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# Human Factors of Flight-Deck Automation — NASA/Industry Workshop

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**Human Factors of Flight-Deck Automation: A NASA-Industry Workshop**

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**SUMMARY**

With the advent of microprocessor technology, it has become possible to automate many of the functions on the flight deck of commercial aircraft that were previously performed manually. However, it is not clear whether these functions should be automated, taking into consideration various human factors issues.

A NASA-industry workshop was held to identify the human factors issues related to flight-deck automation which would require research for resolution. The scope of automation, the benefits of automation, and automation-induced problems were discussed, and a list of potential research topics was generated by the participants.

This report summarizes the workshop discussions presents the questions developed at that time.

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## INTRODUCTION

Modern microprocessor technology and display systems make it possible to automate many of the functions on the flight deck of commercial airlines that were previously performed manually. In fact, the question today is not whether a function can be automated, but rather should it be automated, taking into consideration various human factor issues. Although there are many real benefits to be derived from automation, it seems highly questionable whether total system safety is always enhanced by allocating functions to automatic devices rather than human operators. For a further discussion of these issues, see references 1 - 5.

A NASA-industry workshop was held on July 17 and 18, 1980, in Burlingame, California to discuss these issues. The workshop was organized by Renwick Curry, Earl Wiener, and Alan Chambers of the Man-Vehicle Systems Research Division of NASA, and administered by Science and Human Values, Inc. The primary objective of the workshop was to define the important research areas involved in the human factors of flight-deck automation and to create a list of general and specific research questions.

Workshop participants (Appendix A) were drawn from NASA, the FAA, the RAF, airline companies, aircraft manufacturing companies, universities, and consulting firms. The participants were chosen for their expertise in automation and human factors and their ability to contribute to the design of a research program in this area. The conference chairman was Renwick Curry of Ames Research Center.

The workshop comprised four major sessions:

Session 1: Group meeting to introduce the participants and discuss the basic human factors issues involved in flight-deck automation.

Session 2: Parallel group meetings to generate a list of issues that require research for resolution. This list was compiled in the form of a set of general research questions.

Session 3: Group meeting to discuss research priorities.

Session 4: Parallel group meetings to generate a list of specific research issues within each general research area.

This report summarizes the research areas described by the participants and presents the questions developed during the workshop.

## SUMMARY OF PLENARY SESSIONS

Prior to the workshop, the participants were asked to consider three questions: (1) What is the scope of "automation" in your field of interest? (2) What benefits does automation provide? and (3) What types of automation-induced problems do you know about? At the beginning of the workshop, each participant was asked to address these questions briefly, and each participant's comments were followed by an open discussion. The issues that arose as a result of this session are summarized here.

### Scope of Automation in Field of Interest

The participants generally agreed that technology is now sufficiently advanced so that it is theoretically possible to automate most systems. However, time and cost constraints often impose practical limits on the scope of automation. For example, in an accident investigation, someone with experience usually goes out to collect information from the site of the accident and to talk to the people concerned. Although it might be possible to build an automated system to accomplish these tasks, such a system would probably be quite expensive to design and use; in addition, the solutions may not be an improvement over those provided by a human expert. On the other hand, fully automated systems such as autoland have been developed and implemented on the flight deck.

The presence of humans in the processing loop also influences the scope of automation. The actual implementation of a system is limited by a pilot's willingness to engage the system (where he has a choice). Anecdotal reports from flight crews have shown that pilots who are not thoroughly familiar with a system, or who feel that the system does not perform as they would like, will not use that system. For example, because of passenger complaints about excessive movement of the aircraft, pilots rarely engage the fully automatic VOR tracking mode of autopilots.

Pilots are also unwilling to engage fully automatic systems for other reasons. When an automated system such as autoland is engaged, the pilot is relegated to the role of a monitor, not a controller, and not only is this less challenging for the pilot, but it may lead to a decrement in the pilot's ability to land the airplane manually.

The driving forces for automation were considered to be mainly economic and safety issues; however, it was pointed out that airlines have allowed new features to be introduced into aircraft simply because the manufacturer included them in the standard version of the aircraft.

### Benefits of Automation

Automation appears to provide two types of benefits. The first is that automation allows certain functions to be performed that could not be performed otherwise, either because humans are not capable of performing the

functions, or because of cost, time, or safety constraints imposed by manual performance. For example, pilots are not allowed to land airplanes manually in Category III weather conditions; they may only land the aircraft by engaging the autoland system.

The second type of benefit derives from the fact that automated systems are often able to provide a better solution to a problem than humans. These benefits are seen in many aspects of flying. From the systems standpoint, automated equipment may be superior to human performance for reasons of cost-effectiveness, reliability, or consistency. From the user standpoint, the benefits include the possibility of the following: decreased workload, an increased safety margin, increased quality of life for the crew and passengers, the ease of learning to operate the system, speed and convenience in actual use, increased operating efficiency, and increased schedule dependability. For example, increased passenger comfort and system operating efficiency can be achieved by allowing a flight management system to compute a flightpath that avoids turbulence while at the same time conserving fuel.

The participants also referred to several possible future benefits of automation. If automation does decrease workload, creating spare time on flights, it might be possible to use that time profitably by providing for on-board training. More attention to the design and use of displays may allow those displays to perform functions that they currently do not serve, such as serving as external memory aids. Moving map displays could provide not only a better representation of the exact location of the airplane at any given time, but also to remind the pilot that he is flying an airplane, not just watching instruments.

#### Automation-Induced Problems

The problems cited by the participants included those that have already been encountered, as well as potential problems in the future.

Violations of benefits - Problems are created by automation whenever the automated system does not actually provide the benefits that have been claimed for it; that is, there will be problems if the automatic system is less reliable, more costly to operate, or creates a heavier workload than the manual system it replaces, or if it creates a decreased safety margin or diminished quality of life. In practice, the participants felt that most first-generation automated equipment exhibits at least some of these negative features. The ground proximity warning system (GPWS), for example, produced many false alarms when it was first introduced into the cockpit. Although succeeding generations of equipment tend to correct initial problems (e.g., GPWS), such has not always been the case.

Credibility - The failure of automated equipment to function as expected leads to a problem of credibility. If users do not trust a system, they are not likely to use it. Credibility extends beyond a gross measure of use or nonuse, however. The limits to which a user trusts a system may vary as a function of past system performance as well as the user's knowledge of a given

system's accuracy. If air traffic controllers are unaware that their consoles are capable of displaying information that is accurate to within a few feet, they will not make appropriate use of the information presented. On the other hand, people may determine locations on maps with greater care and accuracy than are warranted by the original data from which the map was drawn.

Training - The development of a training program is difficult where automated equipment is involved because users must be trained in two capacities: as monitors of the system when it is in the fully automatic mode, and as controllers of the system when it is in any other mode. The skills required to function in these two capacities are not only different, but often in conflict with one another. Controlling a system requires considerable knowledge about the system, proficiency in the manual skills required to operate the system, and flexibility in dealing with the system. The flexibility and individual differences that are beneficial in dealing with a manual system may create problems in dealing with an automated system. Conversely, prolonged use of a system in the automatic mode may lead to a deterioration of manual skills and a loss of proficiency, which may degrade performance on a manual system. Given the conflicting nature of the two functions, the decision about where to place priorities in training is difficult.

In normal use, the system operates in the automatic mode and the user does not need to call on special skills (which are expensive to train). The question then becomes one of cost-effectiveness; that is, is the time required to train users to deal with these rare events worthwhile? The answer to this question is complicated by the fact that even after an initial investment in a full training program, an operator's skills may have deteriorated to a non-useful level by the time any particular emergency arises that calls on those skills. The resolution of this problem may ultimately lie not in cost-effectiveness, but in the question of liability; that is, who is responsible for an accident caused by the malfunction of an automated system. In aviation, the "commodity" at stake is human life, and the cost associated with additional training may be worthwhile.

The task of devising an adequate training program is also hampered by the mixture of old and new equipment in cockpits. Often, pilots are trained on equipment that is from a different generation (older or newer) than the equipment they actually use on the job. An example was given at the workshop of a military officer who received extensive training on a fourth generation console. When he reported for duty, he was confronted with a first generation piece of equipment. He sat there and looked at it for a while and said "Oh, I remember that. In the museum at the school they had that locked up in a case." This problem is not restricted to new pilots; a similar problem occurs when pilots transfer from one type of aircraft to another.

Although it is purported that automated systems are easy to learn, in practice, some of the participants have found that the new systems are harder to learn than the old ones. This is due in part to the fact that newer systems often perform more functions and are generally more complex than the systems they replace.

The introduction of automated equipment on the flight deck also may imply a need to make a change in the pilot selection process. It may be that the current pilots, who are good controllers, will not make good monitors. If this is the case, the selection procedures may need to be changed in the future.

System design - Currently, when new systems are developed and tested, it is done with an eye toward the benefits the new system will provide. The participants felt that too little attention had been paid to the shortcomings of the system. Failure to anticipate problems usually leads to "band-aiding" the system rather than redesigning it, and this was seen as a problem. For example, there has been some discussion about displaying Air Traffic Control (ATC) clearances on a CRT in the cockpit rather than sending them out by voice transmission. The proponents of this approach point out that this will reduce pilot errors that are due to misunderstanding the stated altitude. The proponents fail to point out, however, that pilots would then be subject to reading errors, which may or may not occur as frequently as hearing errors. Pilots may also lose their sense of where other aircraft are located, which they now deduce from hearing clearances for all the aircraft in their vicinity. Another example of a design-induced error can be seen in flight management systems, where incorrect data entered by way of the console can be disastrous. Incidents have already occurred using the inertial navigation system (INS), with pilots entering incorrect information about their waypoints.

Another problem stems from the fact that most systems are designed for use by individuals, not by teams. Airline pilots usually function as part of a two- or three-person crew and the participants felt that this should be considered when systems are designed.

The participants were also concerned with the manner of presenting information to the pilots. They pointed out that information must be presented in a way that minimizes ambiguity and inaccurate interpretation of the information which might lead to misdiagnosis of a problem.

System use - When an automated system is functioning properly, the pilot will be relegated to the role of a monitor for that function. It was felt that pilots might not find this role as challenging as their current role and that this might lead to boredom or "complacency." Although boredom and complacency were not actually defined, these terms might encompass reactions such as pilots failing to "stay ahead of" or even to just "stay up to date" with the current status of the flight. This could lead to disastrous results if the pilot is forced to take over the controls suddenly because of an emergency. In addition to the normal "warm-up" time required to make the transition from monitor to controller, there will be the time required to ascertain the current status of the airplane and assess the situation.

Later in the workshop, the participants were asked to put themselves in the position of a research manager who was given the task of deciding how to

establish priorities for spending research money. They were asked what criteria they would use to assess a research program before making this decision. A number of potential criteria were suggested, but no consensus was reached as to which questions were crucial. This summary, then, reflects suggestions from individual participants.

The first criterion suggested was how important the answer provided by a given piece of research might be toward reaching the final goal. Although the participants felt that this was a worthy consideration, they pointed out that importance was not operationally defined and that perhaps the question should be phrased in terms of how long it would take to get a payoff from the research. They also pointed out that some research that is important may be very difficult, or impossible, to carry out. In some areas, researchers have been unable to develop adequate performance measures. In other areas, the problems do not become apparent until after long-term interaction of pilots with the system, making research on these types of problems very difficult in a laboratory setting. For example, the loss of flying skill that can accompany the use of more advanced, more automated airplanes did not become apparent until a number of co-pilots on these aircraft were upgraded and assigned as captains to less advanced aircraft.

Another consideration is the timing involved. The participants felt that NASA should address issues related to systems that are currently on the drawing board as well as longer-term issues. However, there was a consensus that if research could not be completed in a timely fashion, there was little purpose in initiating it. Some questions need to be answered so quickly that it is impossible to carry out the appropriate research.

The participants also suggested that consideration should be given to the history of the problem; that is, how big is the problem, how much work has already been done in this area, and do the answers already exist? In answering these questions, it will be important to assess how directly the existing research addresses the current problem. For example, there is a current controversy over the mandatory retirement age of 60 for air carrier pilots. Although there is a large body of research that shows the effect of age on variables such as choice reaction time, psychomotor skills, and cognitive skills, the evidence does not directly address the effect of age on the ability to fly an airplane.

Lastly, the participants suggested that it is important to consider the goals of the organization doing the research and whether the proposed research is directed toward those goals. In the context of the workshop, the participants suggested that NASA should be involved in high-risk, long-term ventures that try to answer some of the larger questions rather than short-term ventures that answer design questions. They also felt that NASA should be working toward creating a "handbook" of guidelines for the industry and that this handbook should include standards for things that should not be done as well as for things that should be done. The participants suggested that this handbook might also contain some sort of "sensitivity curves" to show how the ability to perform a given task decays as a function of the time elapsed since

the task was last performed.

These suggestions led to a discussion of whether such a handbook would actually be used and to the more general question of how to implement the findings from human factors research. A large body of human factors research has been produced over the last 40 years and the participants felt that the systems designers have not always used that information; however, no consensus on how to alleviate this problem was reached.

## SUMMARY OF PARALLEL SESSIONS

### Question Formulation

The primary objective of the workshop was to develop a list of research topics on the human factors of flight-deck automation. In the second and fourth sessions of the workshop, the participants were divided into two groups of equal size. In the second session, the groups were formed so that the mixture of background interests would be roughly the same in both groups. Each group was asked to generate a list of 25 to 30 broad subjects for automation research. They were asked to choose topics that were not so broad as to provide little or no guidance, but which were not so specific that a single simulation or analysis would answer the question. In the fourth session, the participants were divided so that those with applied backgrounds were in one group, and those with basic research backgrounds were in the other group. In this session, the participants were asked to generate more specific research questions to complement the broader questions generated during the previous session.

The questions generated by all of the groups were compiled in a single list. The questions were reworded as necessary to avoid ambiguity and redundancy, and they were grouped into six categories: systems questions, implementation, methodology, selection and training, man-machine interactions, and field studies. This classification process proved to be difficult since many categorizations were possible, and since within any given classification system, questions were often related to more than one category. This was especially true for the man-machine-interaction category. Subcategories reflecting the human side of the interaction were used (e.g., use of information, representation of information), but equally feasible subcategories describe the task (e.g., controlling, monitoring, planning, decision-making). These task-related aspects are incorporated in the list although they are not highlighted. It should also be noted that the order of the categories and of the questions within each category does not reflect the relative importance of the questions.

### Questions Regarding Flight-Deck Automation

The complete list of questions can be found in appendix B. For the purposes of brevity, only the major questions under each heading are included here. Questions under second level headings in section 5 (5.1, 5.2, etc.), were deleted for the sake of clarity.

#### 1. Systems Questions

1.1 How can levels of cockpit automation be varied to make them compatible with the ATC system?

1.2 How can the benefits and costs of automation be assessed?

1.3 What techniques can be developed for testing system integrity and immunity to human error, particularly to errors arising from use/misuse of the hardware and software?

#### 2. Implementation

2.1 What attributes of automation influence its acceptability and use? How can attitudes toward automation be modified?

2.2 To what extent must individual models of aircraft be considered in making design recommendations and guidelines?

#### 3. Methodology

3.1 Can better ways of measuring crew performance levels and crew workload levels be found?

3.2 Can efficient techniques be designed to investigate rare failures in man-machine systems?

#### 4. Selection and Training

4.1 What are the implications of automation for crew selection criteria/methods?

4.2 What are the problems associated with the transition of pilots across aircraft types and different generations of automated equipment?

4.3 How does automation affect the acquisition and retention of psychomotor and cognitive skills?

4.4 To what extent is on-board training feasible and beneficial?

4.5 Will older or highly experienced pilots be able to adapt readily to advanced equipment? If not, what procedures can be developed to lessen the problem?

## **5. Man-Machine Interaction**

- 5.1.1 How should decision-aiding and decision-making techniques be used?
- 5.1.2 How can data transfer between the device and the crew be improved by effective systems design?
- 5.2.1 How much systems information should the operator be given?
- 5.2.2 How should information given to the operator be represented?
- 5.3.1 What features of tasks make them easy or difficult?
- 5.4.1 What are the advantages and disadvantages of the human monitoring the automatic system, rather than actively controlling it?
- 5.4.2 What can be done to improve the performance of the human acting as a monitor, particularly in his failure-detecting/correcting ability?
- 5.4.3 How will the automatic system and the operators deal with unforeseen and unplanned circumstances?
- 5.5.1 Are there negative psychosocial consequences of automation?
- 5.5.2 To what extent does increased automation lead to boredom and complacency?
- 5.6.1 How should operational procedures for highly automated aircraft be designed? What callouts should be made? By whom? How and when should checklists be used?
- 5.6.2 How does automation influence the choice of crew size and the role that each crew member plays?
- 5.6.3 Apart from crew size, how does automation affect the organization and operation of the crew as a team?

## **6. Field Studies**

- 6.1 Develop a data base, a data base system, and a data collection system for doing research on operational history and operating experience with automated systems. Use this data base to identify today's critical problems.
- 6.2 Use case studies of past commercial aircraft and appropriate military aircraft to examine past automation decisions.
- 6.3 Conduct a user survey to determine attitudes toward the use of currently available automation.
- 6.4 Perform an observational study to determine actual use patterns for automated equipment.
- 6.5 Conduct a risk assessment survey of the use, nonuse, or misuse of automated features of aircraft to identify the current problems.

## WORKSHOP SUMMARY

There was no formal definition of the term "automation" proposed at the workshop, but the operating definition seemed to be the allocation of tasks (a task performed by a machine was considered to be automated even if both the human and the machine were performing the same task in parallel). This definition led to the consideration of questions in many disciplines, e.g., training, equipment design, interactive systems, planning, and decision making.

Not surprisingly, the majority of research topics produced by the workshop (about 75%) concerned Man-Machine Interaction, although the impact of automation in other areas was not overlooked. We asked the participants, while reviewing a draft of this report, to rate the major research areas (pp. 10-11) in terms of the importance and urgency of the information in that particular area. This was not an easy task, primarily because of the wide differences in specificity of the topics. The compilation of the ratings showed a consensus that the most important/urgent topics were 1.3 (What techniques can be developed for testing system integrity and immunity to human error...) and 5.4.3 (How will the automatic system and the operator deal with unforeseen and unplanned circumstances?). The least important/urgent topics, according to the ratings, were 5.5.1 (Are there negative psychosocial consequences of automation?) and 2.2 (To what extent must individual models of aircraft be considered in making design recommendations and guidelines?)

Although the list of research issues generated in the workshop is a broad one, we recognize that some topics of interest may not have been covered and invite suggestions for additional topics to be included.

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Appendix A

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## **Appendix B**

### **Questions Regarding Flight-Deck Automation**

#### **1. Systems Questions**

1.1 How can levels of cockpit automation be varied to make them compatible with the ATC system?

1.2 How can the benefits and costs of automation be assessed?

1.3 What techniques can be developed for testing system integrity and immunity to human error, particularly to errors arising from use/misuse of the hardware and software?

#### **2. Implementation**

2.1 What attributes of automation influence its acceptability and use? How can attitudes toward automation be modified?

2.2 To what extent must individual models of aircraft be considered in making design recommendations and guidelines?

#### **3. Methodology**

3.1 Can better ways of measuring crew performance levels and crew workload levels be found?

3.1.1 What are the ways in which the flight crew might be assisted to determine their own workload level in order to smooth out the peaks and troughs which are now common?

3.2 Can efficient techniques be designed to investigate rare failures in man-machine systems?

#### **4. Selection and Training**

4.1 What are the implications of automation for crew selection criteria/methods?

4.2 What are the problems associated with the transition of pilots across aircraft types and different generations of automated equipment?

4.3 How does automation affect the acquisition and retention of psychomotor and cognitive skills?

4.3.1 How quickly do manual and cognitive skills deteriorate with lack of use? What factors influence the rate of loss?

4.3.2 What factors lead to an increase in the retention of infrequently used skills?

4.3.3 Can automation be used to successfully increase the rate of skill acquisition in complex tasks by automating some of the subtasks?

4.3.4 What is the effect of system complexity on crew training and the retention of training?

4.4 To what extent is on-board training feasible and beneficial?

4.4.1 Can computer-aided learning/instruction (CAL/I) be used for specific on-board training, e.g., emergency procedures?

4.4.2 Will on-board training help in maintaining proficiency and ability to handle sudden and unexpected critical events?

4.4.3 Does on-board training entail any risks?

4.5 Will older or highly experienced pilots be able to adapt readily to advanced equipment? If not, what procedures can be developed to lessen the problem?

## 5. Man-Machine Interaction

### 5.1 Use of Information

5.1.1 How should decision-aiding and decision-making techniques be used?

5.1.1.1 Does this technology cause the pilot to be more detached from his aircraft and the real world? If so, what are the consequences of this?

5.1.1.2 To what extent should strategic planning (routes, clearances, etc.) be handled on the flight deck rather than on the ground?

5.1.1.3 Can this technology be used to allow for in-flight alternate planning?

5.1.1.4 Can automation be used to make caution and alerting systems more comprehensible, and perhaps "intelligent"? How can these systems be evaluated?

5.1.1.5 When will the pilot accept the conclusion of the "smart" system and when will this conclusion be questioned and challenged?

5.1.1.6 What are the characteristics of an ideal (but attainable) alerting and warning system?

5.1.1.6.1 What are the most effective kinds and amounts of diagnostic information the pilot can use in the time he has available?

5.1.1.6.2 Can the format of diagnostic information be adapted as a function of how the pilot seeks information about the system?

5.1.1.7 What events lead to a general or permanent distrust of automated devices?

5.1.1.8 When a decision aiding device presents the user with a decision, how much information should the user be given about the factors which have and have not been considered in making the decision?

5.1.2 How can data transfer between the device and the crew be improved by effective systems design?

5.1.2.1 Should system languages be written to match the "mental model" of the pilot?

5.1.2.2 How can data bases be constructed and accessed to assure speed, convenience to the crew, and their full utilization?

5.1.2.3 How should on-board displays be designed and used to reduce the short-term and long-term memory load?

5.1.2.4 What are the significant variables influencing decisions to use various input devices: multimode keyboards, dedicated keyboards, and voice-actuated controls?

## 5.2 Representation of Information

5.2.1 How much systems information should the operator be given?

5.2.1.1 What effect does the amount of knowledge about the system have on system performance (normal and failure modes)?

5.2.1.2 Should system integrity information be available to the flight crew at all times?

5.2.1.3 How can software errors be detected and identified so that appropriate warning can be supplied to the flight crew?

5.2.1.4 What is the role of time-based information (historical or predictive) in automated systems?

5.2.1.4.1 How can "the time dimension" (historical and predictive information) best be represented on the pilot's display?

5.2.1.4.2 What is the effect on pilot performance of providing a predictor display of various aircraft parameters, such as airspeed, altitude, and position?

5.2.1.4.3 Will the efficiency of a predictor device decay over time and become detrimental if it predicts too far ahead? If so, is the decay function for aural and visual modes different?

5.2.2 How should information given to the operator be represented?

5.2.2.1 How can information be coded to show its accuracy and reliability?

5.2.2.2 If the automatic device is changing the system configuration, should it make the change automatically and inform the operator, or make the change only after operator acknowledgment? Should it tell the operator why it is making the change?

5.2.2.3 What are the relative merits of visual versus auditory communication for air-ground dialogues?

5.2.2.3.1 Is it important that the mental image of the surrounding traffic, developed by auditory communication, might be destroyed when the visual display of ATC communication is used?

5.2.2.4 How can pilots' mental models of systems be determined? Are the mental models of different pilots sufficiently similar for it to be feasible to complement their mental models in display presentations?

5.2.2.5 Can automation improve the extent to which on-board aircraft systems can be temporarily modified, or altered, to better accommodate individual differences among crews and/or crew members?

5.2.2.6 When should the information content of displays be controlled automatically and when should it be controlled manually?

### 5.3 Task Features

#### 5.3.1 What features of tasks make them easy or difficult?

5.3.1.1 What features make tasks easy or difficult to time-share?

5.3.1.2 What features make tasks sensitive to interruptions?

### 5.4 Monitoring Aspects

#### 5.4.1 What are the advantages and disadvantages of the human monitoring the automatic system, rather than actively controlling it?

5.4.1.1 How should the operator perform as systems degrade? How will the system communicate its failure to the operator?

5.4.1.1.1 Can a diagnostic computer be used to tell the operator the degree to which he must assume active participation in control, increased monitoring, or further investigation of problems?

5.4.1.1.2 Given that a system failure does not involve a loss of function or have immediate detrimental consequences, what information about the failure, if any, should the pilot be given?

5.4.1.2 How will the system become aware of and deal with human failure?

5.4.1.2.1 What are the problems associated with flight crew data entry errors in present (e.g., INS and ACARS) and planned (e.g., B-767) cockpit man-computer interfaces?

5.4.1.3 What are the advantages and disadvantages of the prioritization of alarms?

5.4.1.4 Can functional tasks and displays be devised that will keep the aircrew member "in the loop"? Is this always desirable?

#### 5.4.2 What can be done to improve the performance of the human acting as a monitor, particularly in his failure-detecting/correcting ability?

5.4.2.1 Is there a "warm-up" delay when he transitions from passive monitor to active controller in the event of a failure? If so, can this be prevented by system design?

5.4.2.2 How can monitoring of the other crew members' functions be performed in other than a random manner? Can or should it be more systematized as is supposedly done during final approach?

5.4.2.3 How can monitoring be improved in highly distractive situations, such as intense communications workload, unanticipated changes in plan, system or other emergencies?

5.4.2.4 Does automation lull the monitor into states of low alertness when he is primarily a monitor? Can the operator-monitor be easily distracted from his monitoring task by unimportant stimuli (e.g., casual conversation)?

5.4.2.5 What are the behavioral and performance differences between simple and complex monitoring tasks?

5.4.2.6 What means are available (or could be developed) for maintaining a monitor's alertness? Artificial signals? Will additional workload help or harm primary monitoring task performance?

5.4.3 How will the automatic system and the operators deal with unforeseen and unplanned circumstances?

5.4.3.1 When these occur suddenly, and the human must assume control, how can a smooth transition take place? How will it be determined that a transition is necessary? What are the human limitations in dealing with these problems?

5.4.3.1.1 Is the ability to make a smooth transition conditionable or trainable? If so, how?

5.4.3.1.2 How is pilot reaction time and correctness of response affected by early warning of impending reversion to another operational mode?

5.4.3.1.3 To what degree can procedural precautions minimize pilot reaction time and enhance the probability of correct initial input?

5.4.3.1.4 What role does startle threshold/reaction play?

5.4.3.1.5 Under what conditions should flight control systems fail active, passive, or safe?

5.4.3.1.6 To what degree can initial and recurrent training minimize the undesirable effects of such reversions?

5.4.3.1.7 What effect will training have on user confidence in, and willingness to use, the automated equipment? (worst case/time training?)

## 5.5 Psychosocial Aspects

5.5.1 Are there negative psychosocial consequences of automation?

5.5.1.1 If so, what precautions and/or remedies will be effective?

5.5.1.2 How will automation influence job satisfaction, prestige, and self-concept?

5.5.2 To what extent does increased automation lead to boredom and complacency?

5.5.2.1 What causes boredom?

5.5.2.2 Can people be trained to cope with boredom?

5.5.2.3 What kind of nonproductive or hazardous behavior is apt to result from boredom?

5.5.2.4 Are individual differences in boredom and complacency operationally important? How are these differences measured?

5.5.2.5 Can techniques, methods, or systems be designed to reduce or eliminate boredom and complacency?

5.5.2.5.1 Can vigilance be improved by filling periods of inactivity with other activities (e.g., computer games, advance planning, refresher training)?

## 5.6 Resource Management

5.6.1 How should operational procedures for highly automated aircraft be designed? What callouts should be made? By whom? How and when should checklists be used?

5.6.2 How does automation influence the choice of crew size and the role that each crew member plays?

5.6.2.1 How does automation affect the role of a pilot in a one-person crew, such as in commuter airlines?

5.6.3 Apart from crew size, how does automation affect the organization and operation of the crew as a team?

## 6. Field Studies

6.1 Develop a data base, a data base system, and a data collection system for doing research on operational history and operating experience with automated systems. Use this data base to identify today's critical problems.

**6.2 Use case studies of past commercial aircraft and appropriate military aircraft to examine past automation decisions.**

**6.2.1 Compare commercial and military design decisions.**

**6.2.2 Retrospectively, was the decision to automate a function such as autoland a wise one? Why?**

**6.2.3 What was right and what was wrong with the implementation and introduction of the automated systems?**

**6.3 Conduct a user survey to determine attitudes toward the use of currently available automation.**

**6.4 Perform an observational study to determine actual use patterns for automated equipment.**

**6.5 Conduct a risk assessment survey of the use, nonuse, or misuse of automated features of aircraft to identify the current problems.**