General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Produced by the NASA Center for Aerospace Information (CASI)

NASA TECHNICAL MEMORANDUM

NASA TM X-62,472

NASA TM X-62,472

(NASA-TM-X-62472) A METHOD FOR THE STUDY OF HUMAN FACTORS IN AIRCRAFT OPERATIONS (NASA) 49 p HC $3.75 CSCL 05E

N75-32747

Unclas

G3/53 41388

A METHOD FOR THE STUDY OF HUMAN FACTORS IN AIRCRAFT OPERATIONS

William Barnhart, Charles Billings, George Cooper, Rod Gilstrap, John Lamber, Harry Orlady, Bert Puskas, and Warren Stephens

Ames Research Center
Moffett Field, California 94035

OCT 1975
RECEIVED
NASA STI FACILITY
INPUT BRANCH

September 1975

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
TM X-62,472		

4. Title and Subtitle	5. Report Date
A METHOD FOR THE STUDY OF HUMAN FACTORS IN AIRCRAFT OPERATIONS	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
W. Barnhart, C. Billings, G. Cooper, R. Gilstrap, J. Lauber, H. Orlady, B. Puskas, W. Stephens	A-6237
9. Performing Organization Name and Address	10. Work Unit No.
NASA Ames Research Center Moffett Field, Calif. 94035	504-09-32
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
National Aeronautics and Space Administration Washington, D. C. 20546	Technical Memorandum
	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared by an informal NASA — industry working group. Industry numbers are from United Airlines, the Air Line Pilots Association, Douglas Aircraft Company and G. E. Cooper Associates.

16. Abstract

This report describes a method for the study of human factors in the aviation environment. It provides a conceptual framework within which pilot and other human errors in aircraft operations may be studied with the intent of finding out how, and why, they occurred. An information processing model of human behavior serves as the basis for the acquisition and interpretation of information relating to occurrences which involve human error. A systematic method of collecting such data is presented and discussed. The classification fo the data is outlined.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Human factors Pilot error Human error Man/machine integration Aircraft operations Behavioral sciences Man/system technology	Unlimited STAR Categories — 03,53

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	47	$3.75

*For sale by the National Technical Information Service, Springfield, Virginia 22151

CAUTIONARY NOTE

This report is intended as a guide for persons trained in the application of human factors principles of aviation problems. It is not and cannot be a substitute for a thorough grounding in this field, and the application of these methods by untrained people may lead to erroneous or misleading conclusions.

PRECEDING PAGE BLANK NOT FILMED

CONTENTS

Introduction 1

Glossary 4

1. Task Analysis in the Study of Human Factors in Aircraft Operations 7

2. The Collection of Human Factors Data in Aircraft Operations 21

3. Classification of Human Factors in Aircraft Operations 36

Summary 42

PRECEDING PAGE BLANK NOT FILMED

INTRODUCTION

Human behavior is generally believed to be responsible for a substantial majority of both fatal and non-fatal aircraft accidents throughout the world. The social and economic costs of these accidents are high and rising rapidly despite comparatively low overall accident rates. If further progress is to be made in the field of aircraft accident prevention, it is imperative that a concerted effort be directed at accidents and other anomalies caused by human error.

It has long been recognized by aviation safety workers that the attribution of an accident or incident to "pilot error" leaves unanswered the question of why the error was committed. Yet attempts to answer this most difficult question have often been thwarted by a lack of evidence, especially in fatal accidents. The investigation of incidents has been somewhat more productive, but even here, problems related to legal liability and punitive measures have inhibited the free flow of information regarding the possible reasons why an error occurred.

As a result, we do not have a clear understanding of the factors which cause even well-trained, professional pilots to become involved in errors at critical points in flight. Neither do we understand, except in isolated cases, the factors which may be responsible for their failure to recognize and react to presumably clear warnings, or to intervene under circumstances which seem to clearly require such intervention. We lack, in short, understanding of the microstructure of human behavior in the

aviation environment, and thus an understanding of the causes of human errors in that environment.

In an effort to gain a better understanding of these problems, a small group of interested aviation workers began to meet and discuss them in November, 1973. The group included professional pilots, flight surgeons, psychologists and engineers, all active in the field of aviation safety. The meetings were held under the auspices of NASA's Ames Research Center.

The group has attempted to examine the range of human and system problems which may be associated with human errors in aircraft operations. This working paper is an outgrowth of that examination. Its intent is to provide a structure and format within which systematic and comprehensive investigations of behavioral problems in aircraft operations can be undertaken.

The paper has three sections. The first examines the conceptual framework of our investigative method. It attempts to characterize human behavior in terms which can lead to an understanding of why that behavior may have occurred.

The second section is a guide for interviewers who may have occasion to collect information from pilots or others in the system who have observed an occurrence involving human factors or human errors. The section seeks to help the interviewer to inquire systematically into all of the system and other factors which may have been related to the occurrence under study.

The third section introduces a classification system which we have developed in order to derive general conclusions from our examination of a considerable number of reports of occurrences, incidents and accidents in air transportation. It is provided to help those who may collect such data to understand the necessity for comprehensive inquiry into each such event. This section is not an exhaustive explanation of the classification scheme, which is described more fully in an annex to the working paper, available on request from the authors.*

We have chosen to publish this preliminary working paper at this time in the hope that our colleagues in the aviation safety field will examine it, criticize it and share with us their suggestions for its improvement. Their comments will be welcomed by the authors and will be acknowledged in future revisions.

William Barnhart
Charles Billings
George Cooper
Rod Gilstrap
John Lauber
Harry Orlady
Bert Puskas
Warren Stephens

*: Requests and comments may be directed to:

Charles E. Billings, M.D.
Man-Machine Integration Branch, 239-3
NASA-Ames Research Center
Moffett Field, California 94035

GLOSSARY

The following definitions describe the specific meanings of a number of terms used in this working paper. The sources of many of the definitions are given.

ACCIDENT: An occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, in which any person suffers death or serious injury as a result of being in or upon the aircraft or by direct contact with the aircraft or anything attached thereto, or the aircraft receives substantial damage.

ANOMALY: A deviation from the common rule; an irregularity. As used here, an anomaly is a departure from normal or expected performance in the course of a mission. The departure from normal operation may be that of the airplane, including its components, its crew or others concerned with the direction and control of aircraft. Synonym: Operational anomaly. A <u>behavioral anomaly</u> is a departure from normal or expected performance of some person -- an error. Carl Lager's term "dysfunction" -- an unwanted result of operation, an unwanted system state or unwanted component response -- is analagous.

BACKGROUND: This term includes all relevant activities to the conduct of a mission which take place prior to the beginning of a flight.

ERROR: An act involving a departure from...accuracy; a mistake.

FACTOR: One of the elements that contribute to produce a result; a constituent.

FACTOR, ASSOCIATED: An element which is present in the history of an anomaly and which is pertinent to the occurrence under study, but which does not fulfill the requirements of an enabling factor.

FACTOR, ENABLING: An element which is present in the history of an anomaly and without which the anomaly probably would not have occurred.

FLIGHT: A flight begins when an airplane's engines are started, or when it is moved from its blocks for the purpose of undertaking a mission. It ends when the airplane is parked at its blocks and engine shut-down is complete, or when it comes to rest following an impact with the surface of the earth.

FUNCTION: A distinctive process or activity; a useful activity. As used here, a specific class of behavior.

INCIDENT: An unwanted occurrence less serious than an accident, which involves any of several specific classes of occurrence:

Flight control system malfunction or failure;
Inability of a flight crew member to perform his duties because of injury or illness;
Turbine engine rotor failures of certain types;
In-flight fire;
Aircraft collide in flight.

MISSION: This term refers to the composite of pilot and vehicle functions which must be performed to fulfill a given set of operational requirements. Those operational requirements impose the boundaries on expected operation during a flight.

POST-ANOMALY: This term includes all activities related to the conduct of a mission which occur after an anomaly and prior to the end of a flight.

POST-FLIGHT: This term includes all activities related to the conduct of a mission which take place subsequent to a flight. It includes post-crash rescue and survival efforts.

PRE-ANOMALY: This term includes all relevant activities from the beginning of a flight to the occurrence of an anomaly.

PRE-FLIGHT: This term includes all activities relevant to a mission which occur prior to the beginning of the flight.

PROCESSING: The act of making a decision.

STRESS: Any element in the environment of man which evokes a response.

SUBSYSTEM: A complex of aircraft components, as: electrical system, hydraulic system, etc.

SYSTEM, AVIATION: The total complex of persons, components and facilities involved in the movement of persons and cargo by air.

1. TASK ANALYSIS IN THE STUDY OF HUMAN FACTORS IN AIRCRAFT OPERATIONS

The immediate goals of a human factors study of an aircraft anomaly, incident or accident are to discover, first, what role human behavior may have played in the causal chain of events, and second, to discover why the people in the system behaved as they did. The ultimate objective of such a study is to develop measures which can be used to prevent a recurrence of inappropriate behavior, or to minimize the effects of such behavior on the safety of the operation.

One way to approach these objectives is described in this working paper. Nearly all studies of aircraft incidents and accidents involve the construction of a chronology, or time line, which describes each significant event known to have occurred prior to the incident, and if appropriate, afterward. We also construct such a chronology, with particular emphasis on the behavioral events, relating them as closely as possible to all other events in the sequence. In this process, we attempt to discover or infer what effect the behavioral events may have had upon the sequence, and also what external events may have motivated a particular behavior. We call this process a <u>function analysis</u>. It is described in more detail below. It should be noted that the function analysis must encompass the behavior of all of the people concerned with a particular occurrence, not merely the pilot or cockpit crew.

The function analysis can often help to demonstrate the role which human behavior played in the causation of the incident under study.

In non-catastrophic incidents, it can also help to demonstrate what behavioral events may have aided the recovery of the system after the deviation occurred. It cannot, however, provide a full insight into why the people in the system behaved as they did. We therefore include a second, parallel analysis in our study of these occurrences. This is called an information processing analysis. In this part of the study, one examines:

a. the sources of information available to each person involved in the occurrence;

b. which information was perceived and used and in what ways;

c. what decisions were arrived at from the alternative choices available, and

d. whether the actions taken were in consonance with the decisions.

The information processing analysis can often help to demonstrate why the various people in the system acted as they did. Equally important, it can often demonstrate what actions must be taken to prevent a recurrence of inappropriate behavior, or to minimize the potential impact of such behavior on system safety. These actions may involve any one of the many elements in the aviation system, or a number of them.

The Function Analysis

As used here, the term "function" describes a set of tasks which shares a common subsystem goal and encompasses a common category of behaviors. Table 1 shows the functions considered necessary to fulfill mission objectives in civil aircraft operations.

Table 1: BEHAVIORAL FUNCTIONS IN AIRCRAFT OPERATIONS

FUNCTION	SUBSYSTEM GOAL	CATEGORY OF BEHAVIORS
	INTELLECTUAL FUNCTIONS:	
COGNITION or COGNITIVE BEHAVIOR	Acquisition of information regarding the position or status of the aircraft, the system and the environment.	Attention to external objects, perception of information, awareness of that information, & appreciation of the implications of the information.
DECISIONS; DECISION-MAKING BEHAVIOR	Selection of rules and of actions with which to implement the assigned mission.	Decision-making, concept formation, problem-solving, management skills.
	IMPLEMENTATION FUNCTIONS:	
FLIGHT or GROUND HANDLING	Control of the airplane's attitude and position in space and time.	Closed-loop manual tracking of airspeed, attitude, direction and altitude. Perceptual-motor skills.
SUBSYSTEM OPERATION	Operation of aircraft or ground-based subsystems in order to implement a decision.	Sequential discrete operation of switches and other controls; implementation of memorized or written procedures.
SUBSYSTEM MONITORING	Detection and identification of undesired subsystem states.	Monitoring behavior; scanning; vigilance.
COMMUNICATIONS BEHAVIOR	Transmission and reception of information.	Verbal and non-verbal communications skills.

Cognitive behavior is listed first in the table to indicate its priority among the functions. Cognition encompasses the behaviors by which a person becomes aware of, and obtains knowledge about, his relationship to his environment. In aviation, the flight crew and certain others (air traffic controllers, dispatchers) must all have knowledge of an airplane's location, status and intentions. Cognition is the process whereby each person acquires and appreciates this information.

Having become cognizant of the required information, each of the persons in the aviation system is in a position to do something about it. The process involved is called decision-making. A decision is the formulation of a course of action (from among a limited number of alternatives) with the intent of executing it. A decision may, of course, be to allow things to continue as they are: to do nothing. The process of decision-making is considered in more detail in the following section.

The execution, or implementation, of a decision involves one or more actions. The remaining functions in table 1 may be thought of as implementation functions: the actions one takes to implement a decision. In a sense, they all involve the same goal; they are separated, however, because they represent fundamentally different categories of behavior.

A simple example may help to illustrate the functions as they apply to aircraft operations. Approaching an airport in a terminal area, a pilot may become cognizant that the visibility is excellent and that there are few aircraft operating in the area. Based on his appreciation of the implications of this information for his on-time arrival, the pilot may decide to "cancel IFR" and to complete his flight by visual flight rules, an alternative mode of operation open to him.

Execution of this decision will require the use of some combination of the four implementation functions; it is important to note that the nature of the decision determines the appropriateness of the tasks which comprise the implementation functions. For example, certain subsystem

operation tasks which were appropriate when operating under IFR are no longer appropriate when the decision to proceed under VFR has been made.

In implementing this decision, the pilot must communicate his intentions to his crew and to the air traffic controller handling his flight. He must select and communicate on the radio frequencies appropriate to VFR operations (subsystem operation). He must continue to monitor the status of his aircraft and must also monitor the environment for conflicting traffic. He may elect to control the airplane manually (flight handling) or he may perform this function through the autopilot (subsystem operation).

The human factors investigator must consider what decisions have been made in order to evaluate properly the "correctness" of the resultant behavior -- the performance of the implementation functions. Conversely, changes in the airplane's position or status caused by the performance of these implementation functions generate signals on instruments, etc., which are perceived, appreciated and become the basis for further decisions. This interdependence of the various functions is the principal reason why the function analysis, or behavioral chronology, must be as complete as possible. The development of a comprehensive behavioral chronology is aided immeasurably by the presence and cooperation of the flight crew, for in their absence the investigator must often resort to inferences in place of facts.

In summary, the function analysis is used to develop a chronology of the significant behavioral events in an incident or accident sequence, and to structure that chronology in such a way that behavioral events can be related to the occurrence of other significant events in the time line.

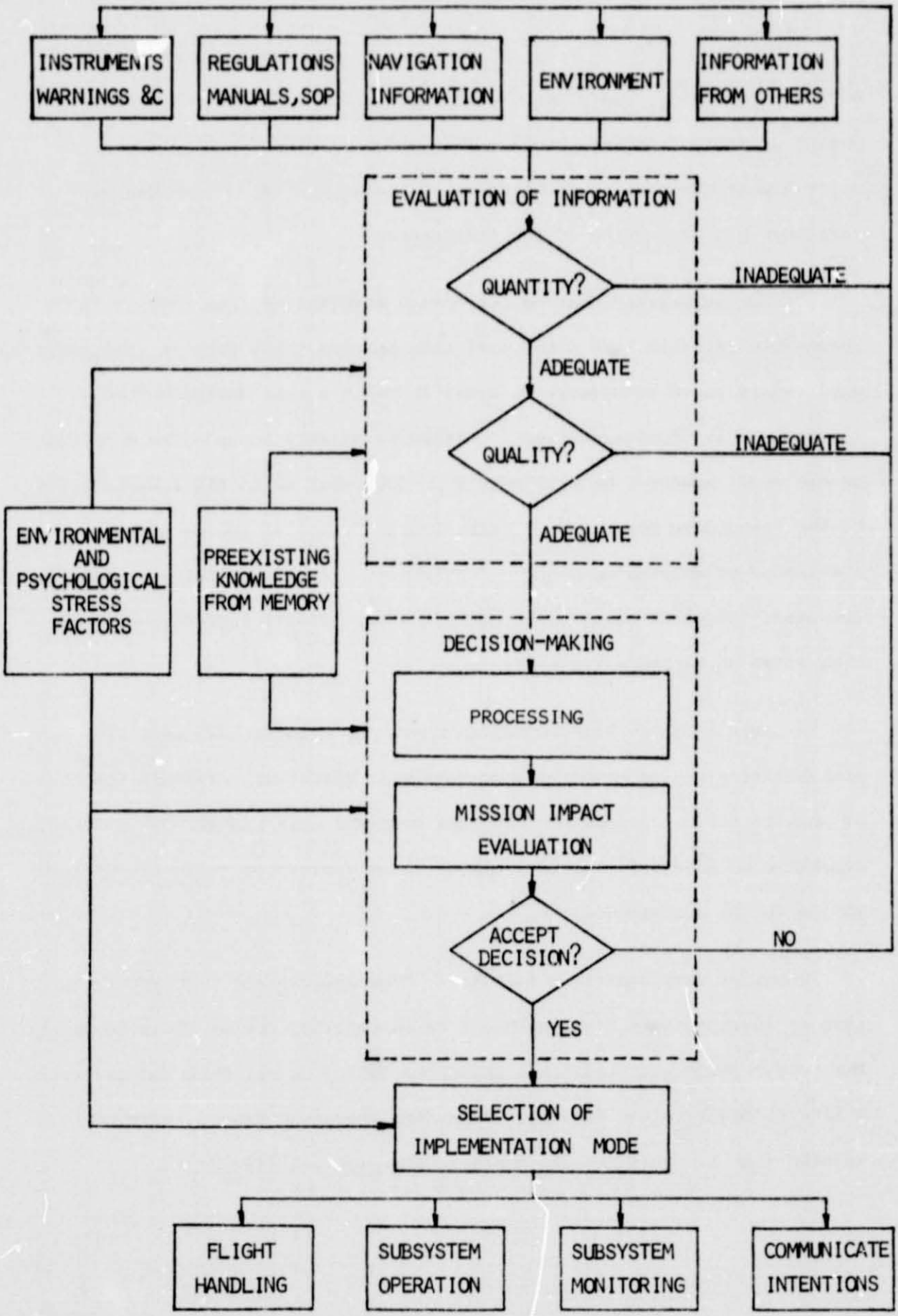
The Information Processing Analysis

The first part of a human factors study is concerned with what happened in the course of an aircraft anomaly, incident or accident. The second, equally important, part of such a study must be concerned with why it happened: specifically, with why the people involved in the occurrence behaved as they did.

If we accept the proposition that there is some reason for all human behavior (and we do), we may proceed to search for the reasons for each significant behavioral event listed in our function analysis. We have already indicated that each action by the pilot or others in the system represents an attempt to implement a previous decision. To structure our thinking about cognitive and decision-making behavior, we have developed an information processing model of behavior (figure 1). The model is simply a schematic way of looking at actions and the decisions which led to them.

Briefly, the model says that, in order to accomplish any task, a pilot must first seek and acquire information from whatever sources are available. He must then make some determination regarding the quantity, and the quality, of the information he has gathered. Previously

Figure 1


INSTRUMENTS WARNINGS &C
REGULATIONS MANUALS, SOP
NAVIGATION INFORMATION
ENVIRONMENT
INFORMATION FROM OTHERS
EVALUATION OF INFORMATION
QUANTITY?
INADEQUATE
ADEQUATE
QUALITY?
INADEQUATE
ADEQUATE
ENVIRONMENTAL AND PSYCHOLOGICAL STRESS FACTORS
PREEXISTING KNOWLEDGE FROM MEMORY
DECISION-MAKING
PROCESSING
MISSION IMPACT EVALUATION
ACCEPT DECISION?
NO
YES
SELECTION OF IMPLEMENTATION MODE
FLIGHT HANDLING
SUBSYSTEM OPERATION
SUBSYSTEM MONITORING
COMMUNICATE INTENTIONS

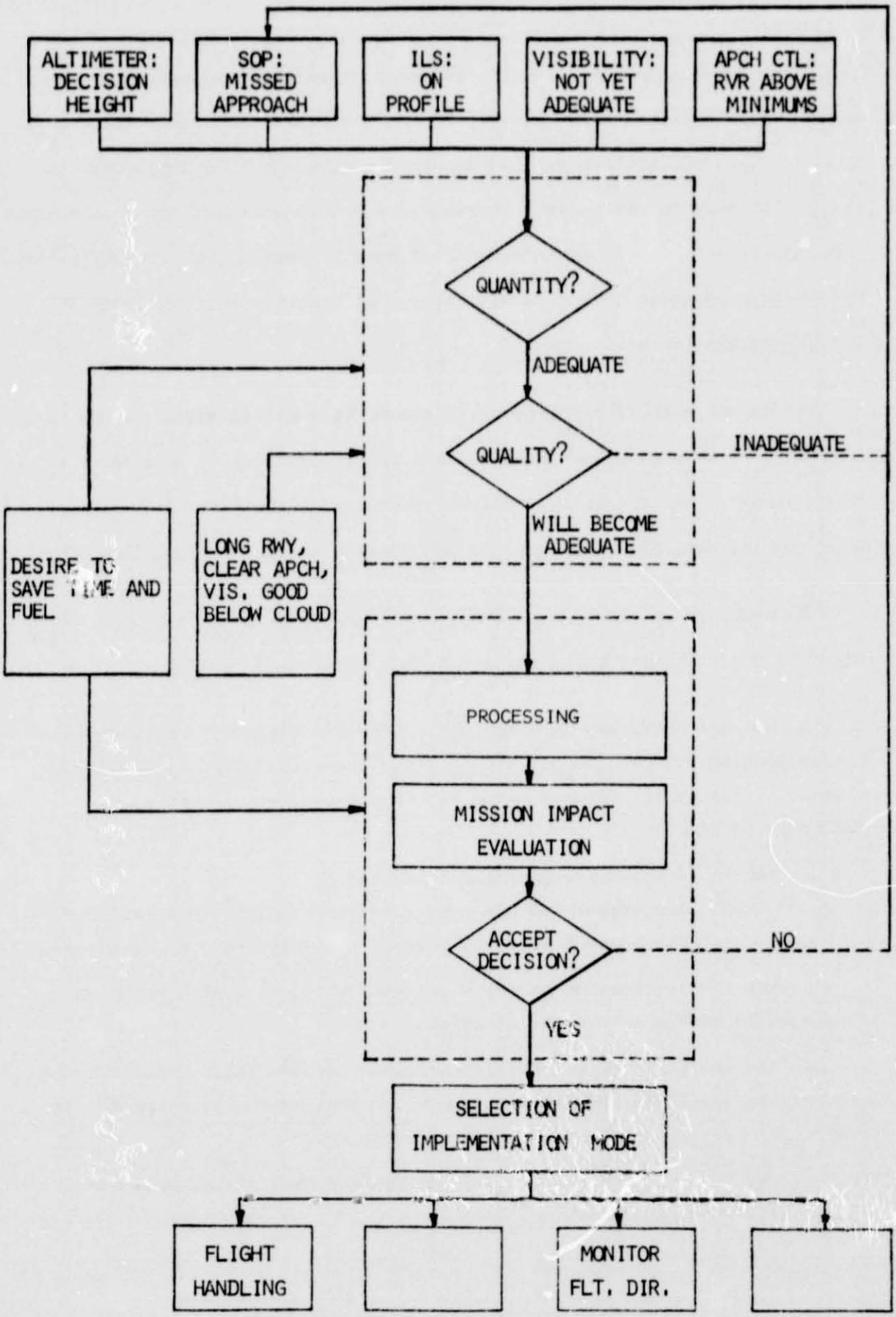
gathered knowledge, contained in his memory, will influence the determination of whether he has enough information, of high enough quality, to allow him to proceed. Psychological or environmental stress can also influence his evaluation of the information.

Having determined that he has enough information, and that it is reasonably reliable, the pilot must then process these data in predetermined ways (again based on memory) in order to reach a wise decision from a limited number of alternatives. Before he finally accepts the decision he has made, however, he will make some judgement as to the acceptability of the "candidate decision" in terms of its potential impact upon the likelihood of successful mission completion. If the decision is finally accepted, the pilot selects the ways in which he will implement it, and then takes appropriate action.

A large part of this process involves the pilot's judgement of probabilities: he is attempting to make wise decisions, often in the face of uncertainty. In addition, he must consider cost and safety tradeoffs, and there is good evidence that all of these factors do influence decision-making in the aviation system.

Consider a hypothetical example. "The information I am receiving from my instruments indicates that I am on profile, and at decision height. The view outside the windscreen indicates that I do not have enough visibility to complete the landing. Standard operating procedures therefore dictate that I should execute a missed approach..." (figure 2).

Figure 2


ALTIMETER: DECISION HEIGHT
SOP: MISSED APPROACH
ILS: ON PROFILE
VISIBILITY: NOT YET ADEQUATE
APCH CTL: RVR ABOVE MINIMUMS
QUANTITY?
ADEQUATE
QUALITY?
INADEQUATE
WILL BECOME ADEQUATE
DESIRE TO SAVE TIME AND FUEL
LONG RWY, CLEAR APCH, VIS. GOOD BELOW CLOUD
PROCESSING
MISSION IMPACT EVALUATION
ACCEPT DECISION?
NO
YES
SELECTION OF IMPLEMENTATION MODE
FLIGHT HANDLING
MONITOR FLT. DIR.

"The RVR has been at or above minimums, however; this approach path is a clear one with a long runway, and the visibility below the cloud base is good. In addition, I've just spent 20 minutes in a holding stack to which I'll have to return if I overshoot, and this will cost us considerable time and fuel. Since the information I have indicates that the visibility will become adequate at a safe altitude, I'll continue a little further before deciding to overshoot..."

We do not mean to imply by this example that pilots verbalize their decisions in this way, nor that the decision to continue is motivated in this manner. We do suggest, however, that this sequence of information acquisition, evaluation, processing and decision selection does take place.

In order to understand the behaviors involved in an occurrence, we must ask the following questions about each behavioral event:

1. Was all necessary and pertinent information acquired by the pilot (or controller, or dispatcher, etc.)? Was the information he acquired correct? Was it in a format which he could assimilate in the time available to him?

2. Was the information properly evaluated:
   a. with respect to quantity (was there enough information)?
   b. with respect to quality (was it consistent and reliable)?

3. Was the information properly processed: did the pilot reach an appreciation of the true state of affairs?

4. Did the pilot select the safest and wisest decision (based on the information available to him) from among the available alternatives? If not, what other factors entered into his decision?

5. Was the decision effectively implemented once it was made?

An illustration of the use of the information processing analysis may be of help in understanding its utility. This case is taken from an incident which occurred several years ago in general aviation.

Situation: A qualified pilot returning from a vacation in northern Wisconsin in a rented Beech Travel-Air encountered a double engine failure due to fuel exhaustion five miles short of his home airfield in Ohio. He landed gear-up in a farm field; the airplane was extensively damaged, but there were no injuries. Because of approaching severe weather at his takeoff point, the pilot had performed a hurried preflight procedure and had made only a cursory check of terminal weather.

After collecting data for the function analysis and preparing a chronology of pertinent behavioral events, the investigator might attempt to analyze the pilot's behavior in this way:

1. Did the pilot acquire all necessary and pertinent information prior to making a decision or performing critical actions?

With respect to the pilot's decision to fly non-stop: was he aware of the distance to be covered? Did he know the winds aloft? Was he familiar with fuel consumption data for various power settings? Did he determine fuel quantity during preflight? How?

2. Did he properly evaluate the sufficiency and quality of the information he acquired?

Fuel gauges in light aircraft are notoriously inaccurate. Did he verify his fuel gauge readings by visual inspection of the tanks? Did

he make use of time-distance checks early in the flight as a check on winds aloft? Had he verified the airplane operating manual data on fuel consumption during previous flights?

3. Was the information properly processed? Did the pilot appreciate the true state of affairs?

Did the pilot know how to transform fuel quantity into aircraft range? Did he take altitude, air temperature and other factors into account in arriving at a most efficient plan for flight management? Did he know about and use economy cruise techniques?

4. Did the pilot select the safest decision, based on the information he had, from among the alternatives open to him?

It might be said that the answer to this question is obviously "no", in view of the outcome of the flight. This answer may not be correct. If the information available to the pilot from the sources he used was incorrect it is quite possible that his decision, based on the information he had, was an entirely appropriate one. He knew, as an instance, that the safest decision was to take off as expeditiously as possible, given approaching severe weather at his point of departure. One must not make the mistake of accepting an outcome as "obvious" evidence of an error. This question can only be answered if answers to the previous questions are available.

5. Was the decision properly implemented once it was made?

Once again, the answer to this question depends on the answers to the previous ones. Given that his decision was that it was quite safe to conduct a nonstop flight, did he use the best power settings for economy cruise? Did he manage other airplane subsystems (cowl flaps, for instance) so as to achieve maximum range? Perhaps most important, did he have in mind a contingency plan or alternate course of action in the event of fuel consumption greater than planned, or winds less favorable than forecast?

Depending on the answers to these questions, the investigator might decide that the primary enabling factor in this incident was lack of knowledge, or unfamiliarity with the airplane, or the stress posed by the threat of weather, or defective judgement because of the pilot's desire to get home, or any of several other pilot-related factors. It is equally possible, however, that after reviewing all aspects of this incident, the investigator might learn that the airplane operating manual did not contain sufficient information, or that the fuel gauges read systematically high as tanks neared the empty level, or that the winds aloft forecast was wrong, or that this particular airplane had much higher fuel consumption than the manual figures indicated, or any of several other factors over which the pilot had no significant degree of control. In this event, the investigator might well reason that what had appeared to be an obvious "pilot error" was, in fact, a system problem which led the pilot to an incorrect decision, and therefore an incorrect course of action.

The investigator's judgement as to the most probable reasons for the pilot's behavior will suggest possible solutions designed to make such incidents less likely in the future. It is possible that the pilot simply did not understand the relationship of density altitude and other factors upon his airplane's range and fuel consumption. More adequate training with respect to cross-country flight planning may be needed, not just for this pilot, but for many others. It is also possible, however, that more accurate fuel gauges, or an accurate fuel flow meter or totalizer, or better manuals, might have provided this pilot with the only information he lacked in order to have made the flight safely.

By systematically considering all pertinent data, the human factors analyst should arrive at a "most probable" explanation of each of the significant behavioral events identified in the function analysis. The necessary inputs for this analytic process include the possible effects of stress upon the decision-making and implementation processes, and the pre-existing knowledge, resident in memory, of the pilot or other person whose behavior is under study.

To repeat, it is obvious that there is no really effective substitute for information furnished by persons involved in an occurrence. Given the proper atmosphere, detailed information of this sort can be provided, and the investigator can substitute knowledge for supposition in his effort to understand the behavior he is studying. The following section discusses methods of obtaining such detailed data from persons in the aviation system.

2. THE COLLECTION OF HUMAN FACTORS DATA IN AIRCRAFT OPERATIONS

This section was prepared as an aid to investigators who participate in the collection of human factors data from persons working in the aviation system. It explains the reasons for collecting such data and suggests methods for systematic data-gathering. It contains an introduction, a human factors outline, an interviewer's checklist and a sample interview.

Documented studies show that deviations from normal or expected performance, often dismissed simply as "pilot error", occur frequently in operational flying. These deviations or errors are frequently cited, correctly or incorrectly, as the causes of aviation accidents. In the vast majority of cases, however, they do not appear to affect seriously the safety of flight unless other factors are present. We know little about why these deviations or errors occur and little about the factors which affect their hazard potential. Operationally relevant human factors data, carefully collected and analyzed, can provide answers to many questions in this area.

There is a need to know much more about the factors involved in the chain of events which leads from normal performance to a deviation, an incident or an accident. It is necessary to learn precisely what behavior occurred and why it occurred. It is vital to learn which factors in any part of the system affected that behavior. Then, and only then, can we begin to have confidence in measures developed to reduce the incidence

of errors and in measures developed to minimize the effect of errors on air safety.

Pilots, air traffic controllers and flight dispatchers are the people most likely to observe problems which affect the safety and efficiency of aircraft operations. Their reports must be a key part of any study of human factors and aviation safety. Their professional judgements as to system operation and critical safety problems are invaluable. With the help of an interviewer who understands both human factor data requirements and the aviation system, they will frequently be able to recall the pertinent details of specific occurrences, the factors involved and, in some cases, the root causes.

An interviewee may wish to discuss a specific incident or to make general observations regarding hazards in the system. If he presents general observations, the interviewer should try to secure specific examples. How did a particular factor create a threat to air safety and what might be done to reduce it? In some cases, even after discussion, you may believe that the factors he identifies are not the basic cause of his concerns. Regardless of your evaluation, it is important to be sure that the interview report reflects his undirected opinion.

If an interviewee wishes to discuss a specific incident, he should be allowed to tell <u>his</u> story. The objective is to learn how this professional person perceived an occurrence which he believes is important enough to discuss. In most cases, questions to help him recall additional details should be asked only after he has been permitted to tell his story.

Any such questions should be non-leading; that is, they should not suggest an "expected" answer. This is sometimes difficult. In most cases, the interviewer may be able to suggest reasonable alternatives. If this technique is used, he should offer more than one alternative if possible, and make it clear that there may be others.

Incident reports should include the exact sequence of events which led up to and followed an operational anomaly: the point at which the first departure from normal or expected performance occurred. They should also include a clear description of the observations, decisions, resulting actions, further observations and subsequent decisions which went on before, during and after the deviation. The event may have preceded and precipitated the observation that a threat to safety occurred, or it may be the reason the report is given. All factors which may have contributed to the occurrence should be documented, including their location in the cockpit, on the ground or elsewhere in the system. It is important to learn what the person reporting believes caused the problem, what factors he believes contributed to it, what things he feels might have prevented it, and what things he believes prevented it from developing into a more critical incident.

Accidents have been defined as "occurrences from which complete recovery did not occur". Therefore, it is as important to learn exactly how the flight crew recovered from a deviation as it is to learn how and why it happened. Effective methods of controlling unanticipated problems are an essential part of aviation safety.

When an interview is completed, the interviewer should have:

1. A clear understanding of what happened, why the person reporting believes it happened, what was done to correct the situation and how he believes the occurrence might have been prevented;

2. Sufficient information to be able to construct a chronological description (the function analysis) showing the decisions and actions which took place from the time the anomaly occurred until all aspects of the flight were again normal;

3. The factors and reasoning which influenced any decision to modify the operation if such a decision was made;

4. The positive and negative environmental factors which may have been present, including those involving other personnel, hardware or software;

5. His own opinion regarding possible causes of the anomaly, his analysis of the contributing factors, and conclusions he has drawn from the report.

OUTLINE OF HUMAN FACTORS REPORT FORMAT

Much of the information called for in this outline will not be relevant in a specific case. While the interviewer must use his best judgement, there are at least two reasons why detailed data should be included if there is any possibility that it is relevant. First, it is rarely possible to go back to get additional information. Second, analysis of previous studies and investigations, which included data presumably deemed adequate, have not produced answers to many critical safety questions. This outline

is an attempt to prepare an inclusive list of factors which may be pertinent in an investigation of an anomaly. It is designed to serve as a checklist for the investigator, and is followed by a short summary checklist.

OUTLINE OF PERTINENT HUMAN FACTORS DATA IN AIRCRAFT OPERATIONS

A. Description of the occurrence

1. Nature of the anomaly (describe the deviation from normal or expected performance as precisely as possible)

2. Aircraft

    a. Make and model
    b. Configuration when anomaly occurred (gear, flaps, IAS, thrust, etc.)

3. Time and location

    a. Local clock time
    b. Elapsed time since departure from blocks
    c. Phase of flight
    d. Geographic location, if pertinent
    e. Airport/runway/approach, if pertinent

4. Radio navigation facilities in use and type of navigation

5. Detection of the anomaly (this information should be given chronologically. Identify the person responsible for each pertinent decision, command, action, communication or interaction with others. Person(s) receiving a command, a communication or interaction should also be identified.)

    a. Who first noticed the deviation? Who should have?
    b. What brought it to his attention? What should have?

6. Cockpit environment preceding the anomaly (this refers to everything going on in the cockpit: the type of operation, the people present, operational constraints, physical environment, activities, distractions, etc., which were or might have been pertinent to the anomaly being described.)

    a. Who was in the cockpit?
    b. What was each person doing?
    c. What was the pace of activity at the time?
    d. Was there anything unusual about the operation?
    e. Were there any distractions immediately before the anomaly occurred?
    f. What was the weather at the time of the occurrence?

7. What actions immediately preceded the anomaly, in order of occurrence?

    a. Did any of these actions contribute to the anomaly?
    b. What decisions motivated these actions? Who made them?
    c. If they were non-routine decisions, why were they made?
    d. What information was the basis for the decisions? Was the information correct?

8. Was there any indication before the anomaly that it was going to occur or might occur? If so:

    a. What was the indication?
    b. Who noticed it?
    c. Was it noticed immediately? If not, why not?

B. Recovery following the occurrence

Note: Using the same chronological format, list each of the decisions made, the information which motivated them and the effect of any actions taken during the recovery period. Include any actions which did not help, or hindered, the recovery.

1. What happened after the anomaly occurred?

    a. What decisions were made?
    b. By whom?
    c. For what reasons?

2. What actions were taken to correct the deviation?

    a. By whom was each action initiated? When? Why?

3. What effect did each action have?

    a. Did it help recovery?
    b. Did it hinder recovery?

4. Did any complicating factors arise during the recovery period?

    Note: After the initial deviation, other events can occur while the crew is recovering from the first one. Be careful to identify these.

5. Was normal operation restored? How long did it take?

6. Was a change in "game plan" necessary?

   a. If so, what was the original plan? What was the change?
   b. How was the change in plan implemented?

7. Was safety threatened at any time?

   a. If so, what was the nature of the threat?
   b. Was it recognized at the time?
   c. Who recognized it?
   d. How was it recognized?
   e. How long did it last?
   f. What was done to control or minimize the threat?
   g. Could the threat have been controlled more effectively?

C. Background

Note: The background includes two periods: the in-flight period which preceded the anomaly, and the period prior to flight extending backward in time as far as necessary to encompass any medical, social or behavioral factors which might possibly have a bearing on the later occurrence of the anomaly.

1. If pertinent, describe the history of the personnel involved and of the airplane and facilities utilized in this flight. Record any factors which might in any way have been related to the anomaly or the way it was handled.

   a. Nutrition and rest: be specific. Describe meals as to time eaten and type of food.
   b. Were there any medical or physiological problems, including transient conditions?
   c. Were there any pertinent psychological factors?
   d. Describe the crew's rest and duty schedule for this flight sequence. Was this flight their scheduled activity?

      (1) Do the pilots believe the duty or rest schedule was a factor?
      (2) Describe their activities during the preceding day.

   e. Was the training or experience of any person a factor with respect to the conduct of the flight, the anomaly or the recovery?
   f. Were there any problems within the flight crew with respect to discipline, coordination, ability, personality factors?
   g. Were there any other personnel problems (cabin crew, ground support personnel, controllers, dispatch, management, others)?
   h. Were any other factors pertinent during the period prior to flight?

2. Describe in brief the history of this flight prior to the occurrence. Emphasize any decisions, actions, events or omissions which might have been related to the later anomaly.

    a. Was the airplane free of writeups or problems?
    b. Was servicing and ground support normal?
    c. Were there any supervisory problems?
    d. Were there any dispatching problems?
    e. Were there any ground or flight delays?
    f. Were there any problems at the departure airport?
    h. Were there any ATC or airways facilities problems?
    i. Was weather a problem at any time? If so, how?
    j. Was flight support normal? Adequate?
    k. Were there any other problems?

D. Analysis and recommendations

Note: This section should contain only the opinions and recommendations of the person reporting the occurrence.

1. Was the situation evaluated correctly when the anomaly was detected?

    a. If so, were any special factors responsible?
    b. If not, why was the evaluation incorrect?
    c. Could anything have improved the accuracy of the evaluation?

2. Was the detection of the anomaly as prompt as it should have been?

    a. If so, were any special factors responsible?
    b. If not, why was there a delay in detection?
    c. Could anything have improved the speed of detection?

3. Was the recovery from the deviation the most effective possible?

    a. If so, were any special factors responsible?
    b. If not, why not?

4. Was there any problem in flight crew management or coordination? Describe any deficiencies, problems or comments in detail.

5. Was the entire flight managed professionally and effectively?

    a. If not, what might have been done better?
    b. Were Standard Operating Procedures, Federal Air Regulations or other rules or policies involved in any way? Should any of them be changed? If so, why?

6. Was Air Traffic Control involved in any way?

   a. If so, was the problem due to ATC handling or instructions?
   b. If so, was there any flight crew misunderstanding of ATC handling or instructions?
   c. Did ATC do anything to minimize the problem?

7. Was any airplane system involved?

   a. Did maintenance contribute to the problem?
   b. Was enough information available?
   c. Was too much information available?
   d. Was any of the available information ambiguous or misleading?
   e. Was this a recurring problem with this specific airplane? With others of this type?
   f. Was a valid but recurring problem disregarded? If so, why?

8. Was this a fairly common problem?

9. Was pilot training adequate:

   a. To have prevented this occurrence?
   b. To correct or control it under these circumstances?
   c. To cope with it under all circumstances?

10. Were any of the following involved in any way? If so, how?

    a. Company management?
    b. Flight crew supervision?
    c. Flight dispatch?
    d. Flight or ground support?
    e. Federal Aviation Administration?
    f. Other?

11. Were any of the personnel or units listed under item 10 helpful in minimizing the threat to safety in this occurrence?

    a. If so, how?
    b. Could they have been? How?
    c. Any further recommendations in these areas?

12. What would have had to be different to have prevented this situation?

13. Are you doing anything differently as a result of this occurrence? If so, what?

14. Do you have any additional comments or suggestions?

E. Interviewer supplement

1. Was the reporting person's memory entirely clear as to the details of this occurrence? If not, in what area(s) did he have difficulty remembering details?

2. In your opinion, did this incident pose a threat to flight safety? If so, how and why?

3. Add any additional comments or opinions you may have as to the factors involved in this occurrence and as to measures which might prevent such problems in the future.

INTERVIEWER CHECKLIST: HUMAN FACTORS INTERVIEWS

A. DESCRIPTION OF OCCURRENCE

1. Nature of anomaly
2. Aircraft type, configuration
3. Where and when
4. Navigation facilities
5. Detection of deviation
6. Cockpit environment
7. Preceding actions
8. Prior warning

B. RECOVERY FROM ANOMALY

1. Decisions made
2. Actions taken
3. Effect of each action
4. Complicating factors
5. Time to return to normal operation
6. Change in "game plan"
7. Threat to safety

C. BACKGROUND

1. Crew history prior to flight
2. Schedule prior to this flight
3. History of this flight
4. Problems during this flight

D. ANALYSIS BY PERSON REPORTING

1. Detection of deviation
2. Evaluation of situation
3. Recovery from deviation
4. Flight crew; recommendations
5. Flight management, SOP, FAR
6. ATC; recommendations
7. Airplane systems
8. Pilot training
9. Management and supervision
10. Prevention
11. Additional comments

E. INTERVIEWER SUPPLEMENT

1. Memory and recall
2. Threat to safety
3. Interviewer analysis

SAMPLE HUMAN FACTORS INTERVIEW

The following incident report was written following an interview with an airline pilot. It was prepared using the interview format in this chapter as a guide. This incident was more complex than many, but it is included here as an example of the sort of information which will be helpful in a study of human factors in aviation operations.

THE ANOMALY

(Nature of anomaly) Approach control vectored a wide-body jet through localizer course at an angle of over 90° without informing crew. (Where and when) The incident occurred at 2230 hrs during descent, below 10,000', northeast of XXX. Aircraft was being vectored for approach to runway 22. (Detection) Event was noted by captain, who observed full swing of localizer cross-pointer and ADF swing.

(Environment) Only flight crew in cockpit; captain flying. Pace of activity normal until handoff to approach control. (Prior warning) Crew noted that controller was extremely busy. No other unusual circumstances. Weather IFR; no turbulence. Ground weather: RVR on rwy 22 2400', wind 160 at 7, braking poor to nil, slush on runway. Temperature 30° F.

(Preceding actions) Normal descent pattern and speed reduction. No crew actions contributed to problem. ATC requested aircraft and a preceding DC-8 to slow to 150 after crossing localizer; both were unable and slowed to 165.

RECOVERY

(Decisions, actions, effects) Captain questioned controller intentions, was told the maneuver was necessary for spacing. Eight miles east of localizer course, approach gave a right turn from 90° to 270°.

(Complicating factors) As aircraft again passed through localizer (a second anomaly), approach advised "taking you through localizer for spacing; left turn soon". Controller still extremely busy. He then gave a left turn to 220°, parallel to localizer course, cleared the flight for the approach and cleared it to tower frequency. Captain was unable to question the turn due to frequency congestion, so switched to tower.

Autopilot was on in heading mode; captain initiated a turn to 180°, armed the ILS, intercepted and captured glide slope abeam the outer marker, and lowered landing gear, flaps and lights. Autopilot captured localizer inside outer marker and proceeded inbound. Tower cleared flight to land on runway 22.

At 200', first officer called runway lights. Captain looked up, saw about 5 lights, went to manual control, turned on landing lights and almost immediately flew into a cloud (third anomaly). He was momentarily dazzled by glare, turned lights off, saw runway clearly emerging from cloud, turned lights back on and prepared to land. His flare was high and rather abrupt; captain had difficulty seeing the wet runway surface. He landed long (he estimates 3000'), stopped with reverse thrust; braking was poor to nill, as reported.

(Return to normal operation) Normal operation was restored the first time after full ILS capture. After encountering cloud, normal operation was restored only at the end of the landing roll.

(Game plan) If autopilot had not captured effectively, captain was prepared to abandon the approach. He had "negative feelings" about going back for another approach under an overloaded controller, and thinks this influenced his decision to continue the approach after encountering cloud inside the middle marker.

(Threat to safety) Captain discussed his handling with ATC after landing, and reported the incident to company. The threat, he feels, was an overloaded controller resorting to non-standard procedures in an attempt to cope with extremely high workload. The resulting cockpit workload was lessened by the use of the autopilot and couplers.

BACKGROUND

(Prior to flight) ATC supervisor referred to a personal problem in the controller; no other known pertinent factors. Flight from ZZZ was routine until handoff to approach control. (Crew schedule) This was the first flight in this duty sequence, after 4 days off.

ANALYSIS AND RECOMMENDATIONS

(Detection) ATC should provide warning of its intentions when non-standard procedures are to be used.

(Evaluation) Situation was evaluated correctly. Knowledge of position would have been more precise if DME had been available at XXX.

(Recovery) "Recovery from final problem (cloud entry) would have been better if I had looked once more at descent rate." Second officer now calls radar altitude from 100' to landing; this is also useful and a help in visual flare under these conditions.

(ATC role) Handling was inadequate; so was information as to ATC intensions. "Pilots have no way to communicate with an ATC supervisor when a controller is obviously overloaded, yet they are the ones most likely to see evidence of it." Captain thinks this kind of communications ability might help to prevent such incidents.

(Prevention) VASI would have helped during final approach; "... I needed more help than I had (in flare) ..."

INTERVIEWER SUPPLEMENT

Memory and recall were excellent; pilot brought map as aid. The information appears to be reliable.

The information was reported to company and ATC at the time. The pilot's conclusions are believed accurate. Standard operating procedures now include radar altitude callouts below 100'.

3. CLASSIFICATION OF HUMAN FACTORS IN AIRCRAFT OPERATIONS

In the preceding sections of this working paper, we have presented the conceptual framework of and an interview method for human factors studies of aircraft operations. An analytic system must be able to extract information which can be used to reduce the number of incidents and accidents due to human factors. Our methods are designed to produce an information base -- a collection of data -- which will allow us to identify at least some of the possible causes of behavioral anomalies in the aviation system.

This section introduces a method of classifying reports of anomalies so that information as to factors associated with human errors can be easily extracted. This classification scheme does not cover the full scope of our analytic methods; it is designed only to describe the behavioral anomaly in an incident and the system or human factors associated with that behavior. One might liken it to a method of describing causes and effects, except that we cannot say, on the basis of historical data, that any effect was produced by any cause. At best, we can state only that factor "A" was associated with, or found in the presence of, effect "B" with a certain frequency.

If we find that a certain effect is always, or frequently, associated with a particular factor, we may begin to question whether the relationship between them is more than casual. It is then reasonable to suspect a cause-and-effect relationship, though this cannot be proved by such data.

For this reason, we have preferred to think of the factors found in our reports of operational anomalies as <u>enabling factors</u>: had they not been present, the anomaly probably would not have occurred; and <u>associated factors</u>: factors which were present and pertinent to the incident under study, but which probably were not an essential part of the incident.

We classify each report of an anomaly, then, in terms of the behavioral anomaly, or human error, which occurred, and in terms of the human or system factors which we believe were pertinent to that anomaly. We further categorize these factors as enabling or associated on the basis of our review of the function analysis in each case. This categorization is necessarily a matter of judgement; by application of precise definitions and rules, we hope to minimize the subjective nature of such judgements, though it can never be eliminated. An annex to this paper describes the classification system in detail, discusses the rules for its use, and summarizes the results of preliminary interrater reliability tests and other studies of the method.

The behavioral anomalies are categorized as shown in table 1, page 9. To recap them, they are the two intellectual functions: cognition and decision-making, and the four implementation functions: flight or ground handling, subsystem operation, subsystem monitoring, and communications behavior. We permit the use of one or two function descriptors, with a code indicating the person committing the error.

The enabling and associated factors are described briefly here, since they have not been discussed previously. It is worth mentioning again that our ability to categorize the factors which may play a role in an operational anomaly rests entirely on the completeness of the incident or anomaly report, and the care with which that report has been prepared.

Hardware: Several types of factors may intrude upon the smooth flow of an aviation operation. An aircraft component may cease to function properly. Similarly, a component of the ground-based tracking or computer system may fail. Aircraft instruments or warning systems may malfunction, either providing the crew with spurious information or failing to alert them to a real problem. The component failure may, or may not, be obvious to the pilot, who therefore may, or may not, take appropriate action to correct the defect or compensate for it. When the failure occurs in a system designed to provide the flight crew with information, they may or may not be able to verify the nature of the failure. Subsequent errors based on unverifiable false information may occur. Finally, in the case of information transfer systems, there may be no failure, but the design of the system may be such that the pilots receive ambiguous or misleading information, on which they may act properly or improperly.

Software: Aircraft operations require a great deal of information not ordinarily provided by aircraft information systems. Such information concerns navigation, operating rules and regulations, aircraft performance data, and normal and emergency operating procedures and checks. This information is normally made available by the printed word. In view of the

enormous volume and complexity of the information which must be provided, it is hardly surprising that flight and navigation manuals may on occasion contain incorrect, misleading or ambiguous data, or that the data may be missing or effectively missing because of inadequate or incorrect indexing. In such cases, the crew may be making decisions and acting upon them on the basis of incorrect data, or a misunderstanding of correct but ambiguous data. As in the case of hardware information transfer systems, we attempt to differentiate between problems related to the content of the system, and problems related to the manner in which the information is presented to those who must use it.

"Liveware": Still other types of information are provided to pilots by other people in the system: their fellow crew-members, air traffic controllers, dispatchers and other ground support personnel. Whenever people communicate, the possibility of a misunderstanding is always present. The misunderstanding may be due to a low signal-to-noise ratio, to a lack of common understanding of rules or phraseology by speaker and listener, to language problems or a variety of other factors. Similarly, pilots may fail to communicate their intentions clearly, leaving others in the system with a lack of necessary information on which to base their own subsequent decisions.

Environment: Other types of factors may adversely affect the pilot, the airplane or the system. Environmental factors: weather, turbulence or restricted visibility, may perturb the vehicle or prevent the crew from establishing visual contact with their touchdown point. Precipitation

on runways may markedly affect their ability to handle the aircraft after touchdown. The ground environment: lighting and marking systems, or hidden hazards, may lead crews into errors. Toxicological or physiological hazards may affect both cognitive and motor function in pilots; such hazards may not be evident to the crew.

Control: Those who direct and control air traffic may impose conditions or restrictions on aircraft which their crews cannot meet without exceedin · the airplane's operating envelope, or without decreasing their margin of safety. Attempts to meet such conditions may lead crews into errors of judgement or flight handling.

Medical: Known or unknown acute or chronic medical problems may seriously interfere with a pilot's, or a controller's, decision-making capacity. Drugs and medications may have similar effects. These factors are rarely the sole cause of a human error, but they are often cited among a number of causes. Incapacitation, either obvious or subtle, is, of course, a constant threat to operating safety.

Psychological factors: Psychological factors in an individual, or interpersonal problems within a crew, may inhibit the normal and necessary flow of information among the members of the cockpit team. Other psychophysiological problems such as fatigue, boredom, or overload caused by the rapid pace of cockpit duties may likewise be associated with errors in pilots; similar factors can interfere with the performance of air traffic controllers and others on the ground.

While it may be impossible to decide in retrospect whether one or more of these factors has caused a human error in aircraft operations, it is often possible to determine whether such factors were present when an anomaly occurred. It is sometimes possible also to determine whether such factors interfered with recovery from the anomaly. From such information, gathered and reported in sufficient detail, we may begin to examine the association between such factors and behavioral anomalies in flight operations. Our classification scheme is designed to facilitate this examination.

SUMMARY

This working paper has attempted to provide a conceptual framework within which pilot and other human errors in aircraft operations may be studied with the intent of finding out how and why they occurred. These methods of collecting data on human factors in aviation appear to have been helpful in initial studies of operational anomalies in the aviation system. The authors hope that others in a position to collect such data will make use of this approach and will share their criticisms with us, so that a viable common approach to the recording of human factors data may be constructed. Such a system could be an immensely useful tool for the solution of some of our most persistent problems in civil aviation.