputs were rated low in workload but also low in situation awareness. These represent the classic case of automating functions that take the pilot out of the loop which results in their being less involved and informed than if the function were not automated.

For Questions 27-31, most of the correlations between dimensions were significant (see Table 7b). However, there was no evidence for any higher-order dimensions. It is interesting to note the strong negative relationship between trust and frequency of alert ($R=-.3316$); it is very likely higher frequency means higher false alarm rates, which obviously reduces trust in the alert. The alerts that are trusted the least (master caution and warning and TCAS traffic advisory), are also the ones that require the most thought in responding (see Appendix B, Tables B9 and B11).

Aircraft Differences

The effect of flight deck experiences on pilot attitudes and opinions was examined by comparing survey responses of the pilots in the three aircraft groups (Boeing 747-400, Douglas MD-11, and Airbus A-320). These flight decks are thought to vary along a dimension of increasing technology, from Boeing, to Douglas, to Airbus. Evidence in support of this difference was sought by examining the number of components in questions 1-26 that subjects were able to rate. Subjects were instructed to leave a question blank if the aircraft that they currently fly did not have that automation component. Because the list was constructed to be a representative inventory of the types of automation systems found on advanced flight decks, the number of blanks serves as at least a rough measure of the extent of the automation on the different aircraft. The average number of blanks was : Boeing 2.8, Douglas 1.4, Airbus 1.1. An analysis of variance showed a significant effect of aircraft, $F(2, 129)=11.258$, $p<.0001$. A

Tukey test revealed that Boeing had significantly more blanks than either Airbus or Douglas. However, the latter two did not differ from each other (Tukey $p>.05$). Using blanks as a measure, we can at least be confident that Boeing is less automated than the other two groups.

Philosophy. There were no overall group differences in responses to the philosophy questions (Q32-42; 46-48), $F(2,129)<1$, $p>.05$. The average human-centeredness scores were: Boeing 3.55 Douglas 3.54, Airbus 3.49. However, examination of individual questions revealed a significant difference on question 41, which concerned attitudes towards envelope protection, $F(2,129)=7.728$. $p<.0007$. A Tukey test indicated that the mean for the Airbus pilots (2.67) was significantly ($p<.05$) less human-centered than the mean for either the Boeing (3.45) or Douglas pilots (3.59), who did not differ from each other ($p>.05$). On this question, the Airbus pilots were the only ones to favor an envelope system that actually prevented envelope exceedence as opposed to just providing an advisory. This difference is interesting because it reflects the envelope features available on the respective flight decks.

Good/Trustworthy Automation. There were no obvious group differences in rankings of the attributes for good and trustworthy automation in questions 51 and 52. The average ranking for each of the attributes was similar across groups.

Physical and Mental Workload. Analysis of the workload ratings in question 55 produced one of the two results (see next section) in which the Douglas pilots appeared to differ from the others. In this case, there was a significant interaction between aircraft type and flight phase, $F(12, 648)=2.639$, $p<.002$, with the Douglas pilots reporting a significantly higher overall workload than the other pilots for two flight phases, approach and landing (Tukey, $p<.05$). These results are uninterpretable, however, because of the confounding with background. They may reflect the conservatism of an older and more experienced group of pilots, rather than a real aircraft difference.

Levels of Automation: Promise and Concerns. Analysis of the promise ratings for the three different levels of automation in question 78 showed no aircraft differences. The concern ratings, however, were similar to the workload ratings discussed above in showing a higher overall concern from the Douglas pilots than from the others at every level, $F(2, 108)=6.922$, $p<.002$; Tukey$<.05$). Again, these results may reflect a conservative bent rather than real aircraft differences.

Ideal Level of Automation for Different Situations. The analysis of actual versus ideal levels of automation across different situation attributes, encompassing questions 56-75 yielded clear and robust group differences. Figures 6a-6e show the satisfaction measures (actual minus ideal rating)) for the categories of each of the situation attributes. It is clear from the figures that in every case in which there was a negative bar (indicating a maximum available level of automation that was less than ideal), pilots of the Boeing 747-400 responded more negatively than did the other two groups. These trends were confirmed by conducting an analysis of variance for each situation attribute with aircraft as a between-subjects variable and category and judgment (actual, ideal) as within-subjects variables. In all but one case (Q72-74), a significant three-way interaction was found, confirming that for those categories that were rated as not ideal, Boeing pilots tended to perceive their available level of automation as being farther below the ideal than did the others.

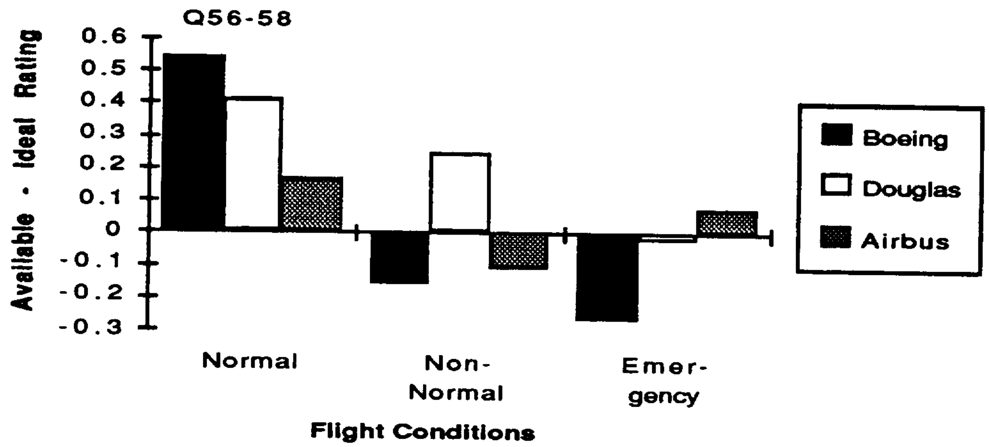

Figure 6a. Satisfaction with level of automation for different flight conditions; aircraft differences.

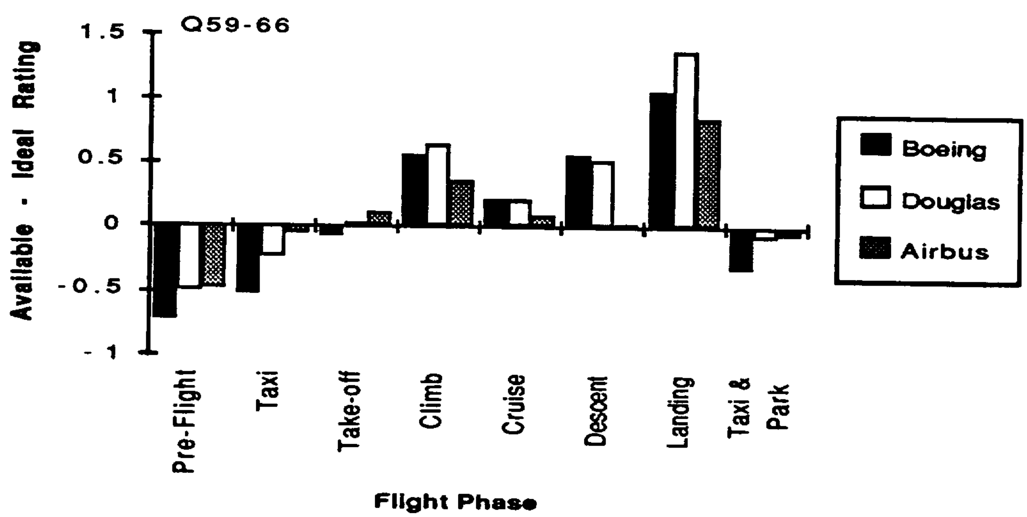

Figure 6b. Satisfaction with level of automation for different flight phases; aircraft differences.

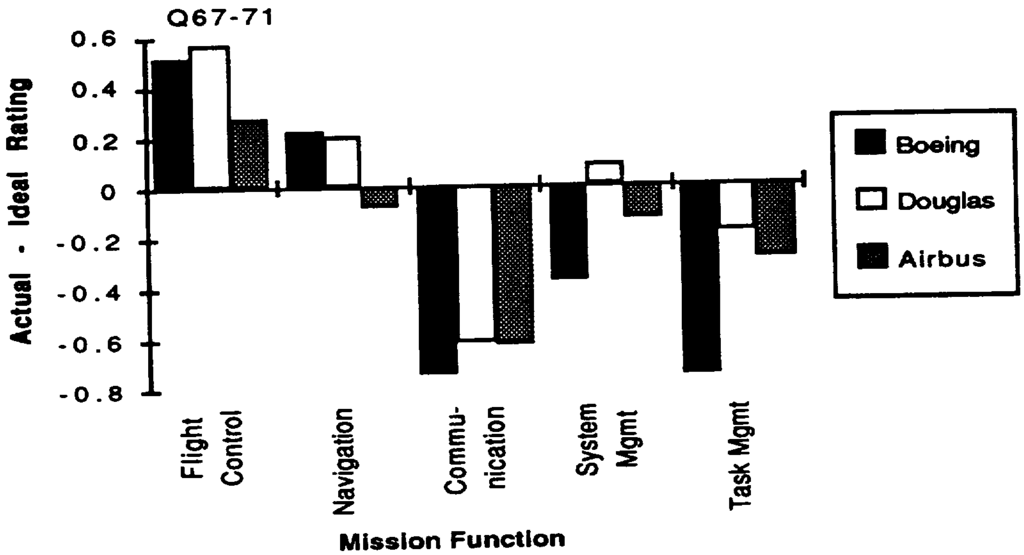

Figure 6c. Satisfaction with level of automation for different mission functions; aircraft differences.

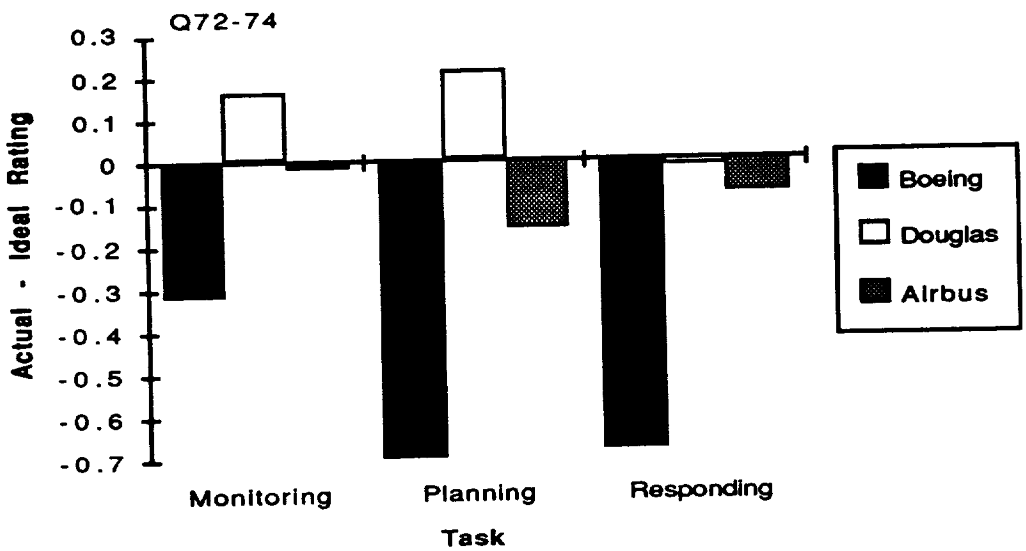

Figure 6d. Satisfaction with level of automation for different cognitive tasks; aircraft differences.

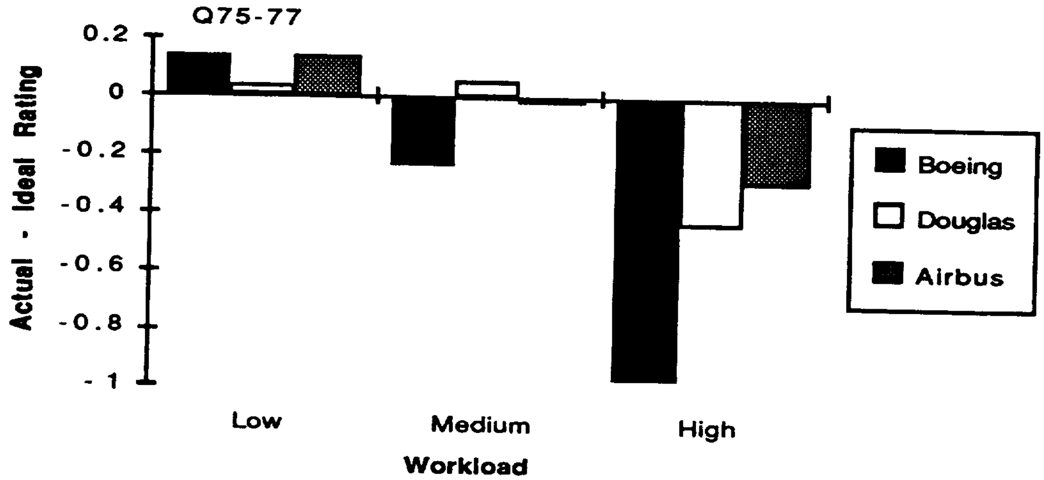

Figure 6e. Satisfaction with level of automation for different workloads; aircraft differences.

The details of these interactions are:

Q56-58, (see Figure 6a). The closer the situation is to an emergency, the more pilots, especially Boeing pilots, could use a higher level of automation, $F(4,216)=5.272$, $p<.0005$.

Q59-66, (see Figure 6b). A higher level of automation is desired, especially by Boeing pilots, at the beginning (pre-flight, taxi) and very end of the flight, (taxi & park, but not landing), $F(14, 756)=2.366$, $p<.004$.

Q67-71 (see Figure 6c). A higher level of automation would be helpful for communication, system management, and task management, especially for Boeing pilots, $F(8,432)=2.369$, $p<.02$.

Q72-74 (see Figure 6d). This question failed to show a three-way interaction. However, a significant two-way interaction, between aircraft and judgment (actual, ideal) confirmed that Boeing pilots rated the maximum available level of automation further below the ideal than the others for cognitive tasks in general, $F(2,108)=8.913$, $p<.0003$.

Q75-77 (see Figure 6e). The higher the workload, the more pilots, especially in the Boeing group, feel the need for a higher level of automation $F(4,216)=2.621$, $p<04$.

To be sure that these group differences in satisfaction with automation levels were not an artifact of certain uncontrolled variables, a reanalysis of the data was carried out using a subset of the data. To eliminate the confounding factors of seat and age, only the data from the Boeing and Airbus First Officers was carried out (N=23 per group). (A similar analysis for Captains was not possible because of insufficient numbers in the Boeing sample, see Table 2). The results of the First Officer analysis supported the results obtained for the larger sample. Three out of the four three-way interactions that had been significant were still significant ($p<.02$); the one that did not reach significance (Q56-58) showed a trend in the right direction. In addition the two-way interaction in Q72-74 remained significant ($p<.002$). One possible explanation of the consistently larger negative gaps in the available minus ideal level of automation ratings for the Boeing pilots is the lower available level of automation reported by these pilots.

<u>Amount of Automation</u>. Ratings of the amount of automation in their current aircraft (Q81-85a) for the three pilot groups are shown in Figure 7a. It is clear from the figure that the Boeing pilots felt they had lower amounts of automation, than did the other pilots. This difference was most pronounced for protective automation, where A-320 pilots reported the most automation and 747-400 pilots reported the least. The results reinforce the original assumption that the Boeing 747-400 is less automated than the other two aircraft and suggest that the Airbus A-320 is more automated than the MD-11 at least in the area of protective automation.

An analysis of variance with aircraft type as a between-subjects variable and automation type as a within-subjects variable supported these trends by showing a significant main effect of aircraft group, $F(2,108) = 11.31$, $p<.0001$, a significant main effect of automation type, $F(4,432)=62.44$, $p<.0001$, and a significant interaction between aircraft group and automation type, $F(8,432)=4.038$, $p<.0001$. A Tukey test revealed no significant differences between groups for control and systems automation. For information and decision automation, 747-400 pilot ratings differed significantly from those of MD-11 pilots ($p<.05$) and marginally significantly ($p<.10$) from those of A-320 pilots. All three aircraft groups differed significantly from each other in the perceived amount of protective automation ($p<.05$).

Ratings of the ideal amount with respect to the current amount (Q81-85b) are shown in Figure 7b. It is evident from the figure that Boeing pilots expressed a greater desire for more automation than did the other two groups, especially in the categories of systems, information, and decision automation.

An analysis of variance confirmed these trends by showing a marginally significant main effect of aircraft type (F, 2,108)=2.777, $p<.10$, a significant main effect of automation type (F4,432)=8.644, $p<.0001$, and a significant interaction between aircraft and automation type, $F(8, 432)=2.214$, $p<.03$. A Tukey test revealed only one significant difference between groups: 747-400 pilots' desire for more information automation was significantly greater than that of MD-11 pilots ($p<.05$). In addition, a trend toward greater desire on the part of 747-400 pilots was found for systems automation, where the difference between 747-400 pilots and MD-11 pilots was marginally significant (p<.10), and for decision automation, where the difference between 747-400 pilots and A-320 pilots was marginally significant (p<.10).

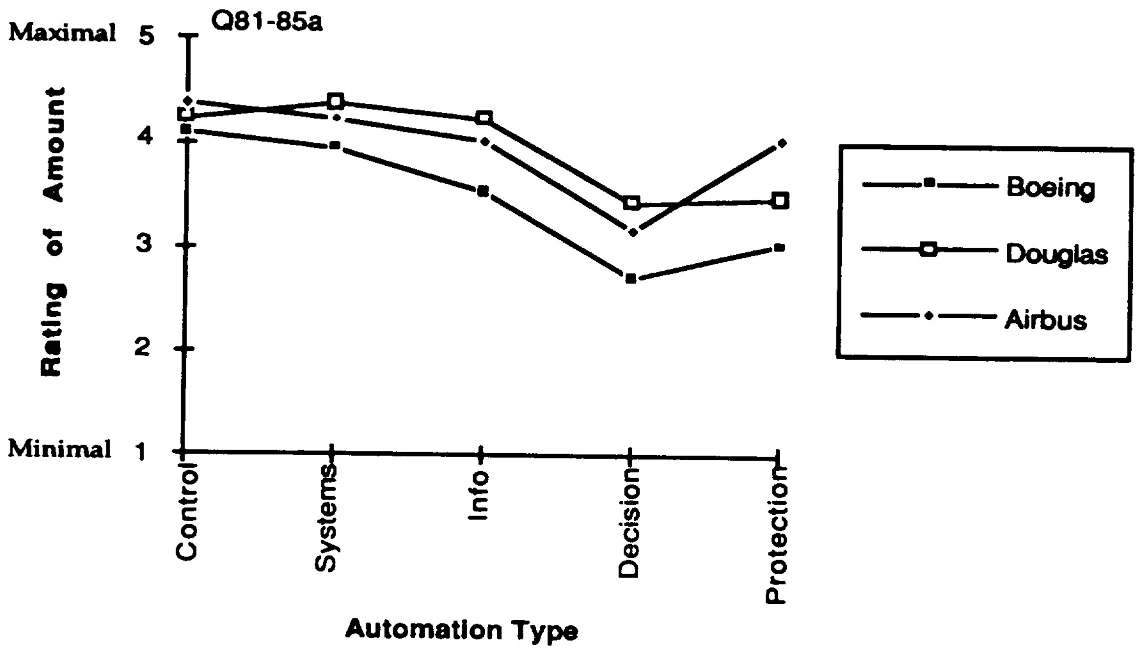

Figure 7a. Amount of different types of automation; aircraft differences.

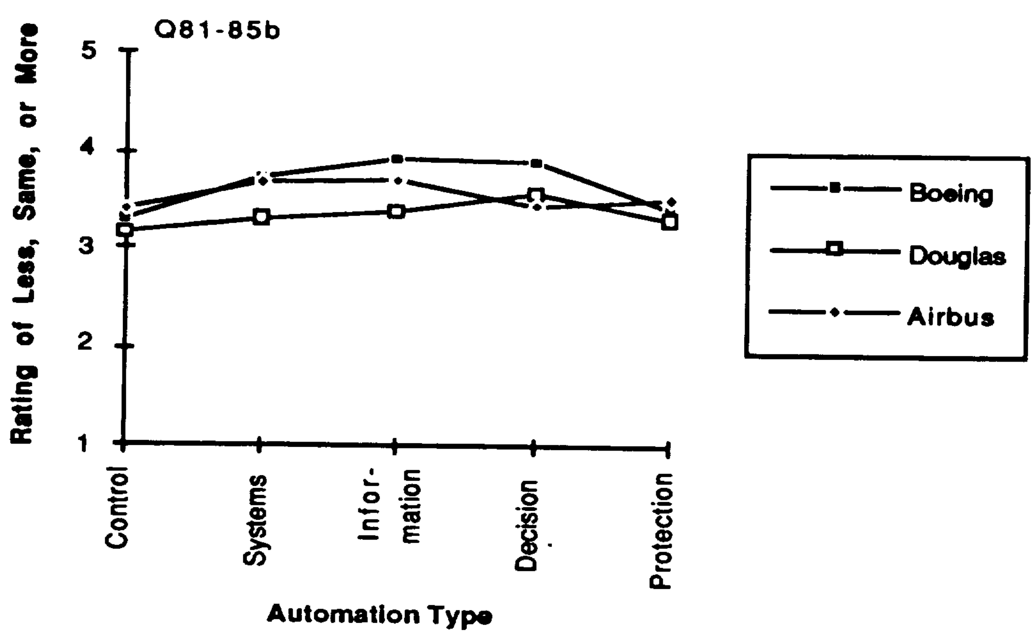

Figure 7b. Desire for less, same amount, or more automation; aircraft differences.

An analysis of variance with data from First Officers only (23 Boeing and 23 Airbus) supported the conclusions about group differences in ratings of the amount of automation on the current aircraft (part 'a') but not of the desire for a greater or lesser amount of automation (part 'b'). In part 'a,' the main effects of aircraft and automation type were significant ($p<.0002$), as was the interaction between aircraft and automation type ($p<.02$). Only the main effect of automation type was significant ($p<.02$) in part 'b.'

Phenomenological Experiences

No group differences were apparent in the ranking of the components in questions 1-31 on any of the scales.

DISCUSSION

Philosophy

Pilots, as expected, generally endorse human-centered positions about use of automation. The notable exceptions were the opinion that pilots, and not design, are the biggest obstacle to flight safety and the opinion among A-320 pilots that automatic systems (envelope protection) should prevent the aircraft from exceeding its performance envelope rather than providing alerts and allowing the pilot to override soft limits. This position among A-320 pilots may be an indication that pilots' philosophy is influenced to some extent by their training and aircraft design philosophy.

Good/Trustworthy Automation

Pilot rankings of the importance of eleven automation features or attributes were highly correlated for "good" and for "trustworthy" automation, indicating either that pilots do not distinguish between good and trustworthy, or that the same automation attributes are important for both. In both cases, pilots indicated that they want automation to be dependable, predictable, simple and comprehensible. It is less important for it to be flexible, error-resistant, accountable, adaptable, and error-tolerant. The message from pilots to designers seems to be: Don't try to be fancy, just make sure it I can use it and it works.

Physical & Mental Workload

Pilots' ratings of differences in mental and physical workload between glass and conventional cockpits were phase dependent, with higher relative workloads in glass cockpits at either end of the flight than in the middle. Workload was rated as being much higher than it had been in conventional cockpits during preflight and similar to how it used to be for taxi and approach. Reductions in workload with glass cockpits were found for take-off, climb, cruise and landing, where ratings were lower than for conventional cockpits (rating < 3.0). These results suggest that efforts to reduce workload during pre-flight, when activities such as system initialization and data entry must be performed, and during taxi, approach, and landing, where the mental workload is as high or higher in glass cockpits as in conventional cockpits, might be beneficial.

Levels of Automation: Promise and Concerns

Pilots believe that fully autonomous and shared pilot/automation performance clearly have greater benefit than unassisted performance. The fully autonomous level has more benefit than the shared performance level for workload reduction, providing more precise data, and increased airline cost effectiveness, while the shared level has more benefit than the fully autonomous for keeping pilots involved and informed, and improving their performance and situation awareness. However, both automation levels have greater disadvantages or concerns than unassisted performance. Pilots had greater concerns with the fully autonomous level than with the shared performance level. This suggests overall that the shared performance level, which is advocated by the human-centered approach, holds the most promise without the accompanying concerns.

Ideal Level of Automation for Different Situations

As expected, pilots' perception of current and ideal levels of automation depend on important aspects or attributes of the situation in which it is used. There were several situation categories for which pilots would ideally use a higher level of automation than was available on their current aircraft. These situations included: Pre-flight and taxi phases of flight; communication, systems management and task management functions; information processing tasks concerned with planning and responding; and high workload conditions. The design implication is for higher levels of automation in these areas. There were other situations where pilots would use a lower level of automation than is available. These situations included: normal flight; climb, cruise, descent and landing phases of flight; and flight control functions. The design implication is that in certain cases lower levels of automation should be available and operationally sanctioned even if higher levels exist. It should be noted that current aircraft do make lower levels of automation available for these situations.

Amount of Automation

Pilots generally want more of each of the five types of automation that were described. MD-11 and A-320 pilots described their aircraft as having more automation in each category than did the B747-400 pilots. The only difference between the MD-11 and A-320 groups was that A-320 pilots rated their aircraft as higher in amount of protective automation. A-320 and MD-11 pilots felt that the ideal amount of automation was closer to what they had than did B747-400 pilots (although, caution must be taken in interpretation of the analyses of aircraft differences because of the previously described biases in the demographics of the groups).

Phenomenological Experiences

Automation components on current aircraft vary widely on the various dimensions that were explored in terms of obtrusiveness, workload, situation awareness, predictability, and sense of attending to and performing an underlying function versus managing the automation. As expected, components requiring significant input or monitoring, such as the flight management computer and ACARS are more obtrusive, workload intensive, and result in the sense of managing the automation, than fairly autonomous systems such as automatic ground spoilers and automatic rudders. Interestingly, the autoland system looks more similar in profile to the flight management computer than to the automatic rudder. The results of these questions indicate that many automated systems provide increased situation awareness without a workload penalty. The penalty in obtrusiveness, workload, and the sense of managing the automation that occurs for some components requiring significant pilot-component interaction highlights the importance of making pilot interfaces to these devices as intuitive and simple as possible.

Aircraft Differences

There was much evidence that the A-320, MD-11 and B747-400 differ in the level and amount of automation they possess. Generally, pilots indicate they are satisfied with existing automation, and welcome more, particularly for those situations in which they are not provided with much automated assistance currently. There is definitely no indication that there is an "over-automation" problem with any of the three aircraft types, though generally pilots' philosophy seems to indicate they would be more comfortable with a shared pilot-automation performance level than a fully autonomous level of automation. Pilots' philosophy seemed generally consistent across groups of pilots flying different aircraft types, with the notable exception that A-320 pilots prefer hard limits for envelope protection and MD-11 and B747-400 pilots prefer soft limits.

CONCLUSION

The pilots we have surveyed have presented an interesting portrait of the value of existing automation and the directions that they wish to see flight deck design take in the next generation of aircraft. They are appreciative of the automation in current generation glass cockpits and claim to use it whenever it is appropriate. They want their automation to be simple and reliable and to produce predictable results. Not only are these features of automation equated with trustworthy automation, but when the trade-offs are between flexible and adaptable vs. simple and reliable, they still opt for simplicity. Furthermore, in response to questions about the extent to which they felt in control of the aircraft vs. controlling the automation itself, they revealed that simple and reliable is, in some ways, related to how little attention they need to pay to it. The results also identify the kinds of systems in use today that provide this kind of reliability.

Although we began this survey with the objective of trying to understand the contrast between human-centered and full automation, we come away from it with a slightly different perspective. To be against human-centered automation is to be against apple pie. The issues instead are to understand, from the pilots' point of view, how far they want to go in introducing automation and what features need to be present to maintain situation awareness, to assure human control of the integrity of flight and to promote safety and airline cost-effectiveness. The answer provided in these surveys is that the greatest promise for further gains is obtained in moving from manual systems to shared systems, as contrasted with moving from shared control to autonomous control.

Situation awareness, in the pilots' opinions, is supported by the variety of sophisticated navigation, planning and system status displays that are in use today and they report that these are among the most frequently used aspects of automation. The majority of pilots surveyed felt that the biggest needs for additional automation were to further alleviate the mental workload demands imposed on them in time-constrained decision making situations. Although there were differences of opinion among the pilot populations that had experience in different aircraft, the similarities were much greater than the differences. In the aggregate they indicated the desire for more, and higher levels of, automation. When automation level desires were sorted by situation aspects such as flight phase, and mission function, those aspects which posed the greatest mental workload demands were the ones that were highlighted for higher levels of automation.

There is an irony and a challenge in the implications of these two views. On the one hand they would like new automation to be simple and reliable, but they need it to support the most complex part of the job—the cognitively demanding or busy situations.

Finally, a word should be said about the value of this survey from a theoretical point of view. In addition to clarifying pilot preferences for future design efforts, the survey gave a boost to efforts by researchers to develop a scientific basis for a design philosophy. The survey results should increase confidence that the basic concepts and distinctions, or the building blocks that will be needed, are starting to be put into place. For example, user support for the notion of a human-centered philosophy (Billings, 1991; Norman & Orlady, 1989; Rouse, Geddes, & Curry, 1987; Wiener, 1989) was confirmed by the results of the study. Pilots endorsed the philosophy in the sense that they indicated their belief in the need for the pilot to remain in charge, the impossibility of foreseeing all procedural requirements, and the desirability of automation that advises rather than commands.

The notion of different levels of automation (Billings, 1991; Regal & Braune, 1992), while just touched upon in the present survey and in need of further refinement, nevertheless was supported by the clear differentiation of advantages and disadvantages for the levels examined. The next step would be to explore in a similar way a more sophisticated multidimensional scheme for describing levels of automation. Riley's (1989) characterization of different levels in terms of degree of machine intelligence and authority would be a good candidate.

Related to the notion of levels is the idea that the ideal level of automation will depend on the situation, defined in terms of its normalcy or non-normalcy, the flight phase, the functions that need to be carried out, the specific tasks that need to be accomplished and the cognitive resources required (Deutsch, Pew, Rogers, & Tenney, 1994). The results of pilot assessment of ideal levels under variations of these circumstances supported this taxonomy of situations and situation requirements. The next step would be to examine combinations of these attributes, for example, the ideal level of automation for decision making under emergency conditions in the landing phase.

The idea of creating a taxonomy of automation experiences was supported by the results of the component ratings. The scheme that emerged from the data was the following. Pilots seem to categorize their experiences along three dimensions. The first is the way in which they perceive the automation itself (e.g., predictable, unobtrusive). The second is the way in which the automation modifies their task (e.g., improved situation awareness, lower workload). The third is how they perceive the task (e.g., controlling vs. managing, attending to flight vs. automation). The latter category of interaction variables is a concept that has been discussed often in the literature (Hollnagel, 1991; Wiener, 1989), but now has a stronger empirical basis.

In short, ideas that were culled from hours of immersion in the literature, honed by the rigors of questionnaire production, digested by pilots, and subjected to the vagaries of statistical analysis, proved to be remarkably robust.

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APPENDIX A

Pilot Background Questionnaire
&
Automation Survey

Pilot Background Questionnaire

1. General Information

Full Name: ____
First, Middle, Last

Address: ____
Street and Number, or P.O. Box

____
City, State, Zip Code, and Country (if not USA)

Home Phone: (______) __________ Work Phone: (___) ___________
Area Code Number Area Code Number

Age _____

2. Current Position

Airline: ______________________ No. of years ___________
Seat: ______________________ No. of years ___________
Captain, First Officer, Engineer, etc.
Airplane(s): 1. ______________________ No. of years ___________
2. ______________________ No. of years ___________

3. Past Experience

Years Flying Commercial (approximate): ___________
Years Flying Military (approximate): ___________
Total Hours Flying (approximate): ___________
Total Hours Flying as Pilot-in-Command (approximate): ___________
Years of formal education: ________ (e.g. high school graduate = 12)

Please list the aircraft on which you have experience, beginning with that currently flown. Check the appropriate boxes under hours in type and simulator hours to indicate the number of hours in each. Check the I/CA column if you are/were an instructor (I) or check airman (CA) on an aircraft. Check the last column for any aircraft for which you are currently type rated.

Aircraft Type	Hours in Type			Simulator Hours			I/CA	Currently
	< 300	300-1000	> 1000	0	< 50	> 50		Type Rated?

Survey of Pilots of Advanced Automation Aircraft on Philosophy Issues Related to Design and Use of Flight Deck Automation

NASA Langley Research Center

Section 1

This section deals with your experiences with particular automation components. In answering these questions, please answer primarily for the aircraft you currently fly. If your aircraft does not have a particular automation component, then leave the question blank. Most of the labeling of automation components is based on Boeing terminology. If you call the component by another name, please write that label on the questionnaire. If you are not sure what component we are trying to identify, please contact one of the researchers at the numbers provided on the cover sheet.

Please rate each of the automation components on the scales indicated. The labels at the ends of each scale describe the end points of the scale. The midpoint (3) represents a neutral rating. For example, for the first item, if your attention in flying an aircraft with automatic braking were equally focused on the flight and on the automation, you would circle 3. If your attention were slightly more focused on the automation than it was on the flight, you would circle 4. When completing statements (b) and (f), which ask for relative information (e.g., higher or lower, shallower or deeper), please answer in relation to the case in which you do not have or use that automation component.

1. When I use automatic braking:

(a) My attention is focused on the	flight	1	2	3	4	5	automation
(b) My understanding of the big picture is	shallower	1	2	3	4	5	deeper
(c) The automation is	unobtrusive	1	2	3	4	5	distracting
(d) I feel as though I am	controlling the aircraft	1	2	3	4	5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1	2	3	4	5	ease
(f) My overall workload is	lower	1	2	3	4	5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1	2	3	4	5	always

2. **When I use the automatic engine start:**

(a) My attention is focused on the	engine	1	2	3	4	5	automation
(b) My understanding of the big picture is	shallower	1	2	3	4	5	deeper
(c) The automation is	unobtrusive	1	2	3	4	5	distracting
(d) I feel as though I am	controlling the engine	1	2	3	4	5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1	2	3	4	5	ease
(f) My overall workload is	lower	1	2	3	4	5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1	2	3	4	5	always

3. **When I use hydraulic amplification of control inputs:**

(a) My attention is focused on the	flight	1	2	3	4	5	automation
(b) My understanding of the big picture is	shallower	1	2	3	4	5	deeper
(c) The automation is	unobtrusive	1	2	3	4	5	distracting
(d) I feel as though I am	controlling the aircraft	1	2	3	4	5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1	2	3	4	5	ease
(f) My overall workload is	lower	1	2	3	4	5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1	2	3	4	5	always

4. **When I use a flight director:**

(a) My attention is focused on the	flight	1	2	3	4	5	automation
(b) My understanding of the big picture is	shallower	1	2	3	4	5	deeper
(c) The automation is	unobtrusive	1	2	3	4	5	distracting
(d) I feel as though I am	controlling the aircraft	1	2	3	4	5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1	2	3	4	5	ease
(f) My overall workload is	lower	1	2	3	4	5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1	2	3	4	5	always

5. When I use stability augmentation systems:

(a) My attention is focused on the	flight	1	2	3	4	5	automation
(b) My understanding of the big picture is	shallower	1	2	3	4	5	deeper
(c) The automation is	unobtrusive	1	2	3	4	5	distracting
(d) I feel as though I am	controlling the aircraft	1	2	3	4	5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1	2	3	4	5	ease
(f) My overall workload is	lower	1	2	3	4	5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1	2	3	4	5	always

6. When I use a primary flight display:

(a) My attention is focused on the	flight	1	2	3	4	5	automation
(b) My understanding of the big picture is	shallower	1	2	3	4	5	deeper
(c) The automation is	unobtrusive	1	2	3	4	5	distracting
(d) I feel as though I am	controlling the aircraft	1	2	3	4	5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1	2	3	4	5	ease
(f) My overall workload is	lower	1	2	3	4	5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1	2	3	4	5	always

7. When I use the autopilot to control HDG, SPD, or ALT:

(a) My attention is focused on the	flight	1	2	3	4	5	automation
(b) My understanding of the big picture is	shallower	1	2	3	4	5	deeper
(c) The automation is	unobtrusive	1	2	3	4	5	distracting
(d) I feel as though I am	controlling the aircraft	1	2	3	4	5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1	2	3	4	5	ease
(f) My overall workload is	lower	1	2	3	4	5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1	2	3	4	5	always

8. When I use the autopilot for pitch, roll, and yaw control:

(a) My attention is focused on the	flight	1	2	3	4	5	automation
(b) My understanding of the big picture is	shallower	1	2	3	4	5	deeper
(c) The automation is	unobtrusive	1	2	3	4	5	distracting
(d) I feel as though I am	controlling the aircraft	1	2	3	4	5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1	2	3	4	5	ease
(f) My overall workload is	lower	1	2	3	4	5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1	2	3	4	5	always

9. When I use the autopilot to control vertical or horizontal navigation paths:

(a) My attention is focused on the	flight	1	2	3	4	5	automation
(b) My understanding of the big picture is	shallower	1	2	3	4	5	deeper
(c) The automation is	unobtrusive	1	2	3	4	5	distracting
(d) I feel as though I am	controlling the aircraft	1	2	3	4	5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1	2	3	4	5	ease
(f) My overall workload is	lower	1	2	3	4	5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1	2	3	4	5	always

10. When I use the autothrottle:

(a) My attention is focused on the	flight	1	2	3	4	5	automation
(b) My understanding of the big picture is	shallower	1	2	3	4	5	deeper
(c) The automation is	unobtrusive	1	2	3	4	5	distracting
(d) I feel as though I am	controlling the aircraft	1	2	3	4	5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1	2	3	4	5	ease
(f) My overall workload is	lower	1	2	3	4	5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1	2	3	4	5	always

11. **When I use automatic landing:**

(a) My attention is focused on the	flight	1	2	3	4	5	automation
(b) My understanding of the big picture is	shallower	1	2	3	4	5	deeper
(c) The automation is	unobtrusive	1	2	3	4	5	distracting
(d) I feel as though I am	controlling the aircraft	1	2	3	4	5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1	2	3	4	5	ease
(f) My overall workload is	lower	1	2	3	4	5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1	2	3	4	5	always

12. **When I use speed envelope limiting:**

(a) My attention is focused on the	flight	1	2	3	4	5	automation
(b) My understanding of the big picture is	shallower	1	2	3	4	5	deeper
(c) The automation is	unobtrusive	1	2	3	4	5	distracting
(d) I feel as though I am	controlling the aircraft	1	2	3	4	5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1	2	3	4	5	ease
(f) My overall workload is	lower	1	2	3	4	5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1	2	3	4	5	always

13. **When I use fly-by-wire engine and/or flight controls:**

(a) My attention is focused on the	flight	1	2	3	4	5	automation
(b) My understanding of the big picture is	shallower	1	2	3	4	5	deeper
(c) The automation is	unobtrusive	1	2	3	4	5	distracting
(d) I feel as though I am	controlling the aircraft	1	2	3	4	5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1	2	3	4	5	ease
(f) My overall workload is	lower	1	2	3	4	5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1	2	3	4	5	always

14. When I use flap limiting (e.g., auto retraction feature):

(a) My attention is focused on the	flight	1	2	3	4	5	automation
(b) My understanding of the big picture is	shallower	1	2	3	4	5	deeper
(c) The automation is	unobtrusive	1	2	3	4	5	distracting
(d) I feel as though I am	controlling the aircraft	1	2	3	4	5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1	2	3	4	5	ease
(f) My overall workload is	lower	1	2	3	4	5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1	2	3	4	5	always

15. When I use an auto ground spoiler:

(a) My attention is focused on the	flight	1	2	3	4	5	automation
(b) My understanding of the big picture is	shallower	1	2	3	4	5	deeper
(c) The automation is	unobtrusive	1	2	3	4	5	distracting
(d) I feel as though I am	controlling the aircraft	1	2	3	4	5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1	2	3	4	5	ease
(f) My overall workload is	lower	1	2	3	4	5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1	2	3	4	5	always

16. When I use automatic compensation for asymmetrical thrust (e.g., automatic rudder):

(a) My attention is focused on the	flight	1	2	3	4	5	automation
(b) My understanding of the big picture is	shallower	1	2	3	4	5	deeper
(c) The automation is	unobtrusive	1	2	3	4	5	distracting
(d) I feel as though I am	controlling the aircraft	1	2	3	4	5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1	2	3	4	5	ease
(f) My overall workload is	lower	1	2	3	4	5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1	2	3	4	5	always

17. **When I use the FMC for automated flight planning (e.g., planning of route, waypoints, etc.):**

(a) My attention is focused on the	flight	1	2	3	4	5	automation
(b) My understanding of the big picture is	shallower	1	2	3	4	5	deeper
(c) The automation is	unobtrusive	1	2	3	4	5	distracting
(d) I feel as though I am	navigating	1	2	3	4	5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1	2	3	4	5	ease
(f) My overall workload is	lower	1	2	3	4	5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1	2	3	4	5	always

18. **When I use the FMC for automated performance management:**

(a) My attention is focused on the	flight	1	2	3	4	5	automation
(b) My understanding of the big picture is	shallower	1	2	3	4	5	deeper
(c) The automation is	unobtrusive	1	2	3	4	5	distracting
(d) I feel as though I am	navigating	1	2	3	4	5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1	2	3	4	5	ease
(f) My overall workload is	lower	1	2	3	4	5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1	2	3	4	5	always

19. **When I use the FMC for automated flight guidance (e.g., LNAV, VNAV):**

(a) My attention is focused on the	flight	1	2	3	4	5	automation
(b) My understanding of the big picture is	shallower	1	2	3	4	5	deeper
(c) The automation is	unobtrusive	1	2	3	4	5	distracting
(d) I feel as though I am	navigating	1	2	3	4	5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1	2	3	4	5	ease
(f) My overall workload is	lower	1	2	3	4	5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1	2	3	4	5	always

20. When I use a TCAS traffic display:

(a) My attention is focused on the	flight	1 2 3 4 5	automation
(b) My understanding of the big picture is	shallower	1 2 3 4 5	deeper
(c) The automation is	unobtrusive	1 2 3 4 5	distracting
(d) I feel as though I am	navigating	1 2 3 4 5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1 2 3 4 5	ease
(f) My overall workload is	lower	1 2 3 4 5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1 2 3 4 5	always

21. When I use the navigation display:

(a) My attention is focused on the	flight	1 2 3 4 5	automation
(b) My understanding of the big picture is	shallower	1 2 3 4 5	deeper
(c) The automation is	unobtrusive	1 2 3 4 5	distracting
(d) I feel as though I am	navigating	1 2 3 4 5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1 2 3 4 5	ease
(f) My overall workload is	lower	1 2 3 4 5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1 2 3 4 5	always

22. When I use the inertial reference system:

(a) My attention is focused on the	flight	1 2 3 4 5	automation
(b) My understanding of the big picture is	shallower	1 2 3 4 5	deeper
(c) The automation is	unobtrusive	1 2 3 4 5	distracting
(d) I feel as though I am	navigating	1 2 3 4 5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1 2 3 4 5	ease
(f) My overall workload is	lower	1 2 3 4 5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1 2 3 4 5	always

23. **When I use auto radio tuning:**

(a) My attention is focused on the	flight	1	2	3	4	5	automation
(b) My understanding of the big picture is	shallower	1	2	3	4	5	deeper
(c) The automation is	unobtrusive	1	2	3	4	5	distracting
(d) I feel as though I am	communicating	1	2	3	4	5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1	2	3	4	5	ease
(f) My overall workload is	lower	1	2	3	4	5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1	2	3	4	5	always

24. **When I use ACARS:**

(a) My attention is focused on the	flight	1	2	3	4	5	automation
(b) My understanding of the big picture is	shallower	1	2	3	4	5	deeper
(c) The automation is	unobtrusive	1	2	3	4	5	distracting
(d) I feel as though I am	communicating	1	2	3	4	5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1	2	3	4	5	ease
(f) My overall workload is	lower	1	2	3	4	5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1	2	3	4	5	always

25. **When I use sub-systems schematics:**

(a) My attention is focused on the	flight	1	2	3	4	5	automation
(b) My understanding of the big picture is	shallower	1	2	3	4	5	deeper
(c) The automation is	unobtrusive	1	2	3	4	5	distracting
(d) I feel as though I am	managing the sub-systems	1	2	3	4	5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1	2	3	4	5	ease
(f) My overall workload is	lower	1	2	3	4	5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1	2	3	4	5	always

26. When I use envelope protection with active flight control intervention:

(a) My attention is focused on the	flight	1 2 3 4 5	automation
(b) My understanding of the big picture is	shallower	1 2 3 4 5	deeper
(c) The automation is	unobtrusive	1 2 3 4 5	distracting
(d) I feel as though I am	controlling the aircraft	1 2 3 4 5	managing the automation
(e) I can predict the behavior of the automation with	difficulty	1 2 3 4 5	ease
(f) My overall workload is	lower	1 2 3 4 5	higher
(g) In the flight phase or mode where use of this component is appropriate, I use it	never	1 2 3 4 5	always

Please complete the following statements concerning alerting systems.

27. When a master caution and warning alert occurs:

(a) The alert gets my attention	eventually	1 2 3 4 5	immediately
(b) I trust that the alert signals a real event	never	1 2 3 4 5	always
(c) I know exactly what the problem is	eventually	1 2 3 4 5	immediately
(d) My response to the alert	requires thought	1 2 3 4 5	is automatic
(e) Returning to interrupted tasks after the alert is	difficult	1 2 3 4 5	easy
(f) On my current aircraft, these alerts occur	never	1 2 3 4 5	very often

28. When the GPWS warning occurs:

(a) The alert gets my attention	eventually	1 2 3 4 5	immediately
(b) I trust that the alert signals a real event	never	1 2 3 4 5	always
(c) I know exactly what the problem is	eventually	1 2 3 4 5	immediately
(d) My response to the alert	requires thought	1 2 3 4 5	is automatic
(e) Returning to interrupted tasks after the alert is	difficult	1 2 3 4 5	easy
(f) On my current aircraft, these alerts occur	never	1 2 3 4 5	very often

29. When a configuration warning occurs:

(a) The alert gets my attention	eventually	1 2 3 4 5 immediately
(b) I trust that the alert signals a real event	never	1 2 3 4 5 always
(c) I know exactly what the problem is	eventually	1 2 3 4 5 immediately
(d) My response to the alert	requires thought	1 2 3 4 5 is automatic
(e) Returning to interrupted tasks after the alert is	difficult	1 2 3 4 5 easy
(f) On my current aircraft, these alerts occur	never	1 2 3 4 5 very often

30. When a TCAS traffic advisory occurs:

(a) The alert gets my attention	eventually	1 2 3 4 5 immediately
(b) I trust that the alert signals a real event	never	1 2 3 4 5 always
(c) I know exactly what the problem is	eventually	1 2 3 4 5 immediately
(d) My response to the alert	requires thought	1 2 3 4 5 is automatic
(e) Returning to interrupted tasks after the alert is	difficult	1 2 3 4 5 easy
(f) On my current aircraft, these alerts occur	never	1 2 3 4 5 very often

31. When a TCAS resolution advisory occurs:

(a) The alert gets my attention	eventually	1 2 3 4 5 immediately
(b) I trust that the alert signals a real event	never	1 2 3 4 5 always
(c) I know exactly what the problem is	eventually	1 2 3 4 5 immediately
(d) My response to the alert	requires thought	1 2 3 4 5 is automatic
(e) Returning to interrupted tasks after the alert is	difficult	1 2 3 4 5 easy
(f) On my current aircraft, these alerts occur	never	1 2 3 4 5 very often

Section 2

This section addresses general automation philosophy issues, including training, pilot and automation roles and tasks, decision aids, and automation as it relates to pilot workload, pilot trust, and aircraft safety.

Please complete each statement by circling the number on the scale that represents the degree to which one or the other phrase is consistent with your opinions and beliefs. For example, for the first statement, if you believe strongly that initial emphasis should be placed on learning the basic airplane before introducing the automation, you would circle "5;" if you believe that the automation should be introduced first, but only have a slight preference for this position, you would circle "2."

32. Initial emphasis in training should be placed on learning about:

the automation before introducing the "basic airplane" — the "basic airplane" before introducing the automation

1 2 3 4 5

33. I would like to see the introduction of more automation that:

assists the pilot in problem solving — automatically solves problems

1 2 3 4 5

34. I would like to see the introduction of more automation that:

evaluates and advises the flight crew on alternative plans of action — automatically executes alternative plans of action

1 2 3 4 5

35. It is likely that situational information about A/C systems given by automation in the future:

will always require confirmation — can always be accepted as fact

1 2 3 4 5

36. It is likely that procedural information, response recommendations and commands concerning A/C systems given by automation in the future:

will always require confirmation — can always be accepted as fact

1 2 3 4 5

37. It is likely that the pilot in the future will:

not be responsible for flying the aircraft — still be responsible for flying the aircraft

1 2 3 4 5

38. In the future:

there will still be system failures that require deviations from standard procedures				we can expect that every system failure will have a prescribed procedure to follow
1	2	3	4	5

39. The biggest obstacle to total flight safety is:

system design				pilot performance
1	2	3	4	5

40. In pilot training in the future, principles of navigation and aviation are likely to receive:

less emphasis				just as much emphasis
1	2	3	4	5

41. In most cases, an automatic system should:

prevent the aircraft from exceeding its performance envelope				warn the crew of envelope exceedence, but not restrict pilots' control
1	2	3	4	5

42. Autoflight mode annunciation should be organized and displayed by:

what is controlling (autothrottle, roll, pitch)				what is being controlled (speed, lateral path, vert. path)
1	2	3	4	5

43. On my current aircraft, automatic transitions between different autoflight modes are usually:

hard to predict				easy to predict
1	2	3	4	5

44. I think synthetic speech for providing information to the pilot should be:

used only for time-critical warnings (e.g., "pull-up," windshear")				used to convey a variety of messages (e.g., ATC datalink, FMC, ACARS, etc.)
1	2	3	4	5

45. I think the overall amount of information available on my aircraft is:

not enough				too much
1	2	3	4	5

The following questions concern decision aids--automation that provides information, advice, and recommendations about possible alternatives. Examples of decision aids would be systems that help diagnose a systems fault, select an alternate airport or determine the optimal cost index for the current flight conditions.

46. Decision aids should emphasize:

situation information				response information
1	2	3	4	5

47. Decision aids should provide the flight crew with:

one alternative				a list of alternatives
1	2	3	4	5

48. Decision aids should provide the flight crew with:

recommendations				commands
1	2	3	4	5

49. Sometimes decision aids weigh evidence and make a probabilistic assessment (e.g., a physician's diagnostic aid might determine that your headache, fever, and general malaise has an 80% chance of being due to the flu). A decision aid should only provide information to the pilot if it is certain that it is 100% correct.

disagree				agree
1	2	3	4	5

50. If a decision aid tells me the probability of the choice being correct, I will accept information that has as low as a _____% probability of being correct.

51. **Automation can be considered *good* if it enhances safe, economical operation of the aircraft. There are many attributes of automation which designers believe make it *good*. Please rank the importance of the 11 attributes listed below for *good automation*. For example, if *accountable* were the most important quality for good automation, you would put a 1 in the space next to it, and if *adaptable* were the least important quality for good automation, you would put an 11 in the space next to it, and so on.**

Attribute	Rank
Accountable means the automation informs the pilot of its actions and is able to explain them.	____
Adaptable means that displays, control devices, etc., are re-programmable within a wide range of pilot preferences and needs.	____
Comprehensible means that one can figure out what the automation is doing and what needs to be done to operate it	____
Dependable means that the automation does what it is supposed to do and never does what it is not supposed to do.	____
Error-resistant means that the automation keeps pilots from committing errors (e.g., disallowing inputs when automation can detect entry is wrong).	____
Error-tolerant means that the automation can detect and reduce the effects of errors, given that some errors will inevitably occur.	____
Flexible means that an appropriate range of modes and levels are available to the operator (e.g., from manual control to autonomous operation).	____
Informative means that the automation imparts knowledge to the pilot (e.g., information about the airplane, automation, problems, operations, etc.)	____
Predictable means that the automation behaves as expected (i.e., it is clear what it is going to do).	____
Simple means that it is easy to understand and use (i.e., it is straightforward to learn and operate it).	____
Subordinate means the automation never assumes command, except in pre-defined situations. When it does assume command, it can be countermanded.	____

52. Automation can be considered *trustworthy* if pilots accept it, use it, and have faith in its operation or output. There are many automation attributes which may help it be *trustworthy*. Please rank the importance of the 11 attributes listed below for *trustworthy automation*. For example, if *accountable* were the most important quality for trustworthy automation, you would put a 1 in the space next to it, and if *adaptable* were the least important quality for trustworthy automation, you would put an 11 in the space next to it, and so on.

Attribute	Rank
Accountable means the automation informs the pilot of its actions and is able to explain them.	____
Adaptable means that displays, control devices, etc., are re-programmable within a wide range of pilot preferences and needs.	____
Comprehensible means that one can figure out what the automation is doing and what needs to be done to operate it.	____
Dependable means that the automation does what it is supposed to do and never does what it is not supposed to do.	____
Error-resistant means that the automation keeps pilots from committing errors (e.g., disallowing inputs when automation can detect entry is wrong).	____
Error-tolerant means that the automation can detect and reduce the effects of errors, given that some errors will inevitably occur.	____
Flexible means that an appropriate range of modes and levels are available to the operator (e.g., from manual control to autonomous operation).	____
Informative means that the automation imparts knowledge to the pilot (e.g., information about the airplane, automation, problems, operations, etc.)	____
Predictable means that the automation behaves as expected (i.e., it is clear what it is going to do).	____
Simple means easy to understand and use (i.e., it is straightforward to learn and operate it).	____
Subordinate means the automation never assumes command, except in pre-defined situations. When it does assume command, it can be countermanded.	____

53. In the space provided, please describe an experience that exemplifies automation that is trustworthy. The experience can be real or imaginary.

54. Now describe an experience that exemplifies untrustworthy automation.

55. Other surveys have suggested that pilots believe that advanced automation cockpits, relative to conventional cockpits, have changed the distribution of workload over the flight mission. By conventional cockpits, we mean ones which use mechanical gauges, have no flight management computers, etc. (e.g., 727's, DC-9's). By advanced automation cockpits, we mean ones that have glass, computers, etc. (A320's, MD-11's, 747-400's).

The pilot's ***physical*** workload in advanced glass cockpits, relative to that in conventional cockpits, is:

	much lower		about the same		much higher
Pre-flight	1	2	3	4	5
Taxi	1	2	3	4	5
Take-off	1	2	3	4	5
Climb	1	2	3	4	5
Cruise	1	2	3	4	5
Approach	1	2	3	4	5
Landing	1	2	3	4	5

The pilot's ***mental*** workload in advanced glass cockpits, relative to that in conventional cockpits, is:

	much lower		about the same		much higher
Pre-flight	1	2	3	4	5
Taxi	1	2	3	4	5
Take-off	1	2	3	4	5
Climb	1	2	3	4	5
Cruise	1	2	3	4	5
Approach	1	2	3	4	5
Landing	1	2	3	4	5

Section 3

Levels of Automation and Amount of Automation

Questions 56-77 concern levels of automation. By ***level of automation***, we mean **the degree to which automation participates in performance of a task or function**, from unassisted human performance, to shared performance (pilots perform some activities, automation performs some), to totally automated performance (the automation performs the task, and the pilot is simply informed of the operational state of the automation).

There are many ways to describe various aspects of flight deck operations. We have named and briefly described several of these below. For each description, please read the two statements about level of automation and for each circle the number on the 1-5 scale that best reflects your view or opinion. The numbers 2, 3 and 4 on the scales represent shared pilot-automation operation, with increasing involvement of the automation.

One way to think about the flight is by normal, non-normal and emergency conditions. Please think about current and ideal levels of automation for each of these categories.

56. **NORMAL FLIGHT (all systems are operating normally, the flight proceeds with no unusual events or circumstances)**

The maximum level of automation available for ***normal*** flight on the aircraft I fly is:

unassisted pilot performance — totally automated performance

1 2 3 4 5

Ideally, the level of automation I would use for ***normal*** flight is:

unassisted pilot performance — totally automated performance

1 2 3 4 5

57. **NON-NORMAL FLIGHT (a system failure or abnormal situation exists, but does not require diversion to the nearest airport)**

The maximum level of automation available for ***non-normal*** flight on the aircraft I fly is:

unassisted pilot performance — totally automated performance

1 2 3 4 5

Ideally, the level of automation I would use for ***non-normal*** flight is:

unassisted pilot performance — totally automated performance

1 2 3 4 5

58. IN-FLIGHT EMERGENCY (the aircraft must be landed immediately, at the nearest suitable airport if possible)

The maximum level of automation available for ***in-flight emergencies*** on the aircraft I fly is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

Ideally, the level of automation I would use for ***in-flight emergencies:***

unassisted pilot performance				totally automated performance
1	2	3	4	5

Another way to think about the flight is by flight phase. Please think about the current and ideal level of automation for each phase of flight described below.

59. PRE-FLIGHT (all activities until aircraft roll-back)

The maximum level of automation available for ***pre-flight*** on the aircraft I fly is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

Ideally, the level of automation I would use for ***pre-flight*** is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

60. TAXI (roll-back to take-off roll)

The maximum level of automation available for ***taxi*** on the aircraft I fly is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

Ideally, the level of automation I would use for ***taxi*** is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

61. TAKE-OFF (take-off roll to 500 ft. altitude)

The maximum level of automation available for ***take-off*** on the aircraft I fly is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

Ideally, the level of automation I would use for ***take-off*** is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

62. CLIMB (500 ft. altitude to level off at cruise altitude)

The maximum level of automation available for ***climb*** on the aircraft I fly is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

Ideally, the level of automation I would use for ***climb*** is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

63. CRUISE (top of climb to top of descent)

The maximum level of automation available for ***cruise*** on the aircraft I fly is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

Ideally, the level of automation I would use for ***cruise*** is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

64. DESCENT (top of descent to 500 ft. altitude)

The maximum level of automation available for ***descent*** on the aircraft I fly is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

Ideally, the level of automation I would use for ***descent*** is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

65. LANDING (500 ft. altitude to turn-off at taxi way)

The maximum level of automation available for ***landing*** on the aircraft I fly is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

Ideally, the level of automation I would use for ***landing*** is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

66. TAXI & PARK (turn-off at taxi way to flight crew deplaning)

The maximum level of automation available for ***taxi and park*** on the aircraft I fly is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

Ideally, the level of automation I would use for ***taxi and park*** is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

Another way to think about the flight is by mission function. Please think about the current and ideal level of automation for each mission function.

67. **FLIGHT CONTROL (activities related to controlling the immediate attitude, speed, trajectory, and altitude of the aircraft)**

The maximum level of automation available for ***flight control*** on the aircraft I fly is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

Ideally, the level of automation I would use for ***flight control*** is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

68. **NAVIGATION (activities related to planning the flight path of the aircraft in relation to ATC requests, waypoints, destination, etc.)**

The maximum level of ***navigation*** on the aircraft I fly is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

Ideally, the level of automation I would use for ***navigation*** is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

69. **COMMUNICATION (activities related to transferring information among the flight crew, ATC, dispatch, cabin crew, and the FMC)**

The maximum level of automation available for ***communication*** on the aircraft I fly is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

Ideally, the level of automation I would use for ***communication*** is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

70. SYSTEMS MANAGEMENT (activities related to managing on-board automated systems, including fuel, hydraulics, electrical, engines, as well as computer systems such as the FMC, autopilot)

The maximum level of automation available for ***systems management*** on the aircraft I fly is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

Ideally, the level of automation I would use for ***systems management*** is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

71. TASK MANAGEMENT (organizing and scheduling tasks to be done during a flight, including managing required resources)

The maximum level of automation available for ***task management*** on the aircraft I fly is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

Ideally, the level of automation I would use for ***task management*** is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

Another way to think about the flight is by human information processing task; taking information in, processing it, and responding to it. Please think about the current and ideal level of automation for each information processing task.

72. MONITORING (activities such as scanning, looking, detecting-determining the states and status's of the aircraft, systems, etc.)

The maximum level of automation available for ***monitoring tasks*** on the aircraft I fly is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

Ideally, the level of automation I would use for ***monitoring tasks*** is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

73. **PLANNING (mental activities involving assessing the situation, its consequences, making decisions, problem solving, etc.)**

The maximum level of automation available for ***planning tasks*** on the aircraft I fly is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

Ideally, the level of automation I would use for ***planning tasks*** is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

74. **RESPONDING (determining and performing actions that achieve the plans and goals developed in the planning tasks)**

The maximum level of automation for ***responding tasks*** on the aircraft I fly is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

Ideally, the level of automation I would use for ***responding tasks*** is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

Another way to think about the flight is by amount of workload involved. Please think about the current and ideal level of automation for the different levels of workload described below.

75. **HIGH WORKLOAD SITUATIONS (situations in which you are time-stressed and very busy—not sure if you'll get everything done)**

The maximum level of automation available for ***high workload situations*** on the aircraft I fly is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

Ideally, the level of automation I would use for ***high workload situations*** is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

76. MEDIUM WORKLOAD SITUATIONS (situations in which you are busy but not overwhelmed)

The maximum level of automation available for ***medium workload situations*** on the aircraft I fly is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

Ideally, the level of automation I would use for ***medium workload situations*** is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

77. LOW WORKLOAD SITUATIONS (situations in which there is not much to do—obvious periods of monotony and inactivity)

The maximum level of automation available for ***low workload situations*** on the aircraft I fly is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

Ideally, the level of automation I would use for ***low workload situations*** is:

unassisted pilot performance				totally automated performance
1	2	3	4	5

Items 78-80 list potential advantages and disadvantages of three different levels of flight deck automation: autonomous (Q78), shared (Q79), and unassisted (Q80). Please indicate how you feel about the potential advantages and disadvantages of each level of automation, as described.

78. Autonomous operation: automation performs task; pilot may turn on or off, informed of malfunction

I believe that automation at this level holds the promise to:

	Disagree				Agree
keep me involved	1	2	3	4	5
keep me informed	1	2	3	4	5
improve my performance	1	2	3	4	5
improve my situation awareness	1	2	3	4	5
alleviate fatigue	1	2	3	4	5
reduce workload	1	2	3	4	5
provide more precise data	1	2	3	4	5
increase safety	1	2	3	4	5
increase airline cost effectiveness	1	2	3	4	5

I am concerned that automation at this level could lead to:

	Low concern				High concern
temperamental devices	1	2	3	4	5
display complexity	1	2	3	4	5
losing sight of the raw data	1	2	3	4	5
difficulty in learning to operate	1	2	3	4	5
data entry errors	1	2	3	4	5
software engineering errors	1	2	3	4	5
need for new skills	1	2	3	4	5
unforeseen and unintended negative consequences	1	2	3	4	5
workload extremes (high and low)	1	2	3	4	5
increase in the number of alerting signals	1	2	3	4	5
loss of situation awareness	1	2	3	4	5
need to work around the automatics in unusual circumstances	1	2	3	4	5
increased head-down time	1	2	3	4	5
difficulty in recovering from an automation failure	1	2	3	4	5
degradation of pilot skills	1	2	3	4	5
difficulty in detecting system errors	1	2	3	4	5
reluctance of crew to take over from automatics	1	2	3	4	5
complacency	1	2	3	4	5

79. **Shared Pilot/Automation performance: pilot carries part of out task, may utilize advisory systems; automation carries out part of task, usually at pilot's discretion**

I believe that automation at this level holds the promise to:

	Disagree				Agree
keep me involved	1	2	3	4	5
keep me informed	1	2	3	4	5
improve my performance	1	2	3	4	5
improve my situation awareness	1	2	3	4	5
alleviate fatigue	1	2	3	4	5
reduce workload	1	2	3	4	5
provide more precise data	1	2	3	4	5
increase safety	1	2	3	4	5
increase airline cost effectiveness	1	2	3	4	5

I am concerned that automation at this level could lead to:

	Low concern				High concern
temperamental devices	1	2	3	4	5
display complexity	1	2	3	4	5
losing sight of the raw data	1	2	3	4	5
difficulty in learning to operate	1	2	3	4	5
data entry errors	1	2	3	4	5
software engineering errors	1	2	3	4	5
need for new skills	1	2	3	4	5
unforeseen and unintended negative consequences	1	2	3	4	5
workload extremes (high and low)	1	2	3	4	5
increase in the number of alerting signals	1	2	3	4	5
loss of situation awareness	1	2	3	4	5
need to work around the automatics in unusual circumstances	1	2	3	4	5
increased head-down time	1	2	3	4	5
difficulty in recovering from an automation failure	1	2	3	4	5
degradation of pilot skills	1	2	3	4	5
difficulty in detecting system errors	1	2	3	4	5
reluctance of crew to take over from automatics	1	2	3	4	5
complacency	1	2	3	4	5

80. Unassisted Pilot performance: pilot carries out task; unaided decision-making; utilizes raw data

I believe that automation at this level holds the promise to:

	Disagree 1	2	3	4	Agree 5
keep me involved	1	2	3	4	5
keep me informed	1	2	3	4	5
improve my performance	1	2	3	4	5
improve my situation awareness	1	2	3	4	5
alleviate fatigue	1	2	3	4	5
reduce workload	1	2	3	4	5
provide more precise data	1	2	3	4	5
increase safety	1	2	3	4	5
increase airline cost effectiveness	1	2	3	4	5

I am concerned that automation at this level could lead to:

	Low concern 1	2	3	4	High concern 5
temperamental devices	1	2	3	4	5
display complexity	1	2	3	4	5
losing sight of the raw data	1	2	3	4	5
difficulty in learning to operate	1	2	3	4	5
data entry errors	1	2	3	4	5
software engineering errors	1	2	3	4	5
need for new skills	1	2	3	4	5
unforeseen and unintended negative consequences	1	2	3	4	5
workload extremes (high and low)	1	2	3	4	5
increase in the number of alerting signals	1	2	3	4	5
loss of situation awareness	1	2	3	4	5
need to work around the automatics in unusual circumstances	1	2	3	4	5
increased head-down time	1	2	3	4	5
difficulty in recovering from an automation failure	1	2	3	4	5
degradation of pilot skills	1	2	3	4	5
difficulty in detecting system errors	1	2	3	4	5
reluctance of crew to take over from automatics	1	2	3	4	5
complacency	1	2	3	4	5

Items 81–85 concern the amount of different types of automation. By ***amount of automation,*** we simply mean **the total number of automated systems or components.**

81. AIRCRAFT CONTROL AUTOMATION **(automation that assists or supplants a human pilot in guiding the airplane through the maneuvers necessary for aircraft safety.)**

The amount of ***flight control automation*** on the aircraft I fly is:

minimal		moderate		maximal
1	2	3	4	5

The ideal amount of ***flight control automation*** in relation to that on the aircraft I fly, is:

less automation		current level		more automation
1	2	3	4	5

82. SYSTEMS CONTROL AUTOMATION **(automation that assists or supplants a human pilot in controlling system modes and configurations, display modes and formats, information, etc.)**

The amount of ***systems control automation*** on the aircraft I fly is:

minimal		moderate		maximal
1	2	3	4	5

The ideal amount of ***systems control automation*** in relation to that on the aircraft I fly, is

less automation		current level		more automation
1	2	3	4	5

83. INFORMATION AUTOMATION **(automation that informs the pilots about the aircraft and systems states, operations, procedures, regulations, and location of the aircraft and relevant entities in the environment).**

The amount of ***information automation*** on the aircraft I fly is:

minimal		moderate		maximal
1	2	3	4	5

The ideal amount of ***information automation*** in relation to that on the aircraft I fly, is:

less automation		current level		more automation
1	2	3	4	5

84. DECISION AUTOMATION (automation that aids the pilot in selecting alternatives, making choices).

The amount of ***decision automation*** on the aircraft I fly is:

minimal		moderate		maximal
1	2	3	4	5

The ideal amount of ***decision automation*** relation to that on the aircraft I fly, is :

less automation		current level		more automation
1	2	3	4	5

85. PROTECTIVE AUTOMATION (automation that physically prevents the pilot from taking unsafe actions and automatically carries out actions required for safety if the pilot fails to act in a timely manner).

The amount of ***protective automation*** on the aircraft I fly is:

minimal		moderate		maximal
1	2	3	4	5

The ideal amount of ***protective automation*** in relation to that on the aircraft I fly, is:

less automation		current level		more automation
1	2	3	4	5

86. I think ____________________ is the *best* automated feature on my aircraft because ____________________

87. I think ____________________ is the *worst* automated feature on my aircraft because ____________________

Section 4

NASA is performing research to support development of a Mach 2-3, 6000 mile range, 300 passenger commercial aircraft that is economically viable and environmentally sound. Please answer the following questions specifically related to such a high speed commercial transport (HSCT).

It is possible the HSCT will have limited or no forward windows so the cost and weight required to "droop" the nose as is done in the Concorde can be saved. Instead, visual information may be provided by sensors, by computer-based object and terrain data bases validated by GPS positioning, or by both. The image you see may be graphically enhanced to look like an unobstructed, high fidelity, day time view of the outside forward-looking scene, possibly augmented with primary flight information.

Assuming it can be shown that performance with a sensor or computer data base generated visual scene is satisfactory and reliable, please indicate your level of agreement with the following statements:

88. Most pilots would feel comfortable landing a commercial aircraft that supplied a forward visual scene from:

	disagree				agree
imaging sensors	1	2	3	4	5
computer-based obstacle and airport data bases	1	2	3	4	5
a combination of sensor and computer-based information	1	2	3	4	5

89. I would feel comfortable landing a commercial aircraft that supplied a forward visual scene from:

	disagree				agree
imaging sensors	1	2	3	4	5
computer-based obstacle and airport data bases	1	2	3	4	5
a combination of sensor and computer-based information	1	2	3	4	5

90. I could get used to landing an aircraft that supplied a forward visual scene from:

	disagree				agree
imaging sensors	1	2	3	4	5
computer-based obstacle and airport data bases	1	2	3	4	5
a combination of sensor and computer-based information	1	2	3	4	5

91. A forward visual scene generated from sensor and/or computer airport and terrain data bases, augmented by symbology like that found on Heads-Up Displays (HUD's), will likely be presented on a large field-of-view display. Do you think such a display should:

replace the primary flight display				supplement the primary flight display
1	2	3	4	5

92. I would be more comfortable if sensors used to detect the runway, surface objects and aircraft in the terminal area were located:

on the ground				on the aircraft
1	2	3	4	5

93. Given that the HSCT will require continuous automated augmentation of the pilots' primary control inputs (cables will not be directly linked to control surfaces), would you prefer your primary control device to be a: (Check one)

center stick _____ wheel and column _____ side stick _____

94. Which of these control devices have you flown with? (Check all that apply)

center stick _____ wheel and column _____ side stick _____

APPENDIX B

Data Tables for "Phenomenological Experiences" Results

Table B1

Ordering of Components on Attention to Flight/Automation Dimension (a). Components Rated High in Attention to the Flight are at the Top; Components High in Attention to the Automation are at the Bottom.

Q	Component	Score
3	hydra amplif of inputs	4.37
15	auto ground spoiler	4.32
5	stability aug systems	4.26
16	automatic rudder	4.24
13	fly-by-wire controls	4.23
2	auto engine start	4.12
14	flap limiting	4.08
1	auto braking	4.05
7	autopilot-HDG SPD AL	3.97
10	auto throttle	3.97
22	inertial refer system	3.95
12	speed envelope limit	3.87
23	auto radio tuning	3.83
26	envel protect-interv	3.72
21	navigation display	3.61
6	primary flight displ	3.60
20	TCAS traffic displ	3.55
4	flight director	3.40
8	autopilot-pitch, roll	3.25
9	autopilot-vrt hz paths	3.25
18	FMC-auto manage	3.20
19	FMC LNAV VNAV	3.01
11	auto landing	2.84
25	sub-syst schematics	2.81
17	FMC-flight planning	2.59
24	ACARS	2.58

Note. The rating scale has been reversed from the way it appeared in the questionnaire. Here 5 = attention is focused on the flight; 1= attention is focused on the automation

Table B2

Ordering of Components on Situation Awareness Question (b). Components Rated High in Contributing to Situation Awareness are at the Top; Components Low in Situation Awareness are at the Bottom.

Q	Component	Score
21	navigation display	4.30
25	sub-syst schematics	4.27
17	FMC-flight planning	4.05
6	primary flt display	4.04
22	inertial refer system	3.94
20	TCAS traffic display	3.92
18	FMC-auto manage	3.90
15	ground spoiler	3.88
8	autopilot-pitch roll	3.85
9	autopilot-vrt hz paths	3.85
7	autopilot-HDG SPD ALT	3.84
10	autothrottle	3.84
19	FMC LNAV VNAV	3.80
4	flight director	3.76
2	auto engine start	3.72
13	fly-by-wire controls	3.72
12	speed envelope limit	3.69
11	auto landing	3.63
23	auto radio tuning	3.60
5	stability aug systems	3.57
24	ACARS	3.55
1	auto braking	3.54
16	automatic rudder	3.54
26	envelope protection	3.44
14	flap limiting	3.42
3	hydr amplif of inputs	3.40

Note. The rating scale used in the questionnaire was the following: 5 = my understanding of the big picture is deeper 1= my understanding of the big picture is shallower

Table B3

Ordering of Components on Obtrusiveness Question (c). Components rated low in obtrusiveness are at the top; components high in obtrusiveness are at the bottom.

Q	Component	Score
22	inertial refer system	4.45
15	ground spoiler	4.44
3	hydr amplif of inputs	4.34
2	auto engine start	4.32
13	fly-by-wire controls	4.31
16	automatic rudder	4.28
5	stability aug systems	4.23
21	navigation display	4.23
1	auto braking	4.15
7	autopilot-HDG SPD ALT	4.12
10	autothrottle	4.12
6	primary flt display	4.11
4	flight director	4.1
23	auto radio tuning	4.09
25	sub-syst schematics	4.09
18	FMC-auto manage	3.92
14	flap limiting	3.84
12	speed envelope limit	3.83
17	FMC-flight planning	3.82
8	autopilot-pitch roll	3.8
9	autopilot-vrt hz paths	3.8
19	FMC LNAV VNAV	3.8
26	envelope protection	3.72
11	auto landing	3.7
24	ACARS	3.44
20	TCAS traffic display	3.16

Note. The rating scale has been reversed from the way it appeared in the questionnaire. Here 5 = unobtrusive 1= distracting

Table B4

Ordering of Components Controlling/Managing Dimension (d). Components Rated High in Controlling are at the Top; Components High in Managing are at the Bottom.

Q	Component	Score
3	hydr amplif of inputs	4.10
15	auto ground spoiler	4.00
13	fly-by-wire controls	3.95
16	automatic rudder	3.92
5	stability aug systems	3.87
6	primary flight displ	3.58
14	flap limiting	3.58
25	sub-syst schematics	3.55
12	speed envelope limit	3.47
24	ACARS	3.46
26	envelope protection	3.42
4	flight director	3.38
20	TCAS traffic display	3.38
22	inertial refer system	3.35
7	autopilot-HDG SPD AL	3.33
10	auto throttle	3.33
21	navigation display	3.33
1	auto braking	3.27
23	auto radio tuning	3.02
8	autopilot-pitch, roll	2.75
9	autopilot-vrt hz paths	2.75
2	auto engine start	2.67
19	FMC LNAV VNAV	2.59
18	FMC-auto manage	2.56
17	FMC-flight planning	2.25
11	auto landing	2.02

Note. The rating scale has been reversed from the way it appeared in the questionnaire. Here 5 = feeling of controlling the flight; 1= feeling of managing the automation

Table B5

Ordering of Components on Predictability Question (e). Components Rated High in Predictability are at the Top; Components Low in Predictability are at the Bottom.

Q	Component	Score
21	navigation display	4.3
15	ground spoiler	4.2
22	inertial refer system	4.18
3	hydr amplif of inputs	4.17
2	auto engine start	4.14
6	primary flt display	4.12
13	fly-by-wire controls	4.11
17	FMC-flight planning	4.11
1	auto braking	4.09
4	flight director	4.08
7	autopilot-HDG SPD ALT	4.02
10	autothrottle	4.02
18	FMC-auto manage	3.94
11	auto landing	3.91
19	FMC LNAV VNAV	3.91
25	sub-syst schematics	3.89
8	autopilot-pitch roll	3.88
9	autopilot-vrt hz paths	3.88
14	flap limiting	3.86
24	ACARS	3.86
16	automatic rudder	3.82
5	stability aug systems	3.79
12	speed envelope limit	3.74
23	auto radio tuning	3.7
26	envelope protection	3.62
20	TCAS traffic display	3.2

Note. The rating scale used in the questionnaire was the following: 5 = I can predict the behavior of the automation with ease 1= I can predict the behavior of the automation with difficulty

Table B6

Ordering of Components on Workload Question (f). Components Rated Low in Workload are at the Top; Components High in Workload are at the Bottom.

Q	Component	Score
15	ground spoiler	4.21
10	autothrottle	4.14
22	inertial refer system	4.09
2	auto engine start	4.07
16	automatic rudder	4.06
21	navigation display	4.04
7	autopilot-HDG SPD ALT	3.97
3	hydr amplif of inputs	3.96
23	auto radio tuning	3.96
25	sub-syst schematics	3.92
4	flight director	3.9
5	stability aug systems	3.85
13	fly-by-wire controls	3.81
8	autopilot-pitch roll	3.8
9	autopilot-vrt hz paths	3.8
1	auto braking	3.77
18	FMC-auto manage	3.77
17	FMC-flight planning	3.73
19	FMC LNAV VNAV	3.73
6	primary flt display	3.7
12	speed envelope limit	3.62
14	flap limiting	3.53
26	envelope protection	3.52
11	auto landing	3.51
24	ACARS	3.47
20	TCAS traffic display	3.1

Note. The rating scale has been reversed from the way it appeared in the questionnaire. Here 5 = low workload 1= high workload

Table B7

Ordering of Components on Frequency of Use Question (g). Components Rated High in Use are at the Top; Components Low in Use are at the Bottom.

Q	Component	Score
22	inertial refer system	4.92
15	ground spoiler	4.88
17	FMC-flight planning	4.83
21	navigation display	4.75
6	primary flt display	4.73
13	fly-by-wire controls	4.69
24	ACARS	4.69
5	stability aug systems	4.68
20	TCAS traffic display	4.67
3	hydr amplif of inputs	4.63
25	sub-syst schematics	4.59
2	auto engine start	4.58
4	flight director	4.53
18	FMC-auto manage	4.52
23	auto radio tuning	4.46
19	FMC LNAV VNAV	4.38
26	envelope protection	4.27
16	automatic rudder	4.26
12	speed envelope limit	4.24
10	autothrottle	4.22
8	autopilot-pitch roll	4.16
9	autopilot-vrt hz paths	4.16
7	autopilot-HDG SPD ALT	4.14
1	auto braking	4.13
14	flap limiting	3.47
11	auto landing	2.88

Note. The rating scale used in the questionnaire was the following: 5 = In the flight phase or mode where use of this component is appropriate, I use it always 1= ...I use it never

Table B8

Ordering of Alerts on Attention Getting Question (a). Alerts Rated High in Attention Getting are at the Top; Alerts Low in Attention Getting are at the Bottom.

Q	Alert	Score
28	GPWS warning	4.93
31	TCAS resolution advisory	4.93
30	TCAS traffic advisory	4.86
27	master caution and warning	4.83
29	configuration warning	4.82

Note. The rating scale used in the questionnaire was the following: 5 = The alert gets my attention immediately 1= The alert gets my attention eventually

Table B9

Ordering of Alerts on Trust Question (b). Alerts Rated High in Trust are at the Top; Alerts Low in Trust are at the Bottom.

Q	Alert	Score
29	configuration warning	4.53
31	TCAS resolution advisory	4.37
28	GPWS warning	4.26
27	master caution and warning	4.1
30	TCAS traffic advisory	4.09

Note. The rating scale used in the questionnaire was the following: 5 = I trust that the alert signals a real event always 1= I trust that the alert signals a real event never

Table B10

Ordering of Alerts on Knowing What the Problem is Question (c). Alerts Rated High in Knowing are at the Top; Alerts Low in Knowing are at the Bottom.

Q	Alert	Score
31	TCAS resolution advisory	3.93
29	configuration warning	3.76
30	TCAS traffic advisory	3.65
28	GPWS warning	3.59
27	master caution and warning	3.31

Note. The rating scale used in the questionnaire was the following: 5 = I know exactly what the problem is immediately 1= I know exactly what the problem is eventually

Table B11

Ordering of Alerts on Automaticity of Response Question (d). Alerts Rated High on Automaticity of Response are at the Top; Alerts Low in Automaticity are at the Bottom.

Q	Alert	Score
28	GPWS warning	3.96
31	TCAS resolution advisory	3.91
29	configuration warning	3.56
30	TCAS traffic advisory	3.32
27	master caution and warning	2.86

Note. The rating scale used in the questionnaire was the following: 5 = My response to the alert is automatic 1 = My response to the alert requires thought

Table B12

Ordering of Alerts on Ease of Returning to Interrupted Tasks Question (e). Alerts Rated High on Ease of Returning are at the Top; Alerts Low in Ease of Returning are at the Bottom.

Q	Alert	Score
30	TCAS traffic advisory	3.64
29	configuration warning	3.63
27	master caution and warning	3.42
31	TCAS resolution advisory	3.40
28	GPWS warning	3.39

Note. The rating scale used in the questionnaire was the following: 5 = Returning to interrupted tasks after the alert is easy 1 = Returning to interrupted tasks after the alert is difficult

Table B13

Ordering of Alerts on Frequency of Alerts Question (f). Alerts Rated High in Frequency are at the Top; Alerts Low in Frequency are at the Bottom.

Q	Alert	Score
30	TCAS traffic advisory	2.94
27	master caution and warning	2.7
31	TCAS resolution advisory	2.11
28	GPWS warning	2
29	configuration warning	2

Note. The rating scale used in the questionnaire was the following: 5 = On my current aircraft, these alerts occur very often 1= On my current aircraft, these alerts occur never

APPENDIX C

Discussion and Figures for Miscellaneous Results

The results of the question concerning how autoflight modes should be annunciated (Q42) supported the hypothesis that it is more intuitive for pilots to organize the modes by what is being controlled, that is, speed, vertical path and lateral path, than by what is controlling (see Figure C1). However, pilots generally felt that it is easy to predict automatic transitions between different autoflight modes on their current aircraft (Q43), contradicting the hypothesis that this is somewhat confusing on current aircraft (see Figure C2).

Pilots felt strongly that synthetic speech should only be used for time-critical warnings (Q44), despite its potential to reduce visual workload (see Figure C3). One argument for the pilot's view is that the more synthetic speech is used on the flight deck, the less effective it will be in conveying response urgency, which is its primary purpose on current aircraft.

Pilots felt that the amount of information on their aircraft was reasonable (Q45), as indicated by the large number of neutral responses (see Figure C4). The mean response was 3.2, indicating a slight opinion that there is too much information on current aircraft, but the result does not provide strong evidence that there is an "information overload" problem on today's flight decks.

The responses to the questions addressing the presentation of probabilistic information by decision aids (Q49 & 50) indicated that pilots agree slightly with the position that information should not be provided unless it is certain (100% accurate), although it is clear from Figure C5 that pilots opinions are widely distributed on this issue. When asked what probability of being correct would be required before they would accept information from a decision aid, the mean response was 78%, and as can be seen from Figure C6, the preferred range was 90-99%.

Responses to questions about the high speed civil transport revealed several interesting findings. Questions 88-90 addressed the issue of synthetic vision. These questions were designed to assess the effects of two variables: question wording and type of synthetic data—imaging sensors, computer database, or a combination. The wording of the three questions varied in obliqueness. In question 88 subjects were asked to assess how other pilots would feel about having to fly without a forward window. In question 89 they were asked how they would feel, and in question 90, how they would feel after a period of familiarization. The responses were analyzed with an analysis of variance for two within-subject variables. The results showed a significant main effect both of question obliqueness, $F(2,210)=87.12$, $p<.0001$, and of type of data base, $F(2,210)=59.57$, $p<.0001$. The average responses are shown in Figure C7. It is clear from the figure that subjects trusted a synthetic vision system based on a combination of data sources more than one based on a single source. Preferences for each of the single sources were statistically equivalent ($p>.05$) on a Tukey test. Interestingly, pilots expressed more reservations about relying on synthetic vision when they were asked the question indirectly. Tukey analysis showed an increased endorsement with each wording change, as the wording became more personal and more insistent. The responses changed from the negative end of the scale for other pilots (2.69) to fairly positive for self with familiarization (3.63) for the combined data sources. These results suggest that oblique questioning may be a good way to elicit reservations that pilots might otherwise feel uncomfortable about expressing.

When asked whether they would like a synthetic vision display which provides a forward visual scene to replace or supplement the conventional primary flight display (Q91), the overwhelming response was that they would like it to supplement the primary flight display (mean response = 3.82, where 1 was labeled "replace the primary flight display" and 5 was labeled "supplement the primary flight display." Over two-thirds of the pilots responded with a "4" or "5" (see Figure C8). Pilots also preferred that the sensors used to detect the runway, objects, aircraft, etc., for the synthetic vision display be located on the aircraft rather than on the ground (Q92, Figure C9).

Finally, in response to the type of control device they would prefer for an HSCT aircraft (Q93), 78 pilots preferred a side stick, 40 preferred a wheel and column, and 8 preferred a center stick (see Figure C10). This result is especially interesting given that 98% of the subjects have flown with a wheel and column, 80% with a center stick, and only 42% with a side stick (Q94). It is not surprising that the A-320 pilots chose the side stick since they fly with one, but the B747-400 pilots preferred it as well (27 preferred the side stick to 15 for the wheel and column). The MD-11 pilots were the only ones that preferred a wheel and column (23 respondents) to a side-stick (10 respondents); this result may have been due to the fact that the MD-11 pilots were older and more resistant to change.

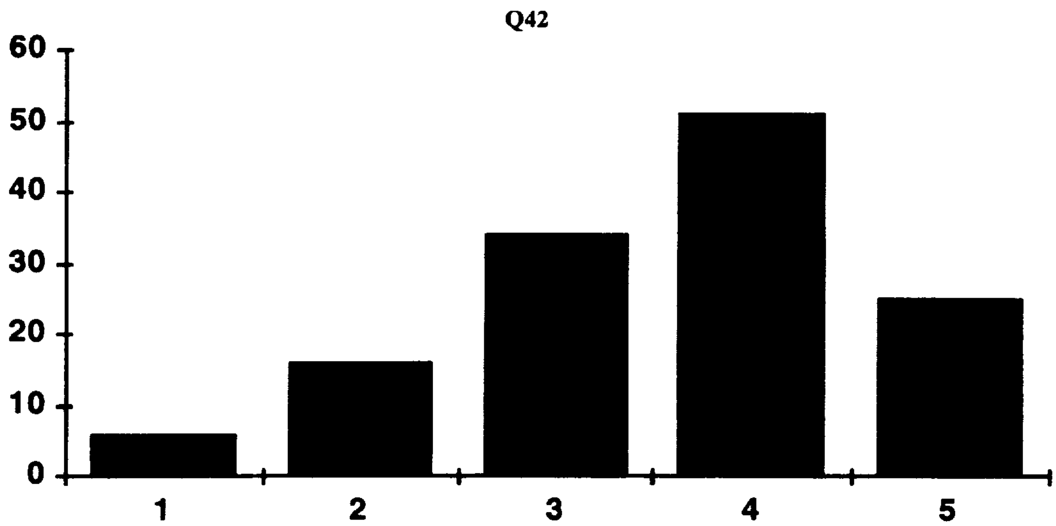

Figure C1. Autoflight mode annunciation should be organized and displayed by:

what is controlling (autothrottle, roll, pitch) — what is being controlled (speed, lateral path, vert. path)

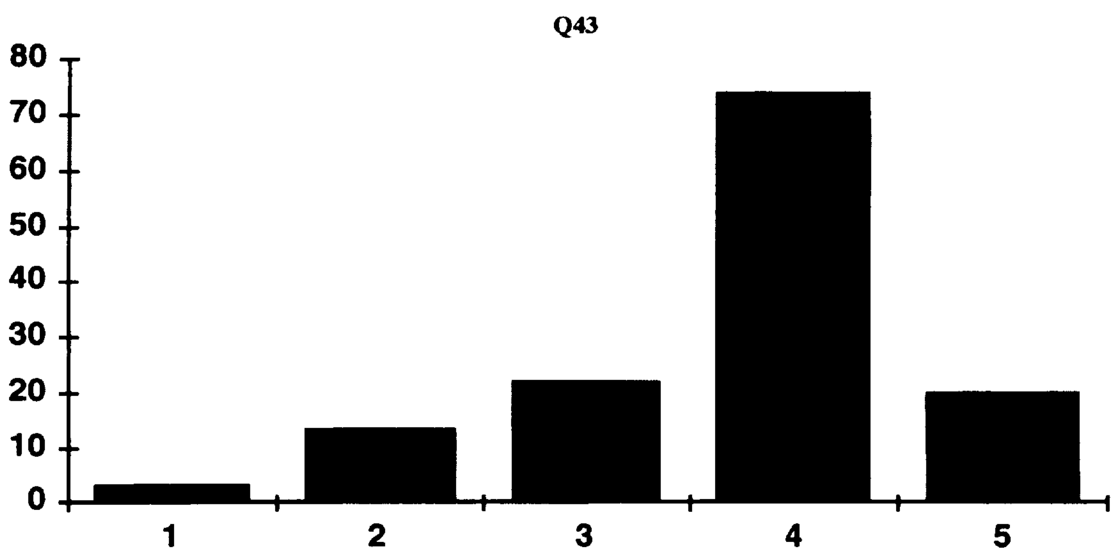

Figure C2. On my current aircraft, automatictransitions between different autoflight modes are usually:

hard to predict — easy to predict

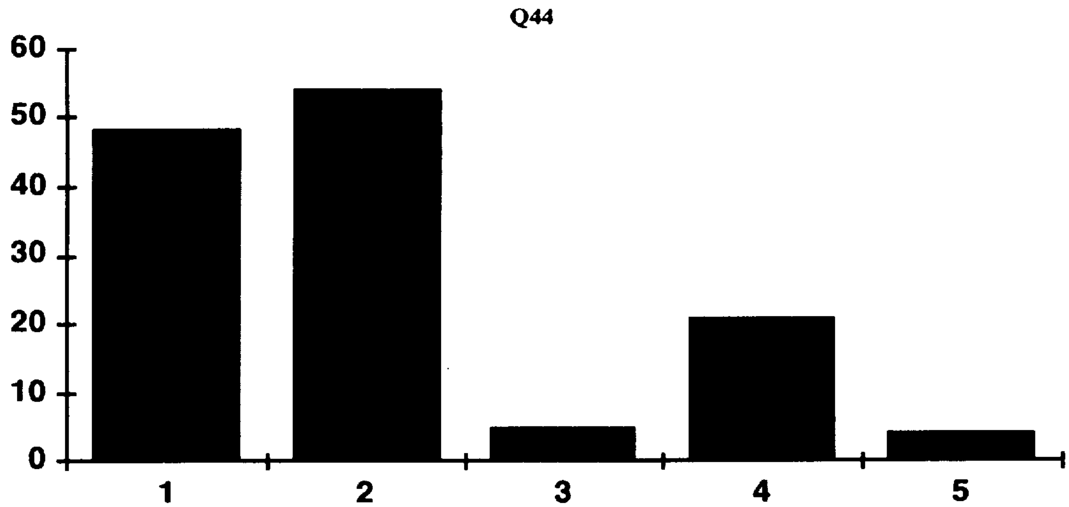

Figure C3. I think synthetic speech for providing information to the pilot should be:

used only for time-critical warnings (e.g., "pull-up," "windshear")

used to convey a variety of messages (e.g., ATC datalink, FMC, ACARS, etc.)

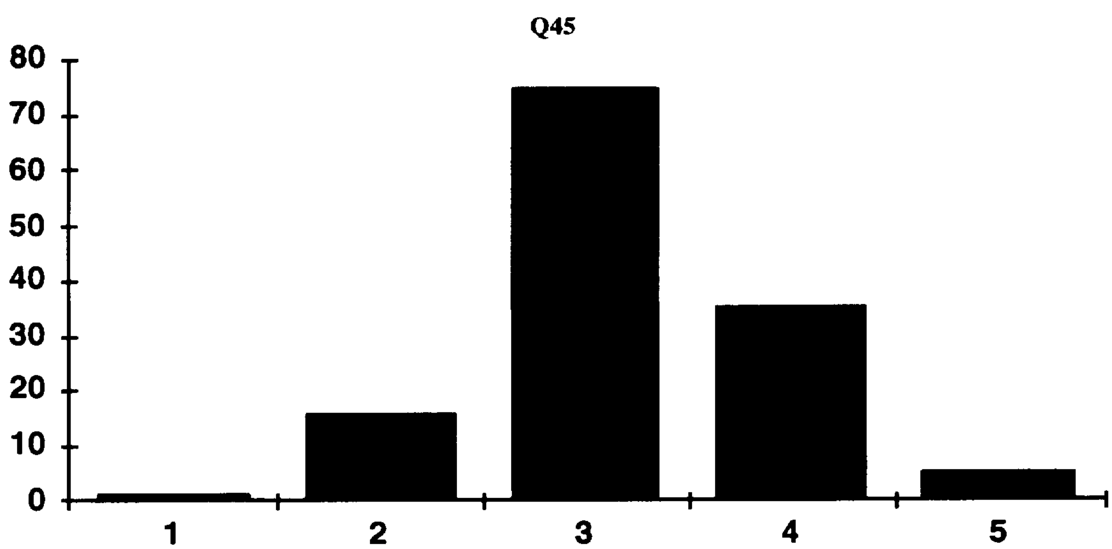

Figure C4. I think the overall amount of information available on my aircraft is:

not enough

too much

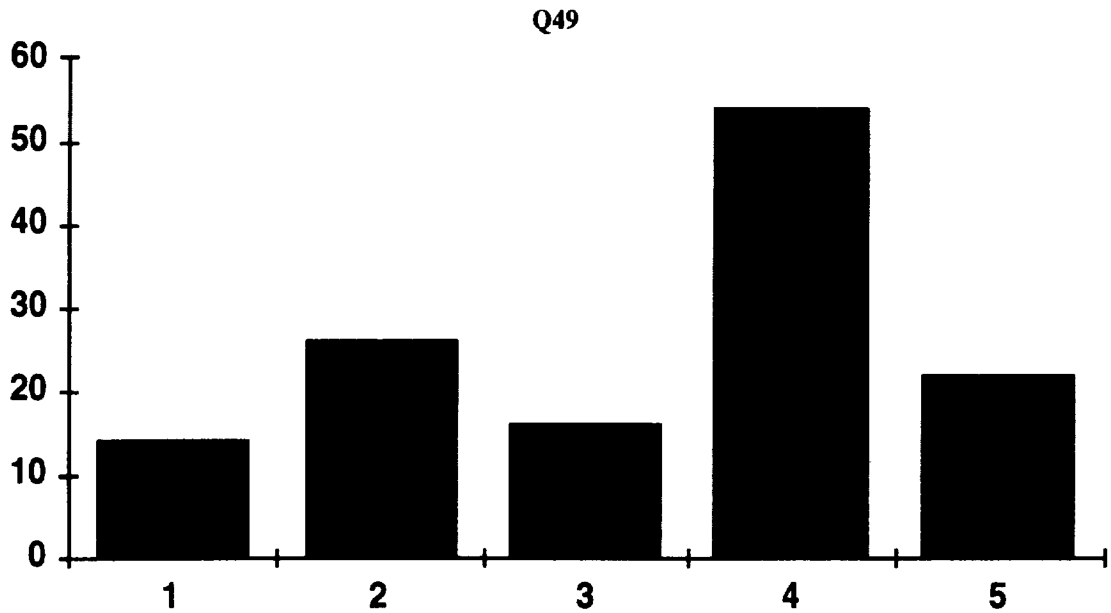

Figure C5. A decision aid should only provide information to the pilot if it is certain that it is 100% correct.:

disagree agree

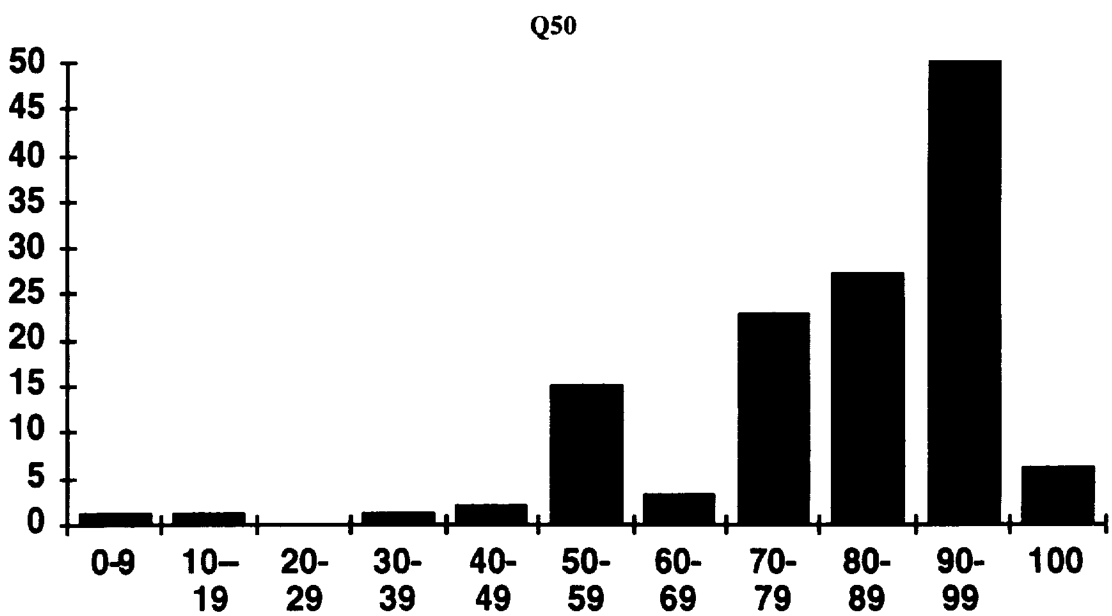

Figure C6. If a decision aid tells me the probability of the choice being correct, I will accept information that has as low as a ____% probability of being correct.

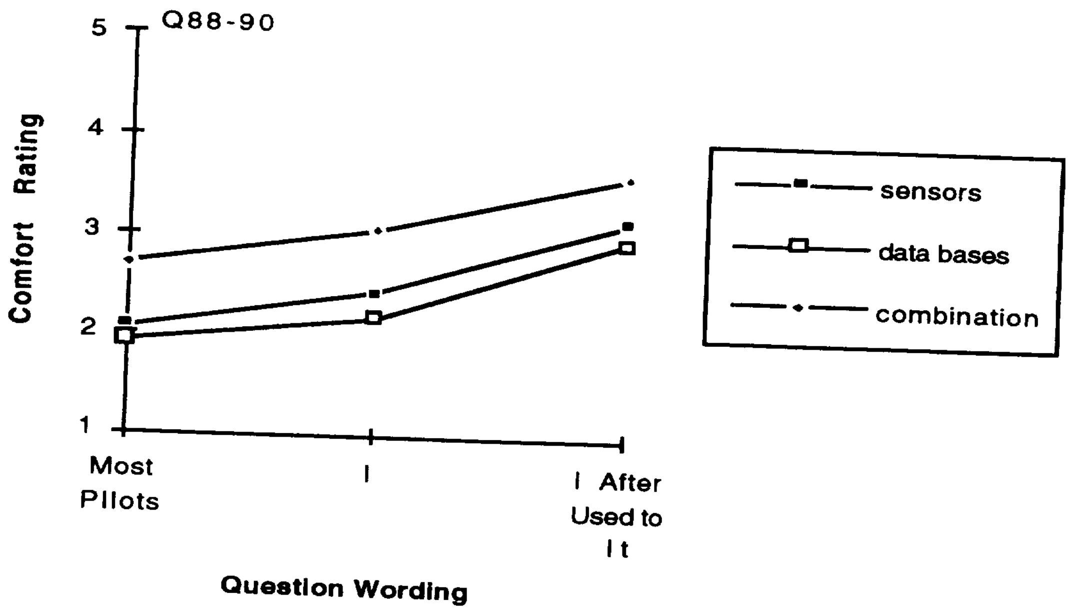

Figure C7. Comfort with different kinds of artificial scene.

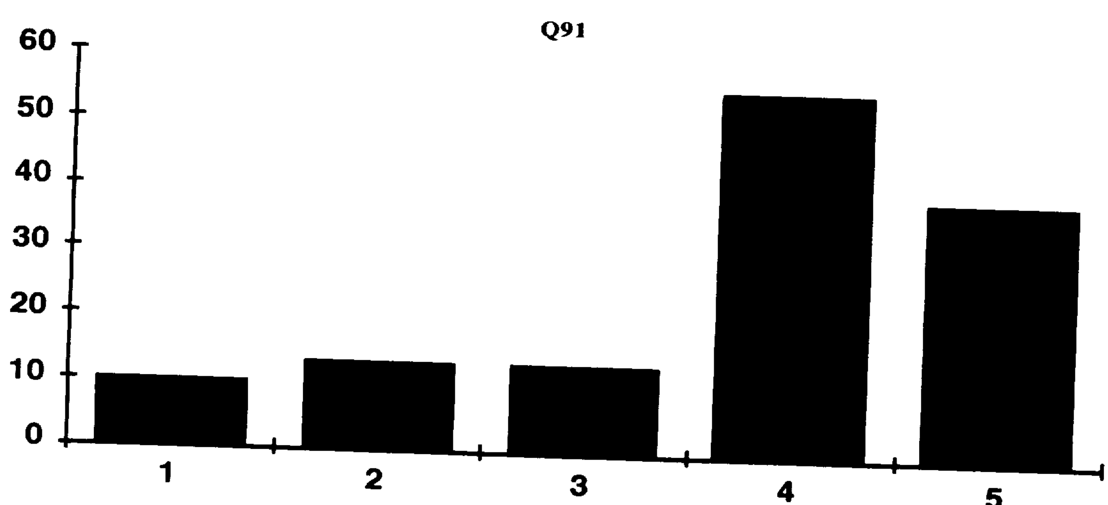

Figure C8. A forward visual scene generated from sensor and/or computer airport and terrain data bases, augmented by symbology like that found on Heads-up displays (HUD's), will likely be presented on a large field-of-view display. Do you think such a display should:

replace the primary flight display

supplement theprimary flight display

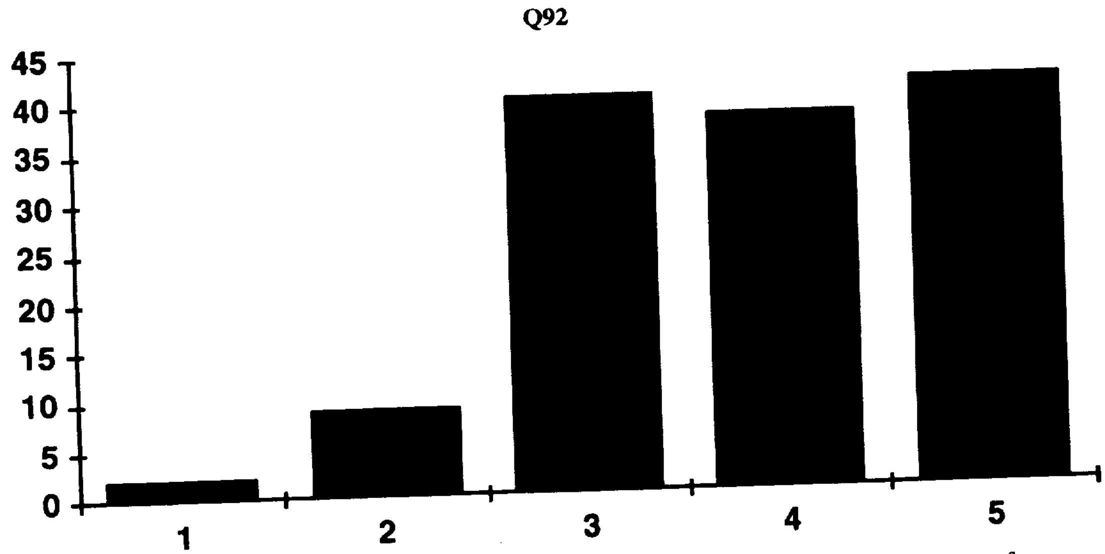

Figure C9. I would be more comfortable if sensors used to detect the runway, surface objects and aircraft in the terminal area were located:

on the ground — on the aircraft

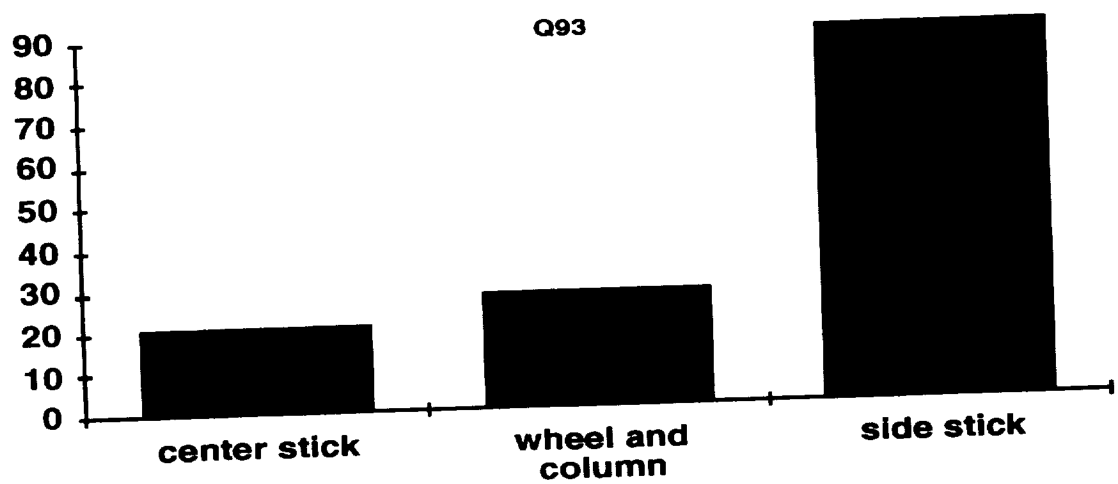

Figure C10. Given that the HSCT will require continuous automated augmentation of the pilots' primary control inputs (cables will not be directly linked to control surfaces), would you prefer your primary control device to be a:

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13. ABSTRACT *(Maximum 200 words)*
There has been much concern in recent years about the rapid increase in automation on commercial flight decks. The survey was composed of three major sections. The first section asked pilots to rate different automation components that exist on the latest commercial aircraft regarding their obtrusiveness and the attention and effort required in using them. The second section addressed general "automation philosophy" issues. The third section focused on issues related to levels and amount of automation. The results indicate that pilots of advanced aircraft like their automation, use it, and would welcome more automation. However, they also believe that automation has many disadvantages, especially fully autonomous automation. They want their automation to be simple and reliable and to produce predictable results. The biggest needs for higher levels of automation were in pre-flight, communication, systems management, and task management functions, planning as well as response tasks, and high workload situations. There is an irony and a challenge in the implications of these findings. On the one hand pilots would like new automation to be simple and reliable, but they need it to support the most complex part of the job-managing and planning tasks, in high workload situations.

14. SUBJECT TERMS
Commercial flight decks, mental workload, pilot survey, levels of automation, automation philosophy, human-centered automation

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