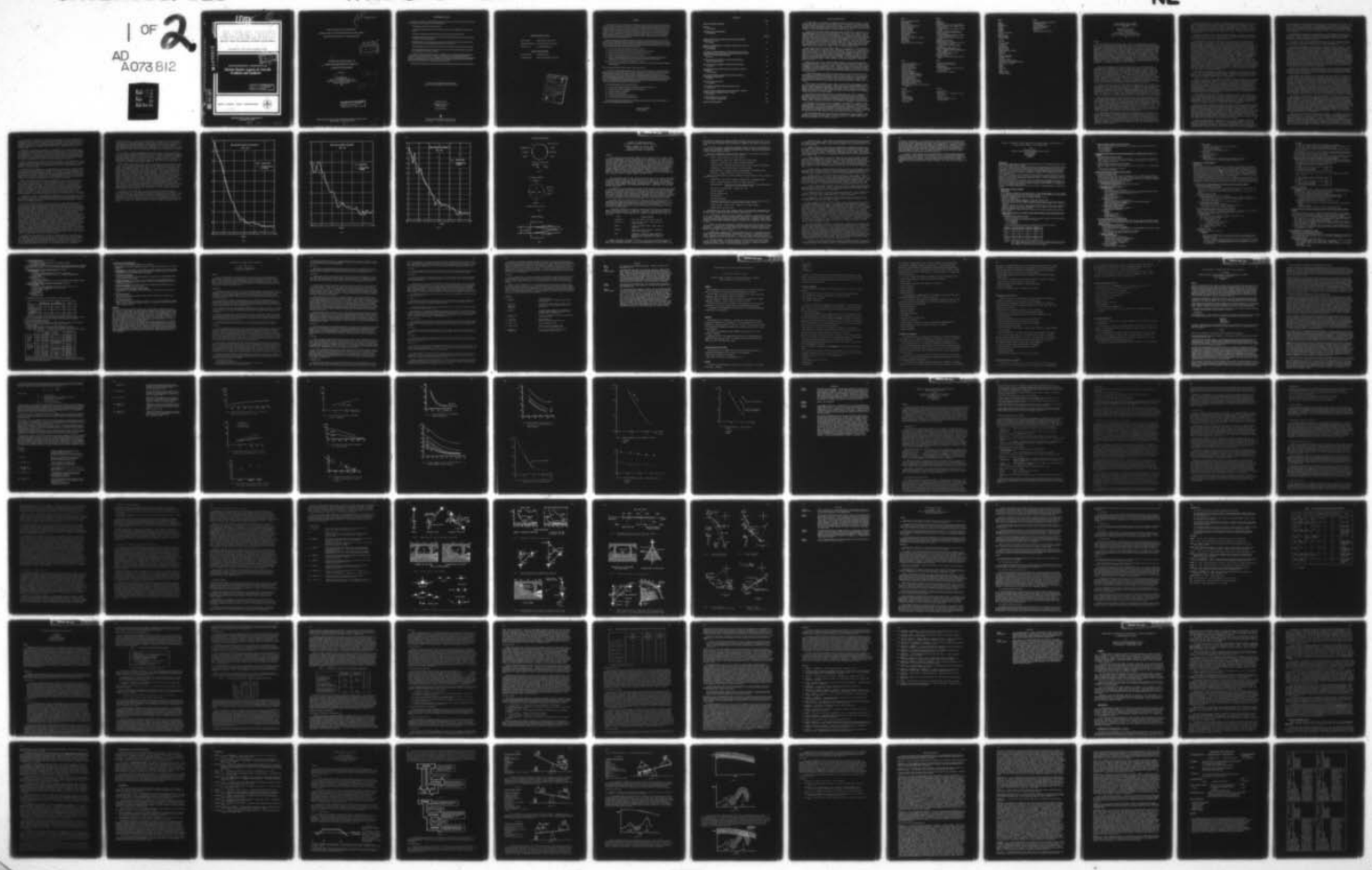
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AGARD Conference Proceedings No.254

HUMAN FACTORS ASPECTS OF AIRCRAFT ACCIDENTS AND INCIDENTS

Edited by

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Papers presented at the Aerospace Medical Panel Specialists' Meeting held in Paris, France, 6–10 November 1978.

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Published June 1979

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ISBN 92-835-0241-8



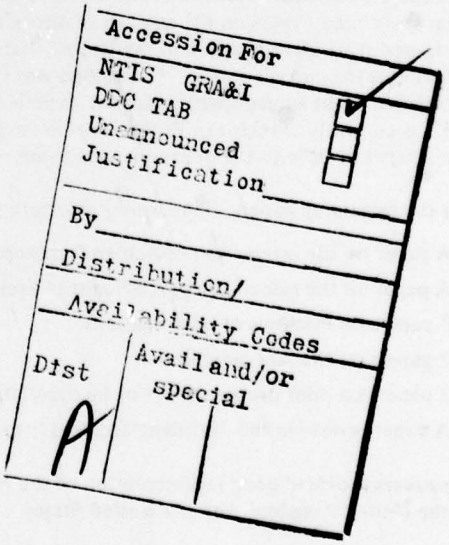
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PREFACE

Experience across the NATO community in general indicates that aircraft accident rates have not declined significantly in the past decade, despite the fact that there is continuing development of safety equipment and various onboard sub-systems designed to enhance safe operations; and despite the increasing emphasis upon flight safety education. Of particular concern are those accidents attributed to human factors, of which "pilot error" is a subset. The cost in lost aircraft and crews is obvious and rising as both aircraft and aircrew training become more complex and therefore more expensive. A further complication is the reduction in flying hours (and an increase in the use of simulators to replace inflight training) necessitated by fuel constraints and declining "real dollar" budgets. There is therefore a significant need for the NATO aerospace medical community to focus renewed and continuing attention upon the problem of aircraft accidents where human factors play a role.

Because of the urgency of the problems identified above, the Behavioral Science Subcommittee of the AGARD Aerospace Medical Panel (AMP) decided that a conference dealing with the human factors aspects of aircraft accidents was in order. This conference is, in essence, a followup of a conference sponsored by AMP in September 1973 (AGARD-CP-132). Inasmuch as aerospace medicine embraces a wide range of disciplines and problem areas, the session considers a diversity of problem areas. Papers were solicited on topics such as:

(1) Factors contributing to pilot incapacitation (partial or complete)

(2) Human factors design deficiencies which enhance the probability of an accident

(3) Human factors improvements which reduce the probability of an accident

(4) Analyses of the underlying mechanisms of "pilot error" accidents

(5) Analyses of significantly large sets of accidents which identify or reject global assumptions/hypotheses regarding causes of human factors accidents ("data base" surveys/analyses would be useful)

(6) Lessons learned or to be learned from investigations of incidents

(7) Techniques for the investigation of accidents/incidents, with specific attention to the demonstrated usefulness of such techniques

We were fortunate in getting an excellent response across this entire listing.

An overview of the papers being presented is in order. There were 2 invited speakers. The first was Dr Anchard Zeller, from the Life Sciences Division of the USAF Inspection and Safety Center at Norton Air Force Base, California. Dr Zeller has spent many years on the analysis of aircraft accident data and has numerous publications. He is a recognized leader in accident research in the United States. Dr Zeller's paper dealt with 2 questions: where have we been?; and what is the current status? The second was Col. Leonard Johnson of the USAF Medical Corps. Dr Johnson is a board-certified flight surgeon with extensive experience in the USAF Tactical Air Command and, in particular, with the F-15. He is currently Director of Professional Services at Headquarters TAC, Langley Air Force Base, Virginia. Dr Johnson's paper dealt with the question: where are we going?

As for the remaining papers, there were presentations on:

(1) A paper on the interaction of human factors problems with primary accident causes

(2) A paper on the role of the psychologist in accident investigations

(3) 3 papers on methods of investigations

(4) 2 papers on the mid-air situation

(5) 2 papers on pilot disorientation or incapacitation

(6) A paper reviewing the "incident/accident" spectrum

The speakers provided good representation of the NATO nations: Belgium, Italy, Canada, Federal Republic of Germany, the United Kingdom, and the United States.

BRYCE O.HARTMAN
Session Organizer

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TECHNICAL EVALUATION REPORT

The eleven papers in this symposium on the Human Factors Aspects of Aircraft Accidents and Incidents covered a broad spectrum of accident areas and a number of different approaches to the problem, ranging from global overviews to extensive listings of specific factors. This TER will focus on the more provocative generalizations and observations and then turn to extracted listings as presented by several authors. The latter are particularly useful in that they provide a "shopping list" which can be used by the research community of NATO in developing R&D programs in accident analysis and prevention.

The first and the last papers propose, appropriately, models which permit the structuring of a general framework within which the aircraft accident problem can be attacked. Zeller's model is that of an integrated management system incorporating three approaches: (a) the administrative approach, the most commonly applied, in which the focus is on investigation, analytic evaluation, and corrective actions for identified problems; (b) the scientific approach which consists of a systematic evaluation of human limits relative to the man-machine environment; and (c) total system management, which calls for new procedures and concepts. Zeller emphasises the need to exercise all three approaches. Zeller also made several significant points: (a) accident rates are the usual statistic, and in this format human factors accidents show little improvement over the years, but if absolute numbers were the report format, there has been a major improvement over the years; (b) in investigations, the focus in on what happened, but we need more energy devoted to why (is this the real research task ?); and finally (c) most accidents result from a gradual erosion of pilot capability or a gradual increase in situational demands or both.

Tepper's model is drawn from the physiological domain; it is the application of the Selye General Adaptation Syndrome (GAS) to the accident problem. GAS focuses on combined stress; in the accident area, three classes of stress exist: physical, cognitive, and emotional. The Selye model conceptualizes three stages of stress response: the alarm reaction, stage of resistance, and stage of exhaustion. Tepper provides lists of factors for his three classes of stresses and then augments GAS by adding the concept of "explosive" events: abruptly presented situations with potentially catastrophic outcomes, which are inherent in the speed and complexity of the aviation environment. He then provides additional concepts which identify background factors (overweight, hangover, smoking, etc.) which further impair the pilot's capability to meet mission demands. Tepper's approach is particularly recommended as instructional material for pilots.

Johnson's paper started with an exceptional effective historical review of aircraft performance growth followed by analysis of human factors in the medical domain and the relationship between these and the operational environment. The listing of factors will appear later in this TER. This paper is also recommended for use in training programs for pilots. Johnson's conceptual orientation was the disequilibrium between the functional characteristics of man vs. operational demands and the simultaneous disequilibrium between aircraft performance characteristics vs. operational demands. One interesting proposal he makes was the establishment of a NATO accident information gathering and dissemination office, a proposal of considerable merit.

Two papers (Hoffman, Weber) deal specifically and concretely with the application of the laws of optical physics to the detection of aircraft (the mid-air collision problem). The second of the two provides the methods required to perform analyses of mid-air collisions or near-misses. Such methodology, if routinely applied, would enrich considerably the data obtained from accident investigations, not to mention providing the expository "why" of some accidents not otherwise explicable. Hoffman proposes training programs specifically directed toward the requirement for detecting other aircraft in one's own airspace.

Training, in fact, was discussed by several authors. We recognize that safety education for pilots exists in all NATO air forces, but the scientists coming together in this symposium strongly supported the need for human factors accident prevention. This was also discussed with some vigor during the round table discussion. It would be a training program significantly different from current flying safety programs, would require innovative course content and procedures, and would probably require considerable support (and progress) from the research community, given that we are not entirely sure of the taxonomy of human factors aspects of aircraft accidents.

This reviewer invites the reader's attention to two papers dealing with "how to" do elements of the investigation phase of aircraft accidents. Paolucci describes how interviews should be conducted, emphasizing the need to gain the interviewer's confidence, conducting interviews one-on-one, preventing cross-talk between interviewers if possible, and following a standardized, logically organized set of questions in each interview. Green describes how the psychologist should function in an interview and provides a number of interesting case histories. Both techniques are recommended to investigation teams.

One paper deals with a truly unique kind of disturbance in pilot performance: geographic disorientation. The author, Taylor, defines it as loss of awareness of the position of the aircraft in relation to geographic points. In this paper, we are reminded that man has no innate sense of awareness and is therefore dependent on various kinds of navigation aids and displays, supplemented by internal functions such as memory plus interpretation and integration of displayed information. The significance is that the sudden realization of geographic disorientation can lead to panic and confusion, resulting in inappropriate and sometimes catastrophic pilot behavior. Better aids and specialized training is recommended.

This review would be deficient if the several listings of human factors were not presented. In the following are the factors identified by various authors, unedited and with no attempt to define, remove duplicates, or organize into a total gestalt. This latter task would be a formidable undertaking; it might be a most worthwhile task for an AMP working group.

Zeller

Physical strength and stature
Anthropometrics
Visual acuity
Visual distortions
Attention provoking lighting
Sensory compatibility
Visual time lapses
Autokinetic effect
Empty field myopia
Photic-orivine phenomena
Dark adaptation
Aging process
Transfer of training
Retroactive and proactive inhibition
Temperament
Peer pressure
Ego function
Physical and psychic incapacitation

Johnson

Courage
Coordination
Comprehension
Vision-finite time to see, focus, identify
Cardiovascular-heart rate, rhythm and stroke volume limits
Pulmonary-respiratory rate, gaseous exchange system
CNS-cerebral electrical activity, TUC
Psychiatric-timeliness and orderliness or decision-making
Musculoskeletal-strength, duration, purposefulness of muscular action
Endocrine-hormonal projection, quantity and balance
Acceleration-switchology
Speed-closure rates, egress
Maneuvering-high-G → EKG rhythm, ventricular filling defects, blackout
Low-level flight-situational awareness, judgment
Delivery tactics-target fixation
Weapons selection-switchology, fatigue
Target I.D.-communications with GCI controller-flight members
Mission profile-fatigue, low-level
System failures-workload
Wx-thermal stress
Deployments-circadian rhythm, rest, nourishment

Flion

Total flight experience
Flight experience specific a/c
Excessive confidence
Attention deficiencies
Errors of interpretation
Late decisions
Excessive competition
Incorrect procedures
Failure of automated system
Insufficient mission preplanning
Marginal operational conditions
Fatigue/stress/illness
Vertigo/disorientation
Questionable medical status
Questionable neurologic status
Questionable psychologic status
Leadership deficiencies
Deficiencies in directives/briefings/special information

Green

Personality-"adventurousness"
Violation of flight discipline
Misperceptions
False hypotheses
Psychomotor programming errors (likely with highly experienced)
Visual illusions
Misleading visual information

Paolucci

Behavior habits
Worries
Fatigue
Drugs
Eating habits
Flight experience
Diseases (family)
Previous accidents
Duty changes

Hoffman

Visual detection
Recognition } Information Processing
Identification } Information Processing
Classification } Information Processing
Luminance
Contrast threshold
Horizontal standard visibility
Inherent contrast

Reader

Nausea
Vomiting
Abdominal pain
Diarrhea
Earache
Faintness
Headache
Vertigo
Loss of consciousness
Hypoxia
Disorientation
Hyperventilation
Coronary disease

Haakonson

Degraded judgment
Carelessness
Inattention
Poor technique
Cognitive stress
Emotional stress
General adaptation syndrome
Inactivity
Turbulence
Noise
Equipment encumbrance
Preventive thinking
Alertness
Level of training
Confidence in self/equipment
Familiarity with aircraft/route/airport
Peer/supervisor pressure
Hunger
Hangover
Anger
Frustration
Guilt
Oversensitivity
Marital stress
Personal lifestyle

Taylor

Inadequate information (navigation)
Interpretation errors
False expectancy
Visual and vestibular cues
Complex ATC procedures
Pilot workload
Illusions
Human engineering deficiencies

THREE DECADES OF USAF EFFORTS TO REDUCE HUMAN ERROR ACCIDENTS 1947-1977

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SUMMARY

The very impressive accident prevention efforts of the United States Air Force (USAF) in its air operations are well known. In 1977, 30 years after its formal inception, major accidents had been reduced from 1,555 to 90. The rate reduction is equally impressive--from 44 accidents for each 100,000 hours of flying to 2.8 on the same basis. Frequently not recognized is that human error associated with these accidents has been reduced as much as materiel and other involvements. Analysis of the preventive efforts shows three distinct, although overlapping, approaches which have been employed. The administrative approach is the best known. This investigate-evaluate-fix cycle is the common dimension of almost all accident prevention effort. The scientific approach supplements the information by centering upon a systematic and intensive evaluation of human limitations in a defined man/machine setting. The third concept--total system management--emphasizes improvement in the management of the entire system, though the details of what will be instrumental in the prevention of a specific accident are often not defined. In practice, a viable accident prevention program incorporates all three approaches, with emphasis defined in relation to need.

A discussion of human error accident prevention must, in the final analysis, be synonymous with an examination of the total prevention program, for human error is indeed the major component in accidents. Because human error can occur to anyone in any facet of Air Force operation, the program must encompass all aspects. While the USAF, formerly the Army Air Corps, has always had an accident prevention effort, the inception of the program currently in force stems from the losses being experienced during the early years of World War II. In 1943 there were 20,389 major aircraft accidents in the continental United States for a rate of 64, based on 100,000 hours of flying. During that year there were 5,024 aircraft destroyed in accidents, in contrast to 3,847 destroyed in actual combat. Fatalities were equally disproportionate. The USAF accidents in the continental United States, for a 6 month period, accounted for 3,426 fatalities, in contrast to 2,392 lost through combat. General Hap Arnold, on the basis of this record, directed a major revision and expansion of the accident prevention effort.

By 1947, when the Air Force was established as a separate service, the number of major accidents had been reduced to 1,555, and, more impressively, the accident rate had been reduced to 44. During the three decades of its history, this downward trend has continued (see Figure 1). The 10-year trend lines, superimposed on the basic data, demonstrate the increasing difficulty of further improvement with time. The 87 accidents experienced in 1976, for a rate of 2.8, indeed represent a notable reduction for three decades of operation, but present a great challenge to further reduction. The 90 accidents, for a rate of 2.8, in 1977, which initiates the fourth decade of Air Force operations, are indicative of the difficulties which will be encountered in further reductions.

While the change in the accident rate is impressive, an equally impressive and more constant measure of progress is fatal accidents, which during the three-decade period were reduced from 205 mishaps, with a rate of 6, to 33 fatal mishaps, for a rate of 1, three decades later. Again, the 10-year incremental trend lines (Figure 2) demonstrate the marked improvement but also the increasing difficulty of further improvement with time. This is again emphasized by the 1977 record of 39 fatal mishaps, also for a rate of 1. Another constant measure is the aircraft destroyed rate (Figure 3). This follows the same pattern. From 536 aircraft destroyed in 1947, for a rate of 15, it has decreased to 68 destroyed aircraft in 1976 for a rate of 2.20. The 1977 record of 78 destroyed aircraft, for a rate of 2.4, further documents the increasing difficulty of further improvement as the numbers become increasingly smaller.

An interesting observation when causation is considered is that, relatively, the human factor aspects of accidents have decreased as pronouncedly as the materiel and other considerations. Historically, human error accounts for from one-half to two-thirds of all accidents, with a major portion of these errors being attributed to the pilot operator. Of the 90 accidents which occurred in 1977, 17 were attributed to 1 human error, 26 were attributed to multiple but only human error, 21 were ascribed to 1 materiel failure, 3 to multiple but all materiel failure, and 23 were partly human and partly other factors. Collectively, 135 unsafe acts and 72 unsafe conditions were assessed in the 90 accidents.

Although the Air Force has modified its assessment of causes so that a primary is no longer the standard measure, a review of the 1977 accidents for comparability purposes indicates that 30 percent would have, under the old system, been attributed to the pilot. A comparison of this with records of the past supports the relative constancy of human, and specifically operator, involvement. Supportive of this is that of the specific errors, the greatest number was associated with poor technique in flight, followed by various forms of maintenance error, which was, in turn, followed by various supervisory unsafe acts.

In order to achieve the very real gains demonstrated, and as methods for engaging the problems which remain, three interrelated and overlapping systems for human error accident prevention have evolved. These might be designated the organizational approach, the scientific approach, and the management approach.

The organizational approach (Figure 4) has as its focal point the evaluation of those accidents which do occur, with a view toward determining cause and developing remedial measures. Conceptually, this method of dealing with prevention may be considered a closed circuit feedback system which starts with a pre-accident plan involving the development of appropriate forms for recording and personnel for investigating. Once the accident has occurred, an intense investigation is conducted. A great number of items of information are systematically recorded and carefully stored for subsequent retrieval and analysis. The analysis of individual and collective accidents leads to categories of causation of varying degrees of importance, which then serve as the basis for recommendations. These may take the form of general information distribution or may relate to specific fixes which need to be accomplished. The changes in the system are then implemented. Only subsequent experience will indicate whether the recommended actions have been effective in preventing future accidents. This classical approach is common to essentially all accident prevention efforts and serves as the basis for organization as well as for a prevention program. Meaningful implementation of this organizational system requires that information for further analysis of human activity be collected and that appropriate forms be developed before systematic recording. The investigation, to be adequate, requires participation by specialists in the human factors area, and the analysis must include both the dynamics of human interactions for individual accidents and employ carefully considered analytical techniques for extracting maximum meaning from data obtained from accidents collectively. The other steps in the sequence must assure equal concern for the human elements in addition to the more usual concentrated attention on the machine variables.

The primary difficulty from the human factors standpoint which this approach highlights is that "what" happened can be documented, frequently with astonishing precision, but that "why" it happened often remains obscure. The fact that over half of all accidents are attributable to human error is a standard finding of this approach, yet why the human error occurred is most frequently not defined.

The need to determine why in order to pursue more definitive remedial actions has led to a number of activities. Among the more systematic of these are those which consider the human in a man/machine context as a part of a total system. The design parameters of both the man and the machine and the interface variables become subjects of systematic analysis. In such a system, the man/machine interaction may be considered as a dynamic closed feedback system along a time continuum (Figure 5). Here, man's portion of the man/machine activities can be considered as a series of perception/decision/response activities. For a comprehensive human factors evaluation, the points of interaction between the man and machine at the perceptual end of the time sequence and the interface between the man and the machine at the response end of the man's portion of the interaction also need consideration.

In considering both the input and output interfaces, as well as the perception/decision/response sequence itself, there are a number of variables which are an inherent part of man's design and which can be profitably examined for their potential contribution to human error. These might be classed as the five "Ps": physical, physiological, psychological, psychosocial, or pathological limitations or strengths. As these are systematically studied, some whys of human error become more clearly defined and the reason for the human contribution to mishaps more clearly understood.

Some of the more obvious physical factors which have been found related to successful man/machine operation are physical strength and stature. As in so many instances where human limitations are involved, the limitations seldom change, but changes in requirements frequently bring specific limitations into focus as a meaningful issue. For example, the recent emphasis upon increasing the number of females in the Air Force population has resulted in efforts to document the effects which these changes will have upon the requirements for strength and physical size. The resulting decisions must then be implemented either through changes in the personnel selection process to insure that only those with sufficient physical strength are assigned to specific tasks, or that the task requirements are modified to fall within the capabilities of those assigned to perform them. In actual practice, both alterations are involved.

In addition to the general anthropometric area, a study of physical limitations includes the sensory functions. Because vision plays such an important role in the acquisition of information to be processed, it is understandable that this area has received a great deal of attention. Considered have been basic acuity; the role of distortions, particularly important in the design of windscreens; attention-provoking characteristics, related to the selection of anticollision lights; sensory compatibility,

of great importance in understanding and preventing vertigo/disorientation mishaps; and visual time lapses, of pertinence to an understanding of displacement in space of moving objects. Some of the more esoteric visual phenomena, such as the visual autokinetic effect, empty field myopia, and the photic-driving phenomenon, have also been examined. All of these, together with relatively mundane phenomena such as dark adaptation, have direct implications for the design of equipment as well as for operational restrictions in some instances.

The other senses, although of lesser importance in this context, also have limitations and attributes which have implications for successful man/machine integration. The auditory sense is important in obtaining information which must be both audible and unambiguous. Further exploitation of this sensory modality offers potential as a vehicle for warning and information systems.

Collectively, then, physical strengths and limitations, when considered systematically, can have a very direct bearing upon the success or failure of the perception/decision/response sequence in the man's side of the man/machine system.

The list of physiological variables which have been evaluated in relation to effective and efficient performance is multitudinous. Examples of these include all of the studies on the role of oxygen and the need for terrestrially equivalent environment regardless of the altitude at which aircraft are operating. The many centrifuge studies investigating both physical and physiological tolerances have added greatly to the definition of the limits past which operation cannot be effectively conducted without compromise and have led to the development of a variety of equipments aimed specifically at compensating for human limitations. The role of fatigue and the need for systematic control of rest periods have been important in the development of crew rest requirements. The effects of a great variety of toxic substances on the human body and its ability to perform have been studied and the results directly reflected in controls and limitations on toxic emissions. The effects of alcohol and the real need for understanding its role in deteriorating efficiency have been the subject of many and varied evaluations. With the increasingly popular consumption of drugs other than alcohol,the role and effects which these play on skilled performance and the restrictions on their use which need be considered have more recently come into prominence.

Another human variable with major physiological as well as physical and psychological components is the aging process itself. Many studies, both of an individual and statistical nature, have resulted in insights which have direct influence upon an understanding of risk associated with utilizing persons in various age categories for tasks of varying degrees of complexity.

Human psychological variables can be considered grossly as those of a cognitive or emotional nature. The cognitive area incorporates recognition that there are great individual differences in capacity and in aptitude for various kinds of activity. The role of learning and the best methods for producing a trained person have been and are currently the focal point of much serious and concentrated study. The phenomenon of transfer of training, how it can best be accomplished, what functions can be best developed with simple training aids, or even with the use of sophisticated simulators in contrast to actual aircraft experience, are all of very current and very practical interest. Statistically, the roles of accidents in relation to various phases of learning, the need for and the optimum amount of current experience in relation to various levels of overall background experience, all have practical implications for not only successful operation but also for the control of human error and the maximizing of accident prevention. The phenomena of both retroactive and proactive inhibition, more commonly described in Air Force circles as "habit interference," have major implications for the prevention or facilitation of human error through design astuteness or ineptness.

The emotional areas of concern, while less tangible, are almost universally accepted as being important to successful accident-free operation. There have been and are continuing evaluations of the role of temperament in relation to aptitude for specific kinds of activity. The role which either transient personnel variables or more deeply rooted psychic pressures have upon the propensity for accidents has been studied extensively. While the role which accident proneness plays in specific kinds of accidents remains obscure in spite of the hundreds of studies in the area, the insights which have come from these studies collectively demonstrate the importance which definition of this area may have for successful completion of the perception/decision/response sequence in a successful man/machine operation. Without attempting to summarize the results of either the cognitive or emotional aspects of psychological factors, the information which has been developed validates the accepted importance of this area and the need for continuing definition of its subcomponents.

Psychosocial forces are also of demonstrated importance. The impact of peer pressures and social mores on group activities is well known. In the understanding and control of human error, it is possible that this is a variable which has been relatively neglected. Evaluations from accidents do indicate, however, that performance is directly related to the expectations of the group. If the social climate is one where adherence to discipline and procedures is the accepted standard and where deviates are ostracized, then precision accomplishment can generally be anticipated. On the other hand, if the social atmosphere is one where violations and deviations are the accepted norm, and are not only condoned but rewarded, then this kind of activity can be expected.

A recent series of studies has indicated that the major factor in escaping from a disabled aircraft is the decision to activate the mechanism. Various reasons have been postulated for this, relating to ego involvement, expectations of peers, and fear of reprisal by supervisors. It is generally accepted, however, that a change in attitude regarding this decision process is the only real hope for improving the survival rate following ejection, as the hardware malfunctions remain a negligible factor in the adverse results.

Pathology, by definition the operation or maintenance of a system, depends upon individuals who are both physically whole and psychically sound. The Air Force system of screening is such that physical incapacity is seldom a factor in aircraft accidents. The infrequency of this attests to the very real success which has been achieved in the screening process. The few cases which remain document the need for continuing effort. More common than major physiological adversities are the minor ailments which neither the individual nor the system recognizes as important, but which still have an impact on efficiency. Self-medication for these frequently aggravates the problem.

Psychic incapacitation is equally rare, again attesting to the effectiveness of the screening, training, and procedural system which controls Air Force operations. The few frank psychiatric disturbances which do occur only reinforce an awareness of the effectiveness of the system. These also demonstrate the need for continued monitoring to improve an effective system.

By definition, this summation of the human variables, which can be considered pertinent both to an understanding and to an improvement in the efficiency and effectiveness of the perception/decision/response sequence, is illustrative, not all-inclusive. It does demonstrate how such considered evaluation can supply background information which, in at least some instances, defines the whys of human error in contrast to the grosser assessment that the human system failed. Further refinements in this area offer great promise for an increase in operational efficiency and effectiveness as a concomitant of reduction of human error and reduction in the probability of accident.

While the organizational and scientific approaches do much to clarify the role of the human and steps which must be taken to preclude his error's being a factor in accidents, there are, realistically, still many accidents which do occur for which the "why" remains obscure even after intense investigative analysis utilizing the best scientific information available. This has led to a third approach to human error accident prevention. This approach is based on the assumption, supported by many evaluations, that improvement in each sequential step of the acquisition and use of both people and equipment will result in a better operation and will involve a decreased potential for accidents. These steps for the utilization of people involve, in sequence, selection, training, and operational use, with programs related to these to assure appropriate motivation and equipment optimization for the mission to be performed.

Included in this total system integrated management must also be recognition of the role and need for change. As circumstances and modified requirements change the role of the man and machine, the variables associated with this must be reexamined to assure that what was adequate or even optimal for one period has not deteriorated to the point that it is no longer applicable.

Selection is based on the recognition of the fact that some individuals are better suited for some tasks than others. Since World War II, efforts have been made to develop selection tests or techniques for aircrew members which would assure minimum losses during training and maximum effectiveness in an operational setting following the training period. These efforts continue. While the specific role which some variables may have in accidents is sometimes difficult to define, the fact that an individual with greater propensity for the task to be accomplished is carefully chosen implicitly suggests that the probability of human error which will lead to accidents has been decreased. By a similar rationale, improved training can be supported, although the specific factor which may have led to a given accident may not be definitively isolated. If the individual is trained in the best known methods, if aids with the best demonstrated effectiveness are used, if the training is consequently redefined to assure that it is directly oriented toward the ultimate task to be accomplished, the assumption must remain that the probability of human error accidents based on lack of information or experience has been reduced. Comparably, assiduous attention to the rules and regulations by which Air Force people operate to take account of the limitations of the human in relation to the mission to be accomplished must surely decrease the probability of accidents. If more than one crewman is involved, the roles and interactions of the crew must be clearly defined and practiced ahead of time, and the hierarchy of control in terms of command and traffic systems must be understood and accepted. Constant practice to assure that known effective procedures become an integral way of life for the individuals concerned, with adequate emergency training which will assure that the individual can assess when a deviation is in progress as well as know the remedial actions to take, can surely help in the prevention of accidents.

Associated with the mechanics of the use of man and equipment to accomplish the mission must be a recognition of the dynamic roles which motivation plays in assuring that competent people are appropriately alerted to the needs for utilizing the talents and skills which they have in an optimum fashion. This means that there must be a clear understanding by all concerned of the need for the activity and its requirements and that these be considered in relation to individual limitations. Education, in a broader sense than technical proficiency, is an integral part of this approach to

accident prevention. It involves the development of attitudes which accept the importance not only of the mission but also of the need for safety if it is to continue to be accomplished in a satisfactory manner. Another aspect of this people recognition is acceptance that people need security with opportunity for professional, personal development and other forms of advancement. The Air Force, in recognition of this, has major programs directed specifically at the management of its rated personnel to assure that, within the limits of mission requirements, these other considerations are kept in focus.

This concept of integrated management of the entire system, taken in conjunction with the scientific material and synchronized with the organizational approach, represents a 3-pronged attitude on accident prevention. At times, one approach is emphasized in contrast to the others, but in the final analysis, all are necessary for a flexible prevention program. Indeed, flexibility is one of the major keynotes of success, for, while humans' propensity to err changes little, the opportunity to err is directly related to the equipment and situation, which means that prevention programs must constantly be alert to the fact that these change.

The discussion of why human error occurs is conceptually relatively simple to demonstrate. As the preceding analysis has indicated, the quantified details of this conceptual "why" frequently are difficult and, at times, the variables themselves remain obscure. Conceptually, however, the mechanics of an accident can be considered in terms of the level of competence and a level of demand (Figure 6). As long as there is a wide margin between these two, no accident will occur. If catastrophic mechanical failure occurs, the individual, no matter how competent, cannot prevent the accident. On the other hand, if the individual becomes completely incapacitated, the level of demand, no matter how minimal, still exceeds his capability. In most instances, however, accidents do not occur because of these drastic circumstances, but are rather the result of a gradual erosion of capability and/or a gradual increase in situational demands. At the point that the demands of the situation exceed the capability of the man, at that moment an accident occurs. During the three decades that the Air Force has been in existence, its history clearly indicates that the systems which have been evolved are, in fact, effective in assuring that situational demands do not exceed human capability. The fact that accidents are occurring which, in retrospective evaluation, could have been prevented, demonstrates that the approaches utilized need to be continued and refined if further reductions are to be achieved. The historic record would give great promise that this can indeed happen, so that accidents, even human error accidents, can be prevented.

In summary, the Air Force has, faced with the problem of reducing accidents, developed a variety of integrated systems which, when implemented as intended, do, in fact, achieve this end. No organization for accident investigation/evaluation is sufficient; scientific information, unless appropriately integrated into the system, is not sufficient. The general improvement of the entire system through astute integrated management also is not sufficient alone; but when all these approaches collectively are utilized, the result is a marked reduction in accidents associated with enhanced efficiency at decreased costs, whether measured in terms of manpower, equipment, money, or time.

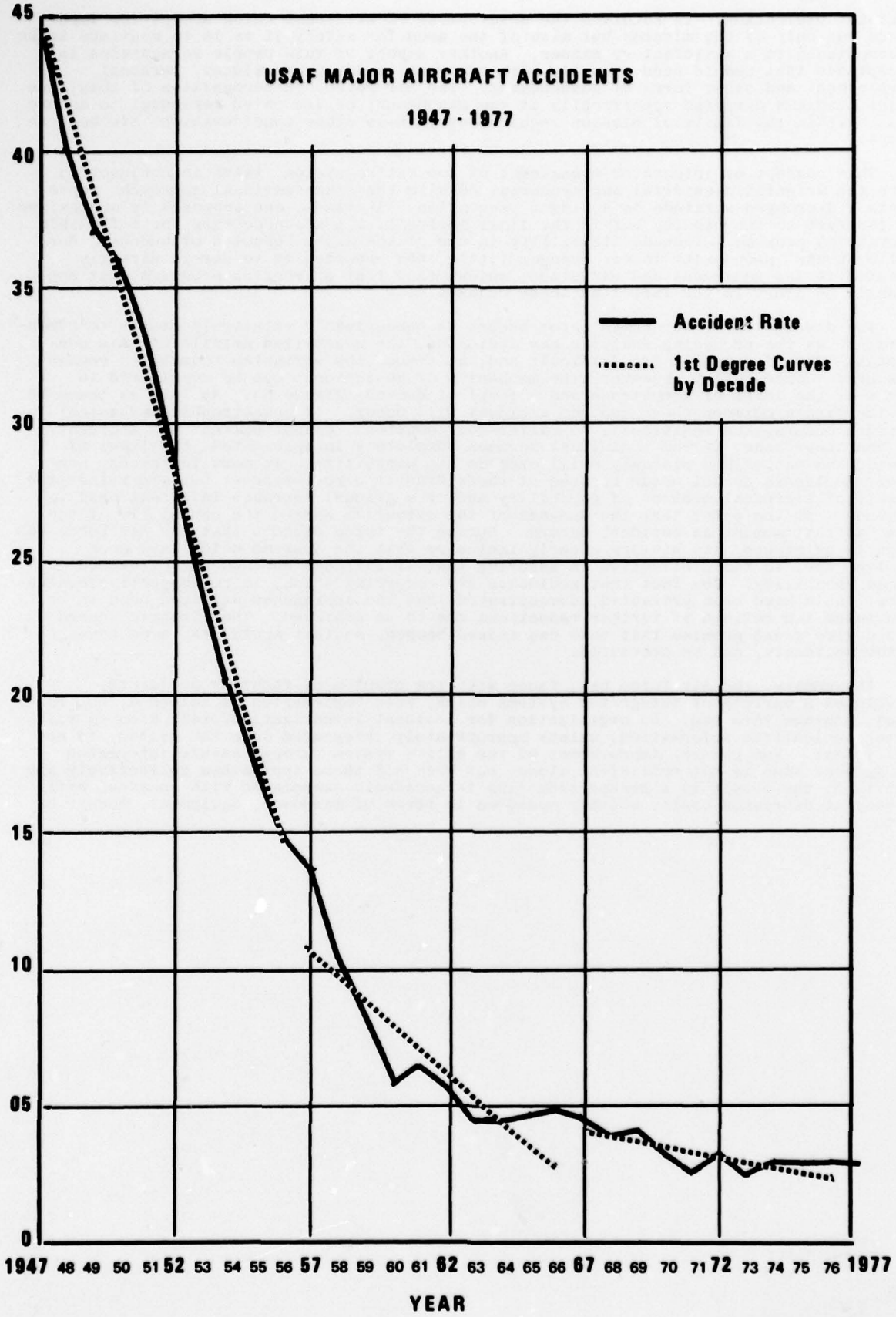

USAF MAJOR AIRCRAFT ACCIDENTS
1947 - 1977
Accident Rate
1st Degree Curves by Decade
45
40
35
30
25
20
15
10
05
0
1947 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 1977
YEAR

Figure 1

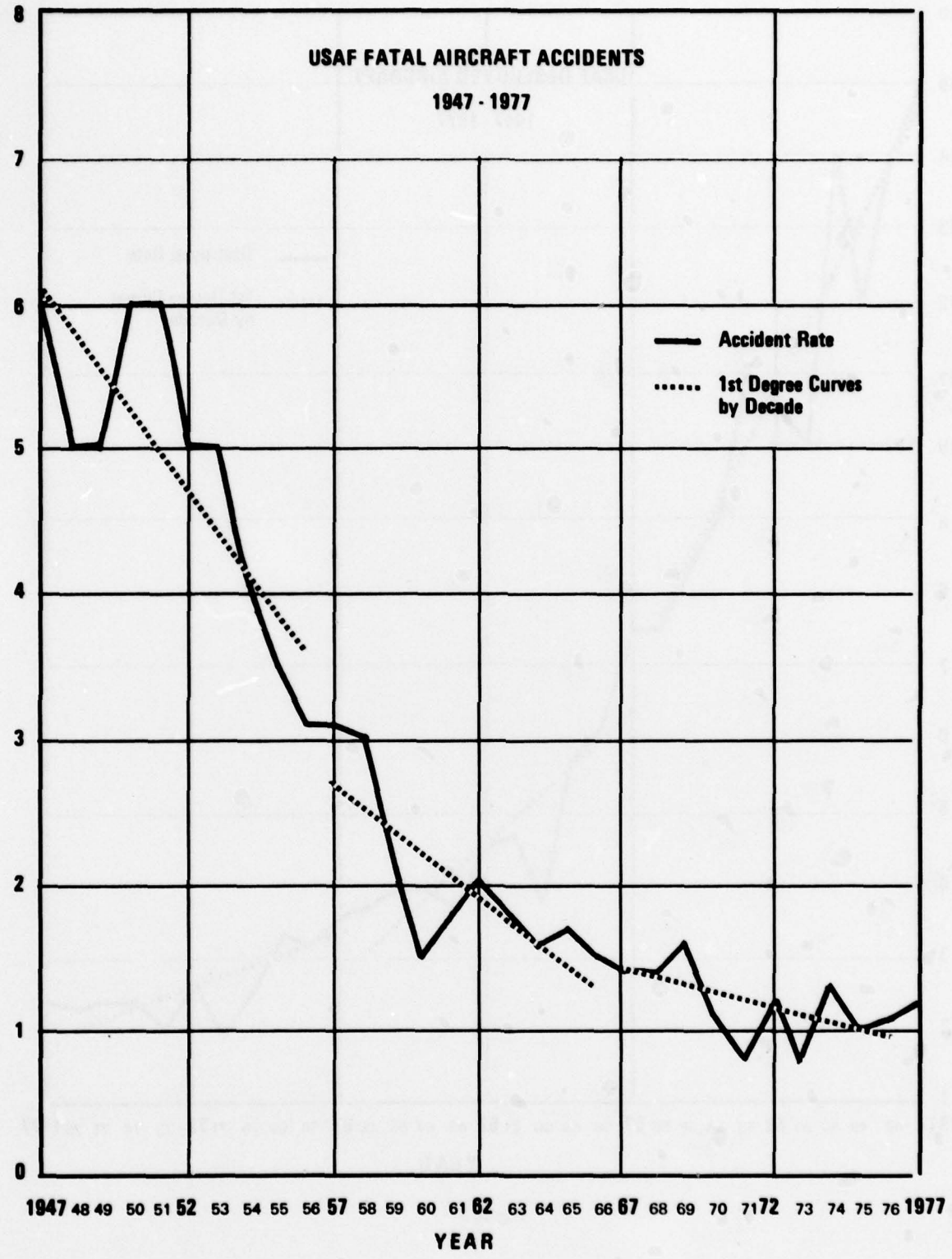

USAF FATAL AIRCRAFT ACCIDENTS
1947 - 1977
Accident Rate
1st Degree Curves by Decade
8
7
6
5
4
3
2
1
0
1947 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 1977
YEAR

Figure 2

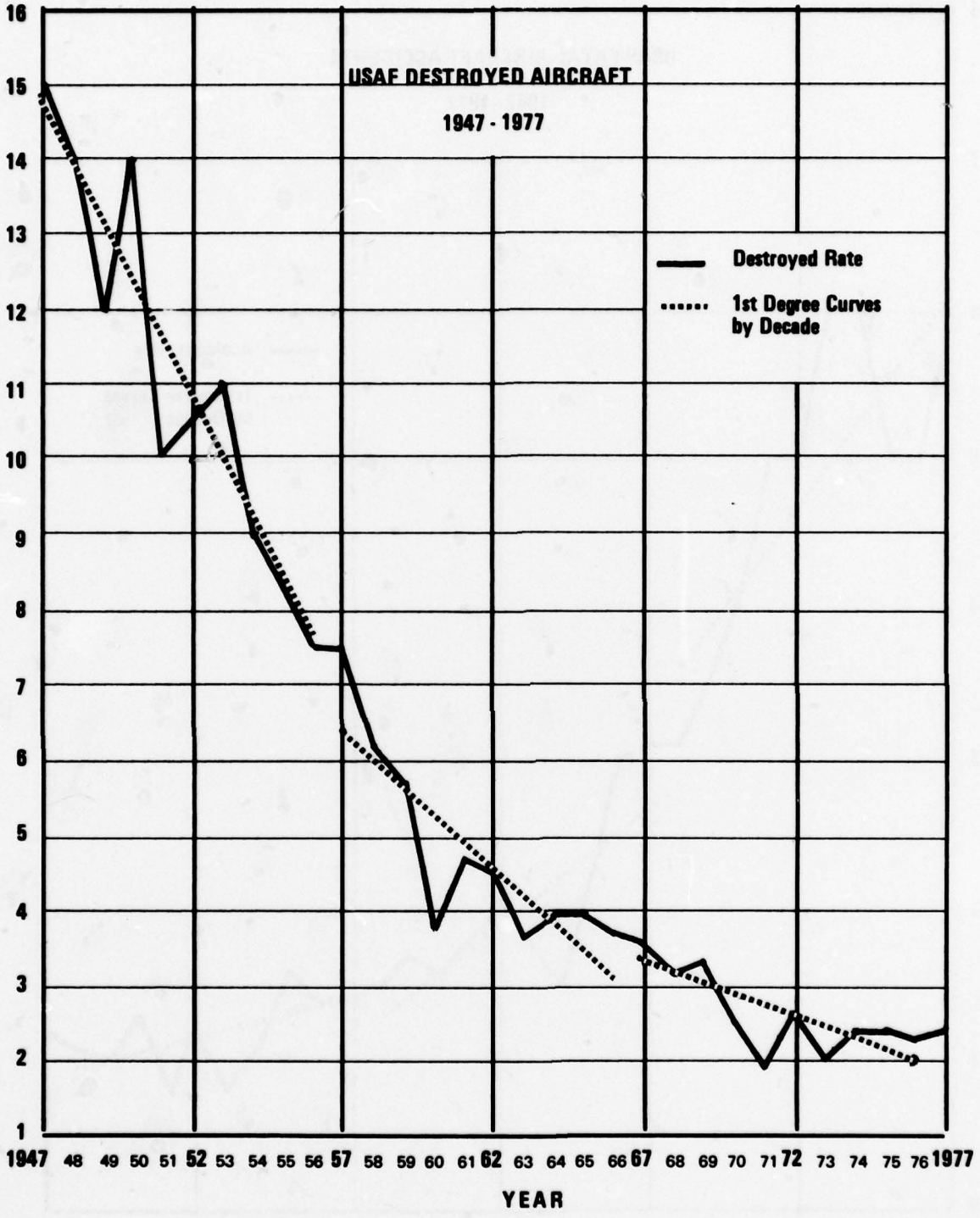
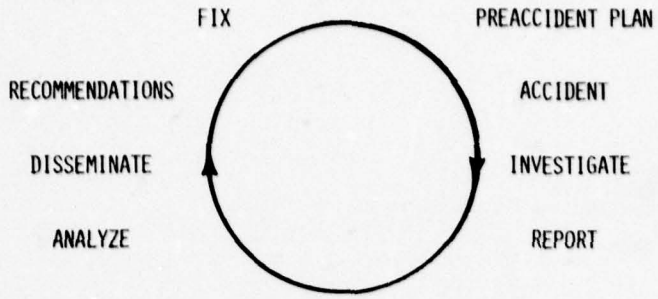

USAF DESTROYED AIRCRAFT
1947 - 1977
Destroyed Rate
1st Degree Curves by Decade
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
1947 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 1977
YEAR

Figure 3

THE ORGANIZATIONAL APPROACH



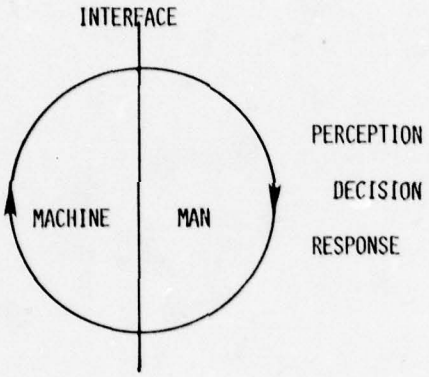
CLOSED LOOP FEEDBACK SYSTEM

HUMAN ERROR - 50% +

WHAT - NOT WHY

Figure 4

THE SCIENTIFIC APPROACH



CONTINUOUS FEEDBACK TIME FLOW

Figure 5

ACCIDENT CAUSATION

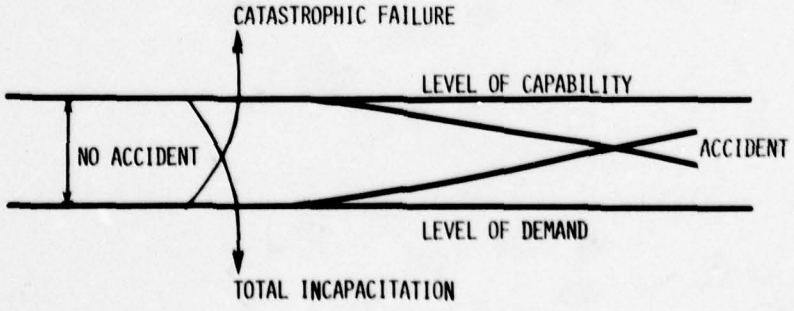


Figure 6

MEDICAL AND OPERATIONAL FACTORS OF ACCIDENTS IN ADVANCED FIGHTER AIRCRAFT

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SUMMARY

Flying advanced high performance fighter aircraft requires of man, courage, coordination and comprehension of the flying machine and its capabilities, the flying environment and its challenges, and man's physiology and its limitations. The proper mix and interface between improving aircraft capabilities and man's capabilities and limitations produce success in aerial and aerospace operations. A dysequilibrium between the medical and operational aspects of man and aircraft combine to produce accidents. This paper addresses some of man's physiological systems and advanced fighter aircraft characteristics. It discusses multiple operational requirements imposed on men who fly high performance fighter aircraft. It also discusses the interface between the operational requirements imposed on men who fly high performance fighter aircraft and the medical aspects of some of the accidents therein related. A proposal for the establishment, in NATO, of a viable aircraft accident information gathering and dissemination program which would prevent accidents in advanced fighter aircraft is made.

Just seventy-five years ago next month, man for the first time enjoyed the phenomenon of sustained powered flight in a heavier-than-air flying machine. It took him less than ten years to realize the utility of this invention as a weapon of war. The airplane offered the warrior unprecedented speed, maneuverability, and weapons delivery advantage. It required of man courage, coordination and comprehension - comprehension of his flying machine and its capabilities, his flying environment and its challenges, his physiology and its limitations.

The simplicity of this marriage of man and his flying machine soon became complicated as man sought to expand the performance envelope of his aircraft and his own physiological envelope. He discovered rather slowly at first and more rapidly later that the aircraft performance envelope was more elastic and expandable than man's physiological envelope. Hence, we see aircraft speed, maneuverability and weapons delivery capabilities continuing to increase even today as man requires higher performance from each succeeding generation of aircraft. Meanwhile, man's cardiovascular, pulmonary, musculoskeletal and central nervous systems limits have been and are being more finitely and discreetly defined.

The proper mix and interface between the improving aircraft capabilities and man's capabilities and limitations produce success in aerial and aerospace operations. A dysequilibrium between the characteristics of man and his flying machine or the medical and operational aspects of man and aircraft combine to produce accidents. Thus, it is the medical and operational factors of aircraft accidents in advanced fighter aircraft that I wish to address today.

A historical perspective of advances in fighter aircraft reveals that major wars appear to describe the limits of a generation of aircraft. Each generation builds on improvements garnered from the previous one. A simplistic overview of five major wars (WW I, WW II, Korean, Vietnam, Next) and the advances in fighter aircraft reveal the following:

WAR	FIGHTER AIRCRAFT
World War I	Slow, open cockpit, fixed gear, biplane
World War II	Faster, closed cockpit, retractable gear, cantilever wing
Korean	Faster, pressurized cabin, swept wing, jet propelled
Vietnam	Supersonic (dash), air-to-air refueling, radar target acquisition
Next	Supersonic (sustained), high sustained G maneuvering, variable geometry wing, long distance target acquisition and weapons delivery

Volanti Subvenimus - We Support the Flyer - is the motto of the United States Air Force School of Aerospace Medicine. Volanti Subvenimus might well be considered the motto of all physicians the world over, who are concerned with the health, welfare, and

performance of those who fly advanced fighter aircraft. Today, more than ever, the need for medical and operational support for flyers is paramount, especially in view of the higher performance capability of the aircraft for tomorrow's war, which are already here today.

For the first time in the history of fighter aviation, we now have an abundance of fighter aircraft capable of imposing physiological stresses on man for sustained periods of time which exceed man's anatomic and physiological design. These are truly high performance advanced fighter aircraft.

Some of the physiologic systems and their constants to be considered in high performance fighter aviation include but are not limited to:

Vision - finite time to see, focus, identify

Cardiovascular - heart rate, rhythm and stroke volume limits

Pulmonary - respiratory rate, gaseous exchange mechanism

Central Nervous - cerebral electrical activity, time of useful consciousness

Psychiatric - time and orderliness of decision making

Musculoskeletal - strength, duration, purposefulness of muscular action

Endocrine - hormonal production, quantity and balance

Some of the characteristics of high performance advanced fighter aircraft include but are not limited to:

Acceleration - less than 30 seconds standing start to supersonic speed

Speed - sustained supersonic flight, top speed above Mach 2

Maneuverability - High sustained G ($+6G_z$ longer than man's normal physiological endurance) in three dimensional flight

High Thrust to Weight Ratio - greater than 1 to 1

Low Wing Loading

Variable Geometry Wing

Air Refuelable

Afterburner Equipped

Advanced Target Acquisition systems providing target data of speed, altitude, direction, closure rate over great distances (beyond 160 Km)

Weapons Variety - Cannon, short, medium and long range missiles

Single and Dual Place Cockpits

Please permit me at this time to present some of the operational requirements and factors imposed on men who fly high performance fighter aircraft and the medical aspect of some of the accidents which have occurred in these aircraft.

a. Acceleration - medically, man must perform the necessary cockpit actions to cause the aircraft to become airborne or change speed while airborne. Buttons must be pushed, levers moved, instruments and gauges monitored, preparations for emergency action taken, emergency procedures made readily accessible (through memory or reading). Engine failure on take off and/or while maneuvering, failure to rotate, over rotation have all produced accidents.

b. Speed - closure rates produced by converging high speed aircraft can preclude sufficient time for aircraft identification and proper evasive action and result in midair collisions. A requirement to egress (bail out/eject) from jet aircraft at high speeds produce flail injuries, contact with aircraft parts, personal equipment damage and malfunction, other bodily injury and death.

c. Maneuvering - high sustained G forces (above $+6G_z$ for 20 to 30 seconds or more) can produce EKG rhythm abnormalities, ventricular filling defects, pulmonary changes to include atalectasis, cerebral electrical dysrhythmias, blackout, severe spatial disorientation, judgment miscalculations and death. In this day of fast supersonic aircraft, it is still possible to fly too low and too slow. This unfortunately also produces fatalities.

d. Low Level Flight - situational awareness involving judgment of terrain height, aircraft attitudinal awareness, speed and distance is required. Impact with terrain, ricochetting weapons, birds, and weather phenomena occur with an alarming frequency in routine low level operations, often with disastrous results.

e. Delivery Tactics - target fixation, pulling excessive $+G_z$ and flying the aircraft into speeds and attitudes outside of the aircraft design limits for given configurations have caused uncontrolled flight, serious structural damage, injury and destruction to both aircraft and aircrew.

f. Weapons Selection - the vast array and complexity of weapons and types of ordnance available to advanced fighter aircraft require selection options and methods which are complex. The prestidigitation required by the pilot to operate the switches, levers, and buttons which will release the appropriate weapon at the enemy, rivals the keyboard artistry of the concert pianist. While these requirements are fascinating and challenging to the fighter pilot, they are also frequently fatiguing and can, in time, cause errors which could be fatal.

g. Target Identification - man can no longer rely only on his own visual identification of aerial targets with the naked eye. This too poses medical problems, for man must now not only operate his radar set to gain the enemy, determine his location and positioning, but he must rely on another agency, to wit, the ground controlling intercept agency to assist in target acquisition. This adds another communications complexity which requires a further subdivision of his attention from his cockpit duties and his inter-communication with his flight members and others who are in the same communications space.

h. Mission Profile - low level flights 100 feet and below at high subsonic or supersonic speeds for prolonged distances and times (greater than 1 hour) are demanding and fatiguing; couple this demand with heat, less than optimal nourishment and/or rest, and variable weather conditions and again one has the prime ingredients for an accident.

i. Systems Failures - the advanced fighter aircraft is a very complex aircraft containing many systems in order to give it its high performance characteristics. These complex systems are designed to decrease man's workload; however, the multiplicity of the systems and their failure and failure potential can produce catastrophic accidents. Some of the systems to be operationally considered include hydraulic, central air data computer, fuel, parachute, terrain avoidance, electrical, canopy, arresting, escape, crew restraint - each has its own medical and accident producing importance when they fail.

j. Weather - modern warfare requires flyers to be able to perform their operational duties in all kinds of weather. Thermal stress (hot and cold), weather navigation and maneuvering have contributed to fatal accidents ranging from midair collisions to meteorological damage to the aircraft and its systems.

k. Operational Tactics - the myriad of tactics varying from air-to-air combat with low level (below 100 feet) to high level about 50 thousand feet to teamwork produce a spectrum of accidents ranging from ground impact to midair collisions.

l. Deployments - often aircrews must deploy great distances to the battle zone. Crew nourishment, crew rest and fatigue, circadian rhythm disruptions have at one time or another been implicated in accident causation.

m. Man - missions, aircraft, weather, target, enemy, all present adverse factors with which a fighter pilot must cope. All of these considerations assume a fighter pilot in optimum health and free of disease or incapacitation. The hazards are multiplied in the case of an aircrew with organic or psychophysiological illness, injury, or fatigue. Even adverse aircrew attitudes regarding the value and use of safety devices and personal equipment can and do contribute to accidents. Man and his reliability are the sine qua non to successful accomplishment in high performance fighter aircraft. His training, skill, and judgment are relied on absolutely once he has been committed to the mission. How well he integrates his total physiological capabilities with the capabilities of the aircraft have a direct relationship to success. The disintegration of the man/machine interface which can be described as excursions outside of their respective design envelopes, often set the stage for accidents. One of the most critical areas resulting in fatalities is the out of envelope ejection. It is important to note that out of envelope ejections may involve (a) ejecting at too low an altitude, (b) ejecting at too high an airspeed, (c) ejecting at an improper attitude, (d) ejecting at too high an altitude, or (e) delaying too long the decision to eject.

Operations supervisors and medical consultants must communicate more frequently and interface more thoroughly to insure that the man and his machine remain in optimal readiness for successful performance in order to reduce the number and extent of accidents in high performance fighter aircraft. Fiscal and political restraints in aircraft manufacture and sale often combine to provide less than state of the art protection for aircrews, e.g., lack of leg restraints in some high performance aircraft, lack of an ejection capsule in today's high performance fighter aircraft. Even more importantly, the research and development community must be included in the communication and decision loop. Because man's physiological limits are inelastic and have been reached with present state of the art high performance figher aircraft, operations, research and development and aerospace medical persons must take man more into consideration when providing capabilities and features for future advanced high performance aircraft.

To illustrate this need for operations, research and medical cooperation and collaboration, consider an extant anomaly in the use of high performance aircraft. Presently, a considerable amount of attention and tactics are focused on low level fighting and this

is medically unquestioned. Two questions arise, however, concerning the defined limits of low level tactical fighting. One question is, how soon will it be before the high performance aircraft combat arena goes above 40-50 thousand feet? The second question is, are the operations, research and development and aerospace medical communities communicating and working towards meeting the challenges and problems of sustaining man in the high altitude combat arena, preventing accidents through engineering improvements in aircraft design and providing personal survival equipment that is unavailable today, yet whose requirement is known - e.g., a pressure suit or get me down jerkin for fighter crews and a high altitude escape system are needed now.

In closing, I would propose that an in-depth analysis of each high performance aircraft accident (in peace and war) be performed and that a viable information feedback program be established in NATO in order that all may learn and benefit from these unfortunate experiences. And finally, I would propose that as the operational, research and development and medical agencies come to know better the aircraft, the man and the mission, that we all adopt the motto Volanti Subvenimus, for indeed we do all support the flyer.

Analyse de l'intervention du Facteur Humain en tant que cause principale ou d'influence dans les Accidents d'Avions "MIRAGE" à la Force Aérienne Belge.

par

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Introduction.

Le Facteur Humain intervenant dans un accident aérien groupe toutes les circonstances impliquant l'homme dans le système "HOMME - MEDIUM - MACHINE".
Le sens de cette définition est extrêmement large puisqu'il concerne aussi bien l'état physique et psychique du pilote, comprenant sa sélection, ses examens de révision médicale périodiques et son état de fatigue momentané, tous les accidents, incidents ou affections intercurrentes que son caractère, son moral, l'intervention de circonstances sociales ou familiales, son pouvoir réactionnel dans des situations imprévues, son instruction et sa compétence professionnelle intimement liés à l'expérience acquise ainsi qu'aux conditions du vol.
Il est évident qu'on ne peut oublier la possibilité d'une intervention du facteur humain dans le chef de tous ceux qui, de près ou de loin, ordonnent la mission aérienne, la préparent ou en suivent l'exécution.
Partant de cet état d'esprit fondamental nous avons voulu examiner, à la Force Aérienne Belge, un groupe homogène d'accidents aériens.
Notre choix s'est porté sur l'avion "MIRAGE" parce qu'il nous permettait d'envisager le problème sous l'angle de l'utilisation d'un avion moderne, couvrant une période de fonctionnement d'une certaine durée (1971 à 1977) et permettant une approche statistique raisonable en évitant de mêler à cette enquête d'autres avions à caractéristiques différentes.
L'objet de notre exposé se subdivisera en deux parties à savoir, un aspect statistique et un aspect analytique.

I. Première Partie : Aspect Statistique.

PRELIMINAIRES.

Dans le domaine des enquêtes lors d'accidents aériens à la Force Aérienne Belge, il y a lieu de signaler que les tâches investigatrices sont réparties entre le SEAA (Service d'Enquêtes d'Accidents Aériens) et les BASES Aériennes, unités d'origine des avions accidentés.
Le SEAA dont la compétence territoriale est illimitée intervient d'office :
- dans les accidents mortels
- dans les cas d'avions détruits (catégorie 5) qu'ils soient mortels ou non
- dans les cas d'avions gravement endommagés (catégorie 4) pour autant qu'il ne soit pas occupé à d'autres missions (auquel cas c'est la Base à laquelle appartient l'avion accidenté qui est chargée de l'enquête)
- il participe également aux enquêtes combinées prévues au STANAG 3531 de l'OTAN et peut intervenir sur requête de l'Autorité Judiciaire pour des accidents survenus en Belgique à des avions militaires étrangers n'appartenant pas à un pays de l'OTAN.

Les Bases Aériennes sont chargées des enquêtes concernant les accidents aériens autres que ceux mentionnés ci-dessus.

1. Nombre total d'accidents et d'incidents d'avions "MIRAGE" survenus à la Force Aérienne Belge entre 1971 et 1977.

a. Dossiers d'enquête traités par le SEAA.

Durant cette période le SEAA a été amené à traiter 26 dossiers d'enquête (28 pilotes concernés) se répartissant comme suit en fonction du type d'avion
- 18 cas de MIRAGE BA
- 6 cas de MIRAGE BR
- 2 cas de MIRAGE BD

Ces 26 cas se subdivisaient comme suit en fonction de leur "catégorie" d'accident

Type	Cat 5	Cat 4	Cat 3	Total
BA	12	3	3	18
BR	5	1	-	6
BD	2	-	-	2
Total	19	4	3	26

Remarque : les accidents catégorie 3 investigués l'ont été par le SEAA soit, parce qu'il s'agissait d'enquête OTAN combinée, soit parce qu'un autre avion accidenté de catégorie 5 était également en cause dans le cadre de cette enquête.

b. Dossiers d'enquête traités par les Bases Aériennes.

Durant cette même période, les Bases Aériennes furent chargées d'investiguer 65 dossiers d'enquête se répartissant en :
- 39 cas de MIRAGE BA
- 10 cas de MIRAGE BR
- 16 cas de MIRAGE BD

2. Intervention du Facteur Humain en tant que cause principale ou d'influence dans l'ensemble de ces accidents.

a. Dossiers d'enquête traités par le SEAA.

Dans les 26 dossiers traités (concernant 28 pilotes) il y a lieu de relever une intervention du Facteur Humain, en tant que cause principale ou d'influence dans la genèse de l'accident, dans 18 cas (concernant 19 pilotes).

b. Dossiers d'enquête traités par les Bases Aériennes.

Dans les 65 dossiers traités le Facteur Humain peut être mis en cause dans 44 cas se répartissant en :
- 6 cas d'erreur d'inspection ou d'entretien
- 38 cas d'erreur de pilotage.

3. Aspects du Facteur Humain intervenant dans ces accidents.

a. Accidents traités par le SEAA.

Nous avons constaté plus haut que sur les 26 dossiers traités par le SEAA, 18 cas faisaient intervenir le Facteur Humain dans l'origine de l'accident. Il nous a paru intéressant de signaler ici les différents aspects de ce Facteur Humain en tenant compte du fait que plusieurs composantes ont pu intervenir simultanément dans un même accident.
Nous avons totalisé 52 composantes dans ces 18 cas.

(1) Composantes extérieures au pilote : 15
- (a) - déficience du leadership à quelque niveau que ce soit : 14
- (b) - erreur de contrôle au sol : 1

(2) Composantes dans le Chef du pilote : 37
- (a) Psychologique : 17
  - excès ou manque de confiance en soi : 3
  - attention (inattention - dispersion de l'attention - concentration excessive d'attention - *manque de surveillance des paramètres en vol*) : 6
  - erreur d'appréciation : 5
  - décision tardive : 1
  - excès d'esprit compétitif : 2
- (b) Expérience de vol : 10
  - expérience limitée sur le type d'appareil : 3
  - manque d'expérience dans le passage du vol à vue au vol aux instruments : 2
  - application incorrecte des procédures : 3
  - rupture des automatismes acquis : 2
- (c) Préparation et exécution du vol : 5
  - insuffisance de préparation de la mission : 2
  - conditions de vol marginales : 3
- (d) Physiques : 5
  - fatigue : 1
  - stress suivi de blocage : 1
  - malaise physique : 1
  - vertigo avec désorientation, 1

b. Accidents investigués par les Bases Aériennes.

Dans la série des 65 accidents investigués par la Base Aérienne d'origine du "MIRAGE" accidenté nous avons constaté que 44 accidents font intervenir un facteur humain se différenciant sous les aspects suivants :

(1) Erreurs d'inspection ou d'entretien : 6
- 3 cas de perte de parachute de freinage
- 1 cas de manipulation de la commande manuelle de la trappe pendant que le réacteur tournait au ralenti
- 1 cas d'aspiration de la broche de sécurité dans le moteur
- 1 cas d'aspiration de la pinne de crosse par le moteur

(2) Erreurs de Pilotage : 38
- (a) Phase d'atterrissage : 22
  - mauvaise technique d'atterrissage : 16
  - cabrage excessif de l'avion à l'atterrissage : 3
  - collision avec les lampes d'approche : 1
  - oubli de descendre la crosse d'arrêt : 1
  - erreur de technique de freinage : 1
- (b) Phase de décollage : 5
  - mauvaise technique de décollage : 5

(c) Phase de Taxi : 5
- collision contre une barrière le long du Taxi-Track : 1
- collision avec un bâtiment : 1
- collision avec un extincteur : 2
- collision avec une porte d'abri d'avion 1.

(d) Phase de vol : 4
- collision entre avions : 2
- larguage de verrière : 2

(e) Phase de combat : 2
- mauvaise manipulation du sélecteur armement-larguage d'une bombe : 1
- tir d'une roquette par inadvertance en dehors du champ de tir : 1

II. Deuxième Partie : Aspect Analytique.

PRELIMINAIRES.

Dans cette seconde partie nous n'envisagerons que les accidents d'avions "MIRAGE" investigués par le Service d'Enquête d'Accidents Aériens (SEAA) à savoir 26 dossiers (mettant en cause 28 pilotes) et parmi lesquels nous avons relevé l'intervention du Facteur Humain dans 18 cas (concernant 19 pilotes). Il nous a paru intéressant d'étudier certains paramètres éventuellement susceptibles d'intervenir dans l'interprétation de la notion du "Facteur Humain", entre autres : l'âge du pilote, son expérience de vol, les circonstances de l'accident dans le cadre de la mission effectuée, les antécédents médicaux (physiques et psychiques) du pilote, l'intervention du leadership ainsi que les facteurs interférentiels survenant dans le triangle formé par l'HOMME - MEDIUM - MACHINE.
Il nous a,également, semblé utile de signaler, et ceci pour l'ensemble des dossiers d'accidents traités par le SEAA, les conséquences physiques de l'accident pour le pilote (en distinguant les accidents se déroulant avec ou sans éjection) et son devenir en tant que membre du personnel naviguant après l'accident (mortalité, délais d'inaptitude ou limitations dans l'aptitude au vol ainsi que l'aptitude finale).

1. Paramètres éventuellement susceptibles d'intervenir dans la notion du Facteur Humain.

a. Age du pilote au moment de l'accident.

- Dans les 18 cas d'accidents aériens (19 pilotes) faisant intervenir le Facteur Humain la majorité des cas (15 pilotes) ont un âge situé entre 21 et 29 ans.
- Dans les 9 cas ou n'intervient pas le Facteur Humain l'âge des pilotes se situe entre 23 et 35 ans.

b. L'expérience de vol du pilote.

(1) Expérience générale de vol (tous types d'avions).
- Pilotes ayant moins de 500 hrs de vol (période d'écolage et débuts en escadrille) : 5
- Pilotes ayant de 500 à 1000 hrs de vol (période de perfectionnement et d'acquisition de l'expérience en escadrille) : 8
- Pilotes ayant plus de 1000 hrs de vol (pilotes expérimentés) : 6

(2) Expérience de vol sur "MIRAGE".
- Pilotes ayant moins de 100 Hrs (écolage) : 2
- Pilotes ayant de 100 à 300 Hrs (période d'expérience limitée) : 9
- Pilotes ayant plus de 300 Hrs (pilotes expérimentés):8

c. Les circonstances de l'accident dans le cadre de la mission.

Dans les 18 cas (19 pilotes) ou intervient le Facteur Humain les circonstances de l'accident peuvent être décrites comme suit (type de mission ou moment de la mission).
(1) Atterrissage (accrochage d'obstacle) : 3 cas.
(2) En vol : 16 cas.
(a) - dans le cadre d'une compétition (TAC EVAL - Royal Flush) : 2 cas
(b) - survol d'un relief montagneux : 2 cas
(c) - collision aérienne : 2 cas
(d) - phase de combat : 4 cas
- attaque simulée d'objectifs au sol : 2
- simulacre de combat aérien : 2
(e) - vol en formation : 2 cas
(f) - accrobatie à basse altitude : 1 cas
(g) - navigation : 3 cas

d. Antécédents du Pilote.

(1) Médicaux (physiques et psychiques).
- Physiques :

- dans un accident (MIRAGE Biplace) les 2 pilotes présentaient des antécédents physiques pathologiques sans qu'il n'ait pu être démontré que ceux-ci soient déterminants dans l'origine de l'accident
- Le 1er pilote souffrait d'hypertension artérielle de longue date sans étiologie organique décelée malgré de nombreuses observations cliniques et biologiques très complètes.
- Le 2e pilote avait un nystagmogramme légèrement perturbé conséquence d'un accident de voiture antérieur.

- Psychiques :
  - 1 pilote était considéré comme un sujet très impulsif et très nerveux
  - 1 pilote avait révélé, lors des tests psychologiques, une tendance de blocage au stress
  - 1 pilote avait une nette tendance à l'excès de confiance en soi

  Dans ces 3 cas le Facteur Humain psychique signalé a partiellement influencé le déroulement de l'accident.

Dans les antécédents médicaux des 19 pilotes incrimmés dans des accidents où intervient le Facteur Humain, nous notons donc que 5 pilotes avaient des antécédents pathologiques susceptibles d'intervenir dans le déroulement de l'accident.
Par ailleurs dans la série des 9 pilotes dans l'accident desquels n'intervient pas le Facteur Humain on ne relève pas d'antécédents médicaux particuliers ni physiques ni psychiques.

(2) Appréciation émise par les chefs hiérarchiques sur ces pilotes (CNA).

- Dans la série des 18 accidents (19 pilotes) investigués par le SEAA, et pour lesquels le Facteur Humain est intervenu, les appréciations émises par les chefs hiérarchiques dans le CNA (carnet de notes de l'Aviateur) peuvent s'exprimer comme suit :

- SATISFAISANT mais inférieur à la moyenne : 2 - MOYEN : 5	7
- BON et supérieur à la moyenne : 6 - TRES BON et TRES EXPERIMENTE : 6	12

- Dans la série des 9 accidents où n'intervient pas le Facteur Humain les avis exprimés sont les suivants :

- SATISFAISANT mais inférieur à la moyenne : 1 - MOYEN : 1	2
- BON et supérieur à la moyenne : 2 - TRES BON et TRES EXPERIMENTE : 3	5

e. Influence du leadership.

(1) Le leadership (leader de paire - leader de formation - officier responsable des vols - commandement) a eu une influence relative dans le déroulement de l'accident dans 13 cas sur 18 accidents dans lesquels le Facteur Humain est intervenu.
Cette influence du leadership peut se subdiviser comme suit :

(a) Dans le chef du leader (paire d'avion ou formation de plusieurs avions) : 10 cas.
- Passivité (manque de réaction dans des situations imprévues) : 4 cas
- Insuffisance de préparation de la mission : 3 cas
- Tolérance de conditions de vol inadmissibles : 3 cas

(b) Commandement (échelons responsables, autres que le leader) : 3 cas.
- absence au briefing du Flight Co qui ignore ainsi que la mission est insuffisamment préparée
- absence de directives
- absence d'information au pilote par l'officier responsable des vols.

f. Influence relative des facteurs interférentiels dans le triangle formé par HOMME - MEDIUM - MACHINE.

Il nous a paru intéressant de vérifier l'importance relative prépondérante de ces 3 facteurs dans l'origine et le déroulement de l'accident. Cet examen nous a livré les renseignements suivants dans la série des 18 accidents dans lesquels le Facteur Humain est intervenu :

(1) Dans 13 cas sur 18, il y a lieu de considérer que c'est en premier lieu l'HOMME qui est facteur causal, qu'il subit en second lieu des influences extérieures aggravantes (MEDIUM et que la somme de ces deux facteurs retentit sur la MACHINE.

(2) Dans 3 cas sur 18 c'est en premier lieu un problème technique (MACHINE) qui est en cause avec retentissement sur l'HOMME qui cependant, par certaines de ses réactions, aggrave la situation pour l'amener à l'accident.

(3) Dans 2 cas sur 18 l'on peut admettre que ce sont des facteurs étrangers (MEDIUM) qui sont en cause première de l'accident avec cependant intervention certaine du Facteur Humain dans le déroulement de l'accident.

2. Les conséquences de l'accident pour le pilote.

a. Les lésions du pilote conséquences de l'accident.

Si l'on examine les lésions occasionnées ches les 28 pilotes dont le dossier d'accident fut traité par le SEAA compte tenu du fait qu'il y eut ou non éjection nous sommes amenés à faire les constatations suivantes :

(1) accident avec éjection : 14 cas (soit 50 %).
- 6 cas de fracture vertébrale dont 5 cas sont dus à l'éjection et 1 cas dû à l'atterrissage
- 3 cas de fracture (bassin - Tibia - peroné) dues à l'atterrissage
- 3 cas de blessures superficielles (dues au masque à oxygène ou causées par les suspentes du parachute)
- 2 cas indemnes totalement

(2) accident sans éjection : 14 cas (soit 50 %)
- 7 cas de décès du pilote
- 1 cas de fracture vertébrale causée par l'atterrissage de l'avion
- 6 cas indemnes totalement

Si l'on tient compte de l'intervention ou non du Facteur Humain comme agent causal ou d'influence dans la genèse de l'accident, il y a lieu de ventiler la série globale de ces 28 pilotes comme suit :

(1) Série dans laquelle le Facteur Humain intervient (19 pilotes).
(a) Avec éjection : 7 cas.
- 3 fractures de colonne vertébrale (D12 - L1 / D8 - D-9 / D11)
- 3 cas de blessure superficielles (face et cou + contusions dorsolombaires)
- 1 pilote indemne

(b) Sans éjection : 12 cas
- 7 cas de décès du pilote
- 1 cas de fracture vertébrale (D12 - L1), lésion causée par l'atterrissage de l'avion
- 4 pilotes indemnes

(2) Série dans laquelle le Facteur Humain n'intervient pas (9 pilotes).
(a) Avec éjection : 7 cas
- 3 fractures de colonne vertébrale (D11 - D12 / D7 - D8 - D11 / D12 - L1)
- 1 fracture Ischio et iléopubienne + fracture du coccyx
- 1 fracture Tibia et péroné
- 1 fracture péroné
- 1 pilote indemne

(b) Sans éjection : 2 cas
- 2 pilotes indemnes

La comparaison de ces 2 séries est reproduite dans le tableau ci-dessous

	Avec Facteur Humain	Sans Facteur Humain	Total
Décès	7	0	7
Blessés graves	4	6	10
Blessés légers + Indemnes	8	3	11
Total	19	9	28

Il ressort de ce tableau que sur 28 cas de pilotes accidentés il y eut 1/4 de décès (7) et que tous ces cas appartiennent à la série dans laquelle le facteur humain est intervenu.

b. Le devenir du pilote après l'accident.

Dans la série des accidents investigués par le SEAA (28 pilotes en cause) les constatations suivantes ont été faites quant au devenir du pilote après l'accident :
- 7 pilotes décédés
- 8 pilotes indemnes : aptitude pilote totale immédiatement après l'accident
- 3 pilotes blessés légèrement : ces blessures n'ayant entraîné aucune inaptitude
- 10 pilotes blessés grièvement : ces blessures ayant entraîné les inaptitudes pilotes suivantes

	CAS	INAPTITUDE TOTALE	APTITUDE LIMITEE	APTITUDE FINALE
Intervention du FACTEUR HUMAIN	N° 1	4 mois	-	APTE TOT.
	N° 2	5 mois	-	APTE TOT.
	N° 3	5 mois	-	APTE TOT.
	N° 4	4 1/2 mois	Avions SANS SIEGE EJECTABLE	APTE LIMITE
PAS d'intervention du FACTEUR HUMAIN	N° 1	5 mois	-	APTE TOT.
	N° 2	7 mois	-	APTE TOT.
	N° 3	-	TEMPORAIRE 3 mois	APTE TOT.
	N° 4	4 mois	-	APTE TOT.
	N° 5	11 mois	12 mois	APTE TOT.
	N° 6	6 mois	8 mois	APTE TOT.

Il ressort de ce qui précède que tous les pilotes survivant à l'accident (21 sur 28) ont été, finalement, déclarés APTE au vol à l'exception d'un seul pilote déclaré APTE mais avec une limitation aux avions sans siège éjectable.

3. Discussion de la partie Analytique.

Les constatations suivantes peuvent découler de ce qui précède.

a. Age du pilote : les accidents investigués montrent qu'il s'agit dans la plupart des cas de jeunes pilotes.

b. Expérience de vol : Dans 13 cas sur 19 les pilotes accidentés n'avaient pas encore acquis l'expérience générale de vol *suffisante (moins de 1000 heures). En outre dans 11 cas sur 19 ils avaient* une expérience limitée sur "MIRAGE" (moins de 300 heures).

c. Circonstances de l'accident :

Il s'agit essentiellement d'accidents survenant durant la phase de vol et principalement durant certaines phases difficiles du vol.

d. Antécédents du pilote : Dans 5 cas sur 19 le pilote présentait certains antécédents ayant pu influencer le déroulement de l'accident. Les avis émis par les chefs hiérarchiques étaient très favorables dans 12 cas sur 19.

e. Influence du leadership : une influence quelconque du leadership s'est manifestée dans 13 cas sur 18 cas d'accidents (19 pilotes en cause).

f. Relation interférentielles HOMME - MEDIUM - MACHINE.

La prépondérance du facteur HOMME sur les autres facteurs est établie dans 13 cas d'accident sur 18.

g. Les lésions du pilote.

Dans la série d'accidents pour lesquels le Facteur Humain intervient on note tous les cas de décès (7 pilotes sur 28).

h. L'aptitude pilote finale.

Dans tous les cas des pilotes survivant à l'accident, qu'il y ait ou non intervention du Facteur Humain, le pilote a été déclaré finalement apte au vol à l'exception d'un seul pilote limité aux avions sans siège éjectable.

CONCLUSION.

L'objectif considéré dans cette étude n'a pas eu pour but de prétendre déterminer qu'il y a, dans l'utilisation de l'avion "MIRAGE", une relation plus particulière entre l'influence du facteur humain et l'origine de l'accident. Notre intention a plutôt été d'apprécier dans une série d'accidents survenus à la Force Aérienne Belge le rôle considérable que ne cesse de jouer la "personnalité" de l'homme dans un système hautement sophistiqué et constamment influencé par de nombreuses variables. Toutefois, et ceci pourrait peut-être se vérifier dans n'importe quelle série "HOMME - MACHINE", il ressort de cette analyse que les jeunes pilotes limités au point de vue expérience de vol en général et plus particulièrement sur un type d'avion déterminé doivent, dans des circonstances de vol plus difficiles bénéficier à tout prix, d'un leadership adéquat.
En outre, il s'avère que la sélection des candidats pilotes devra, de plus en plus, viser à détecter au mieux de probabilités de déficience non seulement physique mais également psychique du postulant en tenant compte du fait qu'il devra, dans le futur, et vu l'évolution prévisible de l'aviation militaire faire preuve, ultérieurement, de qualités supérieures à celles exigées lors de son recrutement.
Enfin, il faudra également tenir compte du rôle important que devra jouer le personnel d'appui au vol tel que les météorologistes, les mécaniciens et les contrôleurs de trafic aérien face à des systèmes "HOMME - MACHINE" de plus en plus perfectionnés mais dans lesquels l'HOMME gardera, malgré tout, la part prépondérante.

THE PSYCHOLOGIST IN AIRCRAFT ACCIDENT INVESTIGATION

by

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SUMMARY

It is well established that in both military and civil flying operations, a large proportion of all accidents occur in serviceable aircraft where the only failure in the system was in the human element. There is therefore an obvious case for the psychologist to attempt to understand the nature of the errors which are made in the hope that such an understanding may lead to the avoidance of such errors. In this paper, the way in which RAF psychologists are involved in the accident investigation process is described. The way in which this work has enabled accidents to be categorised is also speculatively discussed and compared with the findings of more academic work.

INTRODUCTION

Seven years ago, the Royal Air Force set up an experiment which required a psychologist from the RAF Institute of Aviation Medicine to assist, "on the spot", in the investigation of flying accidents. Obviously, the motivation for such an experiment was the consistent and large fraction of flying accidents that are attributed to the causal category of human error. It was reasoned that the reduction of such accidents would depend on the understanding of human error; hence the close participation of the psychologist in the accident investigation.

More specifically, the objects of the work are two-fold. The first is to provide assistance to the Board of Inquiry on those matters where the psychologist possesses specialist knowledge (eg on matters such as human performance under stress, sensory and perceptual problems, and human engineering or ergonomics). In this way it is hoped that the quality of the Board of Inquiry's investigation will be improved, and human factors problems identified at the earliest possible stage.

The second object is to gain a more fundamental understanding of the nature of human error. It is hoped that by building up records of accidents which have been interpreted by a psychologist, different categories of human error accident will emerge, and that these categories will be meaningful in both theoretical and applied terms.

Although this experiment has been proceeding for some years now, accidents are relatively rare events and data is not therefore prolific. However, the rest of this paper discusses some of the obvious categories into which human error may be sub-divided in an attempt to illustrate this form of approach and demonstrate that an understanding of the cause of an accident is a necessary prerequisite of finding a technique to prevent the recurrence of that kind of accident.

A traditional concern of psychologists involved in accident research is whether an "accident prone" personality type exists, and the first category of accidents discussed below addresses this problem.

Personality

Cattell has defined personality as "that which tells what a man will do when placed in a given situation". If so, it is possible that individual differences in accident proneness may be identified by personality measurement. Unfortunately, the measurement of personality can be approached from a number of different viewpoints. What may be termed the empirical approach uses the results of factor analyses on the responses to questions asked of the individual to identify "traits" or personality factors, and one such widely used personality test is the Eysenck Personality Inventory. In this test, the factors which are used to describe different personality types have been reduced to just two - the introversion/extraversion factor or dimension and the neuroticism/stability dimension. Some studies of motor vehicle accidents, such as that of Shaw and Sichel (1), have shown that "accident prone" drivers score highly on both the neurotic and extravert scales, and that drivers with a safe accident record tend to be stable introverts.

At first sight, it would seem that this test could form the basis of a selection test, ie exclude all "neurotic extraverts" from flying training. However, there are problems with this approach in that replications of the study have not found such significant effects and, furthermore, we do not know whether the personality profile which may cause "accident proneness" in motor vehicle driving is the same as that which may case accident proneness in flying. Probably more important though, is the fact that aircrew represent a more homogenous population than bus drivers and one in which a certain informal personality selection has already taken place. All military flying organisations select their aircrew with certain attributes in mind and indeed, it is fair to suggest that a considerable amount of self-selection will already have taken place.

Nevertheless, more specific aspects of personality may well be amenable to analysis. For example, Levine et al (2) have shown that if aircrew are asked to assess how well they feel certain statements describe them (eg, The people I work with think I am even-tempered) and these results are factor analysed, then one factor which emerges contains the following statements:

I am an adventurous person.
I find it exciting to take chances.
If sky diving were available for recreation I would be very interested in it.
Driving motorcycles is more for fun than transportation.

Scores on this empirically derived factor, dubbed "Adventurousness" are correlated (according to Levine) at a highly significant level with accident proneness. The first case studies give examples of accidents where this factor is likely to have been important.

Case Study 1

The pilot of a two man fighter-bomber had a history of indiscipline. On returning to base from a foreign detachment he departed from his authorised flight plan to perform some illegal low flying, struck some power lines and was killed. His flying clothing was also found to be illegally modified.

Case Study 2

An experienced instructor on a training aircraft flew a solo continuation training sortie. He was authorised to fly at low level, but not below 250 ft. He was then seen to fly at a height of less than 10 ft over a lake when he attempted to turn, struck the water and was killed. It subsequently transpired that he had flown other pilots at illegally low levels on a number of occasions before his accident.

It is not being stated here that the factor identified by Levine was the sole or even the main cause of the above accidents. However, when Levine conducted his survey he correlated his "adventurousness" scores with accidents of all types and found a highly significant correlation, but only a low level of correlation ($r = 0.25$, $p < 0.01$). It is suggested here that further study might well reveal a much higher level of correlation between possession of this attribute of personality and the occurrence of the type of accident described. If this proved to be so, then Levine's questionnaire would be valuable in identifying at an early stage those pilots most susceptible to this special form of risk, so that extra care could be exercised in their selection and management.

There are other aspects to the analysis of personality however, and an alternative approach to the problem is that based on more projective and interpretive techniques. These forms of test tend to rely more on a psycho-analytic than an empirical base and, consequently, tend to find less favour among the sort of experimental psychologists who are interested in accident work. However, Neuman (3) of the Royal Swedish Air Force claims to have identified a form of projective test which is able to identify closely accident-prone individuals. The idea of perceptual defence is a long-established one in psychology, and Neuman claims to have identified certain specific aspects of the way in which people respond to a form of perceptual defence test in which potentially threatening pictures are briefly presented. The analysis of an individual's responses is based on Freudian principles and Neuman claims that individuals who have scored in a certain band on the "reaction formation" dimension have subsequently been involved in far more accidents than chance should permit.

Perhaps the divide between this approach and the factor analytic approach described earlier is not as great as at first appears. Cattell (4), who is the traditional proponent of the factor analytic standpoint suggests that one of his traits - autia - is useful in predicting accident proneness. This trait is described by him as a tendency to see and believe things, possibly falsely, in accord with one's wishes. It is tempting to draw a parallel between this empirically derived trait and the psycho-analytic concept of reaction formation in that both involve the individual in generating a model or percept of the world which is at variance with the real world. Such misperceptions or "false hypotheses" are not infrequently identified by the psychologist in the field.

Case Study 3

A solo fighter pilot over the sea believed his position to be roughly south of base when he was actually west of base. On calling base for a steer home he was given a heading of 100^{o}. Although he read back the heading correctly he perceived a heading of 010^{o} - more aligned with his own preconceived notion of his position. He then saw a headland through mist and assumed this to be familiar territory and therefore headed towards it. In fact, the headland was completely the wrong country, yet the pilot flew over it, infringing that country's airspace, before he realised (or was forced to realise) that he had made several errors.

Case Study 4

A large civil airliner approaching Nairobi was given an air traffic control clearance down to 7500 ft. None of the crew heard the "seven", but only the "five" followed by two "zeros", which they all perceived as "five" followed by three zeros (ie 5000 ft). The aircraft then started to fly down to this altitude and none of the crew realised that the runway elevation at Nairobi is in excess of 5000 ft. When the ILS deviation warning light illuminated, the commander interpreted it as a false warning and when the engineer referred to the glide slope bars being out of view in the up position by saying "We have no glide slope" the captain replied "we have" - meaning that the glide slope failure flag was not showing.

Both of these accidents involved the pilot in generating a model of the world (which might be termed his "percept" of the world) which was different from the way in which the world existed, and heavily influenced by the way in which the pilot expected the world to exist. While it may be that it is possible for any individual to make such an error, Neuman and Cattell are perhaps suggesting that individual differences play an important part here and that some people may be more at risk with respect to this special sort of error. Again, if further research proved this to be so, such tests of personality would have importance in identifying such individuals.

Programming Errors

A further category of human error accident involves what might be termed "programming errors". When motor skills are acquired there are identifiable different stages in the acquisition (see Fitts and Posner (5)). Initially, a great deal of conscious effort goes into the execution and self-monitoring of skills,

but as "motor programs" are laid down the execution of the skill becomes more and more automatic. Furthermore, it appears that once the "automatic" stage has been reached, it is possible for the individual to make the correct high level decision but, for some reason, to go on and execute the incorrect program. It is ironic that, almost by definition, such errors will be made most frequently by highly experienced pilots.

Case Study 5

A solo pilot landed his aircraft after a hard flight on a hot day. On turning off the runway onto the taxiway the pilot decided to cool off by raising the canopy, but raised the undercarriage instead.

Case Study 6

A solo pilot performed an overshoot and intended to raise the flaps but leave the undercarriage down. Instead, he unwittingly raised the undercarriage instead of the flaps, flew a visual circuit and landed with the undercarriage up.

At present there is no theoretical structure which allows real understanding of errors such as these but by collecting records of errors such as these, certain conclusions may be arrived at. The errors need not, of course, be committed in aircraft and Reason (6) has collected many examples of such programming errors committed in everyday life (eg a man reported picking up his telephone and shouting "Come in"). Such evidence suggests that if an error in executing a "motor program" is to be made then, the response which is inserted instead of the appropriate response is likely to be in some respect similar to the appropriate response, it is likely to be a more frequently used response than the appropriate response, and so on.

Such knowledge has sometimes proved useful in arriving at the likely explanation of accidents in which the pilot has been killed.

Case Study 7

The wreckage of an aircraft was found with the slats retracted but with the airbrake extended. The official Board of Inquiry found it hard to believe that the pilot could have inadvertently operated the control for one function when he intended to operate the other.

Such behaviour becomes much more credible and understandable when set against a background of mistakes of this type which are made in everyday life.

This area, then, is one where the cataloguing of the observed occurrences of a certain class of event (ie programming errors), is enabling some general statements about how and when such events are most likely to occur. Inevitably this work will give rise to laboratory research aimed at more closely identifying the conditions under which such events occur, and possibly again, at attempting to discover whether certain types of individual are unduly disposed towards making such errors.

Perceptual Problems

The reliance which pilots are forced to place on visual information is obvious, yet accidents continue to occur because pilots have been misled by an illusory visual scene. Nowhere is this more apparent than on the approach to land, and some accidents involving misleading visual information on the approach are now described.

Case Study 8

A young pilot approached the airfield where he was on detachment. The ground was snow-covered but the runway was clear. For no obvious reason the pilot landed in the undershoot of the runway, much to his own surprise.

Case Study 9

A bomber aircraft landed at a strange airfield which had a narrower runway than the pilot's home airfield, and where the terrain sloped downwards away from the threshold of the runway. Again the aircraft landed in the undershoot.

Case Study 10

A solo pilot in a two engine aircraft approached the airfield where he was on detachment with one engine shut down which required that he make, if anything, a steeper than normal approach. However, he made a shallower than normal approach which resulted in the loss of the aircraft. The runway on which he was landing was nearly 50% longer than the runway at his home airfield.

The above accidents are of special interest to the psychologist as it becomes clear from conversation with the pilots involved, their colleagues, and the Boards of Inquiry into this form of accident that although pilots are clearly capable of executing a satisfactory visual approach on most occasions, they are almost entirely ignorant of the visual cues that they are using.

However, knowledge gained from the experimental literature combined with the experience gained from the first hand investigation of these accidents and evidence from new experimental work has enabled a greater understanding of the techniques and cues used by pilots on the approach to be attained. In turn this has enabled likely explanations of the accidents of this type to be offered.

Unlike some of the previous categories discussed, this area is not likely to be one where inherent characteristics of the individual constitute the bulk of the problem. It is suggested that most perceptual errors on the approach occur not just because individual pilots are unaware of the visual cues which they are using, but that this situation exists because their instructors are unaware of the most reliable set of visual cues to point out to the student pilot. Thus each pilot develops his own idiosyncratic set of visual cues which serve him well on the majority of occasions - until, that is, he is presented with an unusual situation in which his personal cues become unreliable. It is therefore suggested that the solution to this problem lies in a re-appraisal of training methods based on research into what represents the most reliable set of cues to use on the approach.

CONCLUSION

It is not suggested that all human error accidents can be subsumed into the categories described above. There are a number of other obvious pertinent areas that have not been considered such as the effect of domestic factors on flying performance (7). The statistical approach to accident proneness has also not been discussed (8), though work of this sort has an undoubted contribution to make to the understanding of accidents.

However, the thesis being made here is that accidents happen for reasons, but that there are not as many reasons as there are accidents. It is contended that the policy of the RAF which requires a psychologist to attend Boards of Inquiry is resulting in a clearer understanding of the nature of error in flying behaviour and is enabling the causal category "human error" to be sub-divided into more meaningful categories of error. Clearly, the aspiration must be that such an improvement in the understanding of the aetiology of accidents will enable preventive measures to be made more appropriate and effective, and there is now good reason to believe that this aspiration will be achieved.

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DISCUSSION

MONEY: (Canada)
You left that 747 fast approaching the ground. I wonder if you would tell us what happened to it?

GREEN: (United Kingdom)
It approached the ground and, in fact, there was cloud cover at about 200 feet. When it broke out, the captain and the crew saw the ground and realized they weren't supposed to be seeing the ground, since they were ten miles short of the runway. But the captain said afterwards that at first he didn't think there was anything wrong, and although the ground looked very close, he thought it must be a vision illusion. In fact, he got down to about 70 feet of the ground before recovering and overshooting the runway. It was only during the overshoot that the crew realized what had gone wrong. Mentally replaying the events at that stage, they were all convinced that the air traffic controller had told them to come down to the wrong flight level. So they got away with it, fortunately.

TEPPER: (Canada)
You talk about various personalities. From a preventive point of view, what would you suggest, and if your suggestion is to screen out the aggressive pilots, does the RAF buy that?

GREEN: (United Kingdom)
That is a question I was anticipating, of course. This is a broader debate than I am capable of conducting, frankly, because it really reflects on the war-time versus peace-time role of an air force. Of course, in peace time, the role of an air force is to prepare for "war," as long as you "don't bend the air planes, please." But, in peace time, flight safety does become a paramount consideration and I regard my role as simply an investigative one. My role is to say, "Look, if you are really serious about wanting to stop this sort of accident happening, then you could stop some of them perhaps by applying this sort of technology." But, I'm not saying that weeding out aggressive pilots should occur. The decision as to whether you should weed out adventurous, aggressive pilots isn't a decision, fortunately, that I have to make. I feel that you are probably right, these may be just the chaps that we need when we go to war. But, if you do need them when you go to war, then I would suggest that it is almost an inevitable concomitant of that decision, that they are going to have accidents in peace.

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THE INFORMATION IN AIRCRAFT ACCIDENTS INVESTIGATION

by

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SUMMARY

The information is part of every investigation, so in aircraft accidents, where it contributes to clarify causes and mechanisms of mishaps.

Into the Board of Inquiry, Medical Investigator has to get in touch with documents, papers and persons linked to the "fact".

In this field, the survey regards the EVENT and the three "M"s - "MAN", "MACHINE", "MEDIUM" -, before, during and after the event.

Particular attention has to be paid to the witnesses, not only for their declaration, but even and mostly, for their trustworthiness evaluation.

In the paper are outlined ways and techniques for collecting information in this type of investigation.

FOREWORD

"Information" can be defined as getting news about events or people through the technique of the interview, or by the examination of papers or documents; in aircraft accidents, the data achieved by the survey on the spot are completed by information, contributing to reach in such a way the cause of the accident.

The fields to investigate are the "EVENT" and the three "M"s -"MAN", "MACHINE", "MEDIUM".

Analysing the "MAN", the investigator must take into consideration the "MACHINE" utilized by that "MAN" for flying, and the "MEDIUM" where that "MAN", with that "MACHINE", was flying.

INFORMATION ABOUT THE "EVENT"

Information about the "EVENT" can be collected only by inquiring eye-witnesses; eye-witnesses can be divided in two categories:

- those ones involved in the accident;
- those ones not involved, but bystanders to it.

Witness

A witness can be spontaneous or stirred up; in both cases it can be utilized when it results:

- objective;
- impartial;
- free;
- trustworthy.

A witness is "objective" when is free from any personal interpretation, "impartial" when there is no interest in the fact, "free" when there are no enticements, pressures, threats or suggestions, "trustworthy" when it is given by a reliable and skillful person.

Witness' assessment

Before accepting a witness, the following factors must be taken into consideration:

- the environment conditions, related to the time when the fact happened;
- the witness' capabilities: to perceive, to remind, to report;
- the witness' will to report;
- the witness' personality.

As regards environment conditions, it is important to know which was visibility level on the spot of disaster at the moment when it happened; furthermore one must know the distance and the space relation between the observer and the accident scene.

Before asking questions to a witness, this one must be analysed in order to establish whether he was able to perceive and if he can remind and report. As it is known, "perception" is aptitude to intecerpt a stimulus, depending on extrinsic and intrinsic factors; the former relied to the nature and intensity of the stimulus, the latter to perceptive man's ability. A perception results clear when the following conditions take place:

- the stimulus, in relation to its nature and intensity, is perceivable;
- the receptor has his own perceiving organs in order, and his mind in alertness state with his attention addressed toward such a stimulus.

Needless to say that an aircraft accident is certainly a very suitable stimulus, both for nature and intensity, but its picking up changes in relation to:

- individual perceiving capabilities, as it regards the observer;
- environment perceiving possibilities, related to the visibility conditions and to the observer's position;
- time disposable for perceiving, as the longer the time the better the perception.

After settled that a witness was able to well perceive, the following step is to establish whether he is able to well remind. It is useful to point out that a mnemonic process is made up of the following parts:

- fixation;
- localization in space and time;
- recognition;
- remembrance.

The property to remind varies from one man to another, and in the same man, on his psychic engagement related to the moment of the perception; time running the memory lowers, and consequently witnesses must be questioned as soon as possible. When are inquiring people involved in the accident, it must be ascertained they did not suffer panic or cranial trauma, as in these cases mnemonic gaps arise.

It must be established whether the witness can report, keeping in mind that reporting capability depends on the following factors:

- mental level;
- consciousness conditions at the moment of the event;
- alerted attention;
- efficient memory;
- speech capability;
- language mastery.

The eye-witness not always wants to report what he saw; while there can be some exhibitionist who comes to refer useless data.

The last witness' test regards his personality, necessary to know for evaluating the worth of the declaration; for this aim, the following factors must be taken into consideration:

- age and nationality;
- place of residence;
- education level;
- professional activity;
- life habits;
- relations with the casualties;
- interests on the fact;
- mental qualities (attention, memory, suggestibility, emotionability);
- present behavior (reticent, exuberant, awkward, sorrowful);
- visual efficiency;
- hearing capability.

Technique of interview

The interviewer has to introduce the questions in clear and comprehensible way, trying not to influence the answers by suggestion or threat. After put a question he must be sure of its understanding from the inquired man.

The investigator has to gain trust and confidence from witness; he will try to pick up from him the news he needs, without hurting his feeling; during the interview, the witness, in the first time, will be let to refer spontaneously, but in the second time, will be specifically asked on those details linked to the fact.

When there is a lot of witnesses, they must be avoided to see each other before the interview, otherwise, knowing in advance the questions, it is possible they can modifiy their answers.

It is useful to put everyone the same questions: the agreement in answers, especially if they are given by impartial and trustworthy persons, can be conside

red reason of trustworthiness. One must put indirect questions when it is possible that the inquired, voluntarily or unvoluntarily, can go into inhibition.
Every declaration must be written and subscribed by the person who made it;
a witness declaration is made up of the following parts:

- general data regarding the event; more specifically the three "W"s (When, Where, What);
- in relation to the moment of the accident, indicate the place of the witness on the spot and the visibility conditions;
- WITNESS' REPORT, and his answers to specific questions;
- date and signature;
- opinion of trustworthiness on witness and his report.

INFORMATION ABOUT THE "MAN"

Information about the "MAN" regards the pilot and every else person who, directly or indirecly, could play a rôle in the accident.
The "MAN" has to be examined "before", "during" and "after" the event; the following aspects of his life, expecially related to the last time, must to be taken into consideration:

- usual behavior and habits; activities of last two days;
- worries; loss of sleep; insufficient rest periods; fatigue;
- alcohol; tobacco; therapeutic drugs; last meal and composition of it;
- flight experience ;
- flying activity during last time (24 hrs, week, month);
- flying incapacitations; toxic hazards during flying;
- previous deseases ; important illnesses in the family;
- previous accidents and causes;
- pilot skilfulness of that "man", related to that "machine" in flight "medium" of the accident;
- extra duty behavior of that pilot in the last time (important the changes).

Most of above information can be collected from the family, collegues, friends or other persons linked to "our man". From that people it is possible to achieve news about abnormalities arisen in the "man" both in psychical and physical fields, before or during the "flight accident".
In addition, the following documents should be examined:

- Flight restrictions periods (duration and causes);
- every medical form;
- post-mortem reports;
- every else paper regarding the "man", useful to know.

INFORMATION ABOUT THE "MACHINE"

If the "MAN" is the main field of investigation for the Medical Investigator, this one, in aircraft accidents,needs even information on the "MACHINE" on

point of view of medical aspect, that is the relation between "that man" and "that aircraft"; in other words it must be established whether "that man" were suitable for "that machine" in such flying conditions.

Medical Investigator has to collect news regarding the technical characteristics of the aircraft, especially as it regards oxygen equipment, pressurization, aids to navigation, board instruments, etc.

INFORMATION ABOUT THE "MEDIUM"

Information about the "MEDIUM" regards relations linking that "man" with that "machine" acting in certain flight conditions.

This category of information regards:

- flying altitude at which the accident started;
- flight history from its beginning;
- duration of the flight;
- flying mission;
- meteorological conditions;
- communications;
- flight procedures and maneuvres.

In addition it is useful to pick up information on the extra duty medium of the pilot.

FINAL RECOMMENDATIONS

According to a specific aim, a logical procedure must be followed on collecting information.

One must bear in mind that not always persons who can offer information are disposed to; consequently, after a first contact , other ones must be taken with them in a second time.

The investigator has to remember that the casualties must be always honoured, but, if some aspects of their private life can be useful to know for the investigation, the collecting news has to be done very respectfully, in order to avoid inhibitions from relatives,when inquired .

On deepening a delicate matter,questions can be concealed or put indirectly.

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The Limited Range of the Human Eye for Optical Aircraft Acquisition

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Summary

A pilot flying according to visual flight rules receives the first information from an approaching aircraft when he can just see this aircraft. The distance in which the approaching aircraft can just be seen i.e. detected, is among other things dependent on the contrast threshold of the human eye. The contrast threshold value indicates what extent must have the difference of luminance between object and its background so that this luminance difference can just be perceived. The DFVLR has made experiments determining the influence of different contrast threshold values on the maximum detection range - that range in which an approaching aircraft just can be seen. The results of these experiments were also influenced by environmental parameters (e.g. degree of atmospheric turbidity, background, adaptation luminance) and by characteristics of the approaching aircraft (e.g. inherent contrast, size).

The conduct of the experiments is described. In diagrams is shown how the maximum detection range depends on the standard visibility (the standard visibility is a measure for the degree of the turbidity in the atmosphere), on the adaptation luminance and on the type of the approaching aircraft and its background.

Mainly Blackwell has investigated the contrast threshold values in extensive laboratory tests. He and other authors show what influence have the following parameters on the contrast threshold: Size and shape of an object, adaptation brightness, exposure time, image location on the retina. Some diagrams are shown.

It has been derived from results of DFVLR experiments how the values for the contrast threshold determined in laboratory tests correspond with those received in field tests.

1. Introduction

When flying according to visual flight rules a pilot gets information from an approaching aircraft by seeing it. That means he must acquire it optically. We can consider four degrees of optical acquisition:

Detection
Recognition
Identification
Classification

An aircraft is detected optically when the mean luminance of the aircraft differs from the luminance of its background so that the threshold of the human eye for perceiving the contrast is just reached. This contrast C is defined by

$$C = \frac{L_O - L_B}{L_B} \qquad (1)$$

where L_O is the luminance of the object and L_B is the luminance of the background.

The range associated with the contrast threshold i.e. the distance at which an aircraft just can be seen is called maximum detection range.

In the Institute for Atmospheric Physics, in the German Aerospace Research Establishment (DFVLR), field experiments are carried out using optical sensors to determine ranges for detecting, recognizing, and identifying objects. In some of the research for the naked eye alone the work has conducted with the DFVLR Institute for Flight Mechanics. In this Institute statistical and flight dynamic studies on conflict detection and resolution in civil aviation are made [1, 2].

All the values for maximum detection range in the figures of this paper are obtained when observed with naked eye alone. When looking at these figures it must be kept in mind that the maximum detection range is not dependent only on the contrast threshold and the parameters influencing it directly: Size and shape of the object, time of observation, location of image on fovea centralis, adaptation luminance. The maximum detection range is depending also on the degree of the turbidity of the atmosphere. Also it must be pointed to that the circumstances for the observers when determining maximum detection range were ideal compared with the conditions in which pilots have to detect aircraft: The observers for whom the maximum detection range was determined had only to detect aircraft and had not to fly their own aircraft, they knew almost exactly the direction and the time of the approaching aircraft, they did not have to look through a windscreen and their eyes did not have to cover a wide range.

After description of the conduct of field experiments to obtain values for the maximum detection range in section 2, some of these values are shown in the figures of section 3. The curves of the figures of section 4 show values for the contrast threshold derived by Blackwell [3, 4] from laboratory experiments. Finally in the last section Blackwell's values are compared with those derived from values for the maximum detection range of DFVLR.

2. Conduct of Experiments for Determination of Maximum Detection Range

During the experiments for determination of maximum detection range the results of which are used in this paper the aircraft to be detected was approaching from distances in which the observers on the ground could not see it. The approaches were directed at the observers so that the effective area of the aircraft was changing very slightly for the observers. The observers had normal sight and were trained in detecting aircraft. The direction of approach was known: The azimuth- and elevationangle were within about three degrees of a given direction. Between starting to observe and detecting the aircraft there was a maximum time intervall of about 2 minutes.

The moments of detection of the different observers were registered by a tape recorder. By means of the distances between observers and approaching aircraft which were measured continuously by a radar device and also registered by a tape recorder the maximum detection range could be determined. The environmental parameters influencing the maximum detection range - the degree of turbidity of the atmosphere and adaptation luminance - were measured by a tele-photometer the spectral sensitivity of which was adapted to the light sensitivity curve of the human eye. As a measure of the degree of the turbidity of the atmosphere the horizontal standard visibility served which was measured by contrast measurements on natural targets [5, 6, 7]. This horizontal standard visibility is nearly equal to the meteorological range. Here it must be pointed out that the measured horizontal standard visibility was the degree of turbidity in an horizontal direction directly over the ground. In the slant direction in which the observers detected the aircraft flying in low altitude, the degree of turbidity could differ a little. More precise informations on the conduct of the field experiments and on the methods of evaluating the observed and measured values are contained in the reports [8, 9, 10].

3. Results of Experiments for Determining the Maximum Detection Range

The experiments for determining the maximum detection range took place in different years and during different seasons: spring, summer, and autumn, therefore also at different horizontal standard visibilities. The results determined when observing a dark green aircraft Do 27 is represented by the curve of figure 1. Around this curve which represents the mean values for different horizontal standard visibilities are lying the single values in the form of a "point-cloud" similar to that also shown in the later figure 6. The deviation of the single values from the curve are based on the individual and temporal non-constancy of contrast threshold, the search the observers had to do, and the uncertainty of the values of horizontal standard visibility. It must be pointed out that very different numbers of single values belong to the several ranges of the horizontal standard visibility of figure 1. That is caused by the fact that in Germany where the experiments took place the horizontal standard visibilities between 15 and 40 km are more numerous than the others. From figure it can be seen that the maximum detection range when observing an aircraft Do 27 is much smaller than the horizontal standard visibility. More over when the horizontal standard visibility is large variations in the degree of turbidity have less influence on the maximum detection range than when the horizontal standard visibility is smaller.

In the next figure 2 is shown how different coloring influences the maximum detection range. Contrary to the curve of figure 1 in which the results were reproduced by a logarithmic function, the results of observations in figure 2 were represented for only small horizontal standard visibilities by a regression line. The effective areas of both the aircraft - the Do 27 and the Piaggio - had only small differences. From figure 2 it is apparent that the dark green aircraft was detected between 2 and 3 km further away than the brightly painted ones. The following figure 3 shows mean values of results which were determined when observing air-liners. For comparison the maximum detection range when observing a dark green Do 27 is depicted also for that range of the horizontal standard visibility in which the observation of the air-liners took place. The effective areas of the air-liners were 6 to 7-fold larger and the wingspans 2 and 3-fold larger than those of the Do 27. In the range 14 to 16 km of the horizontal standard visibility the air-liners were detected about 2 km further than the Do 27.

All the results shown so far were determined when the approaching aircraft was observed with sky as background. Figure 4 shows the influence of the type of background on the maximum detection range. Here the regression line represents the maximum detection range when observing against sky as background and the point represents that value when observing against wooded mountain as background. During the experiments when the aircraft was observed in front of a wooded mountain the contrast between this background and the sky above it was very small: about 15 %. This was effected by the horizontal standard visibility of this test day and the distance between the observers and the wooded mountain. This little difference between sky background and wooded mountain background produced a difference of about 1 km for the maximum detection range.

Figure 5 displays the influence of decreasing brightness during the beginning of twilight on the maximum detection range. The values shown in figure 5 were observed at horizontal standard visibilities between 13 and 32 km. For adaptation luminance the brightness of the sky in direction of approach respectively direction of observation was taken. The dimension for the adaptation luminance of figure 5 asb = apostilb corresponds to about cd/m^2. From the plots it can be seen that, for example for horizontal standard visibility of 13 km, when the adaption luminance was 10^{-1} asb - that means in this case about 80 minutes after sunset - the maximum detection range was smaller than 1 km. For this horizontal standard visibility during daylight the maximum detection range had a value of about 3.5 km. The larger the horizontal standard visibility is the later after sunset is the moment of detecting an aircraft at a distance smaller than 1 km. In the last figure 6 of this section ranges of the values observed by several observers will be shown. The differences between the values of 4 observers could amount to about 1.5 km.

4. Values for the Contrast Threshold Determined in Laboratory Experiments and Derived from Field Experiments

During the laboratory tests of Blackwell [3, 4] the contrast threshold was determined for different parameters. The observers must detect a dark or bright disk. Dark or bright means relative to its background which was homogenous. During one test series the observation time amounted up to 60 seconds and the observers knew exactly where the disk to be detected would appear. During another test series the observation time was only 6 seconds and the region of search had a width of 10 degrees. For comparison in this paper only those values of Blackwell are used which are obtained during the test series mentioned at first: observation up to 60 seconds, no search.

In the following the values of Blackwell are compared with those values for the contrast threshold which are derived from the results of field experiments to determine the maximum detection range. For computing the contrast threshold the following contrast reduction formula was used:

$$C_{th} = C_o \cdot \exp - \frac{3 \cdot D_m}{V_N} \qquad (2)$$

In this formula:

C_{th} = contrast threshold
C_o = inherent contrast (contrast between the object and its background from a distance ≈ 0)
D_m = maximum detection range
V_N = horizontal standard visibility.

In figure 7 there are depicted the values from Blackwell for the contrast threshold versus the diameter of disks for two adaptation luminances. In figure 8 then the dependence of the contrast threshold on the adaptation luminance for several diameters of object is shown. The contrast threshold becomes larger when the diameter of the object becomes smaller and the contrast threshold becomes larger also when the adaptation luminance becomes smaller. When the adaptation luminance is larger than about 10^2 asb - corresponding to about 10^2 cd/m^2 - then the contrast threshold remains constant.

Also based on the research of Blackwell are the results of figure 9. In this figure the contrast threshold is depicted in relation to the observation time for four different diameters of observed disks. Three of the four curves show that for observation times larger than one second the contrast threshold approximates to a constant value.

The next figures will indicate whether and how the values from Blackwell differ from those which are derived from the results of field experiments. But first in the following figure 10 is shown the Blackwell-curve for the dependence of contrast threshold on diameter of observed disk. The thick line section of this curve shows that part for which the results of DFVLR are valid.
Figure 11 shows one comparison in which both the contrast thresholds for bright adapted eye are plotted. The vertical lines of three of the DFVLR values represent the region of confidence of these mean values for a region of confidence of 95 %. The values derived from field experiments are about two times larger than those determined in laboratory tests.
In figure 12 the differences are shown when observing at smaller adaptation luminances. The lower curve represents values from Blackwell and the upper curve those from DFVLR. From this figure results that when observing during twilight the values of DFVLR are about seven times larger than those of Blackwell.

From figure 13 the influence of different instructions to the observers concerning the direction of approach of aircraft on the contrast threshold it can be seen. For these comparisons there were no results obtained for naked eye experiments. The values of figure 13 are observed by 10x50-fieldglasses. During one test series the fieldglasses of the observers were directed exactly to the approaching aircraft. The observers were exactly informed on which point of the field of view of their fieldglasses the aircraft was appearing. During the other test series the observers had to search a sector of about 5 degrees. All these observations were made with supported fieldglasses. When the information of the direction of approaching aircraft was not exact then the contrast threshold was about three times larger than when this information was exact.

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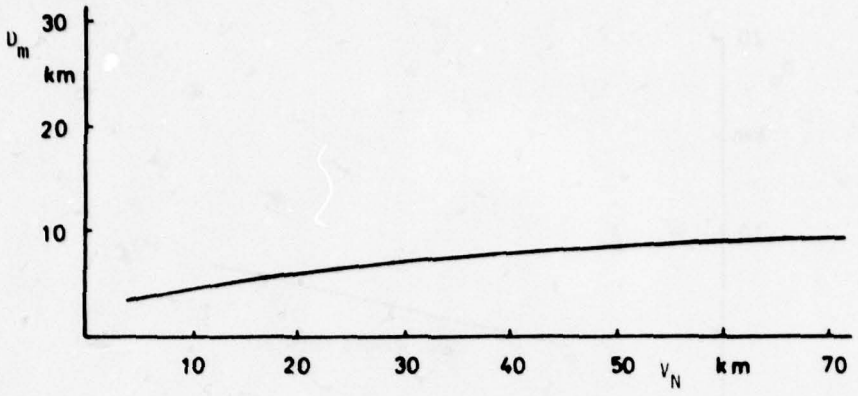


Fig.1 Maximum detection range D_m when observing a darkgreen Do 27 versus horizontal standard visibility V_N

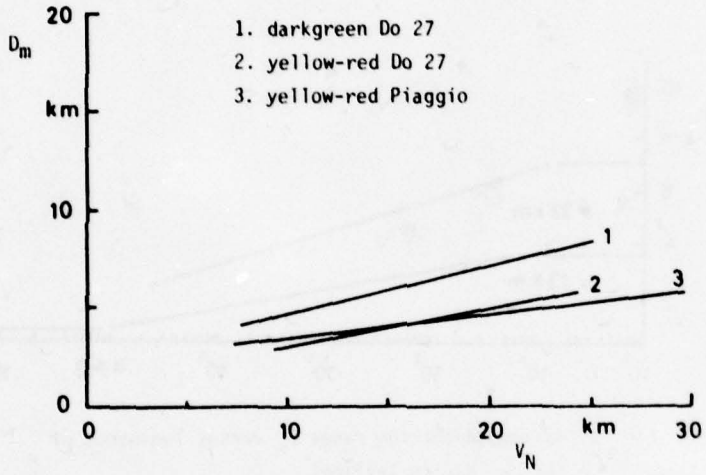


Fig.2 Maximum dedection range D_m when observing different airplanes versus horizontal standard visibility V_N

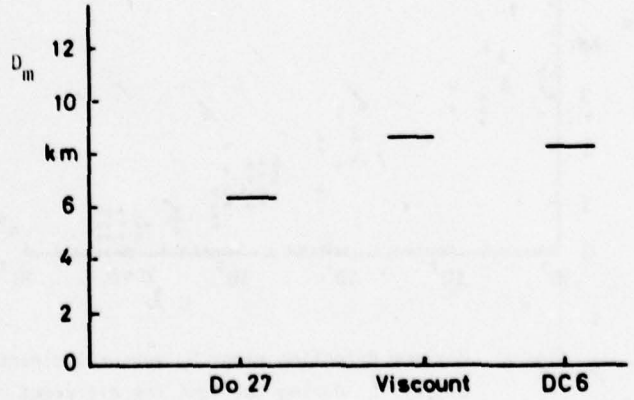


Fig.3 Maximum detection ranga D_m for different airplanes for horizontal standard visibility V_N 14 - 16 km

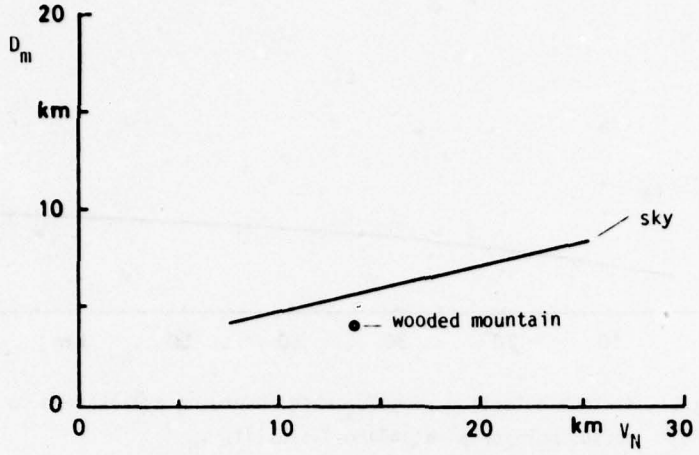


Fig. 4 Maximum detection range D_m for sky and wooded mountain as background

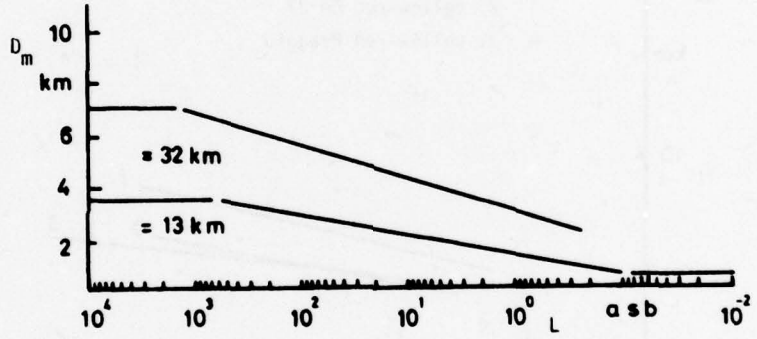


Fig. 5 Maximum detection range D_m versus luminance of sky L during twilight

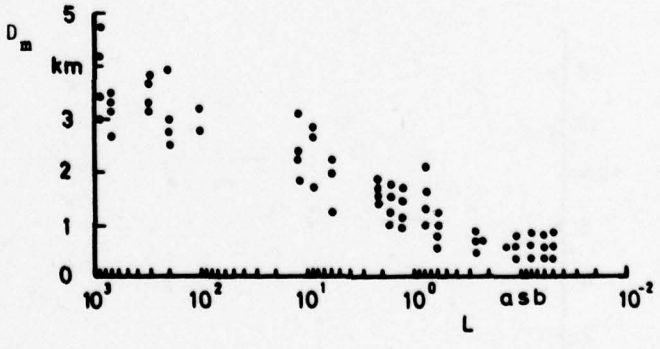


Fig. 6 Maximum detection range D_m versus luminance of sky L during twilight for different observers

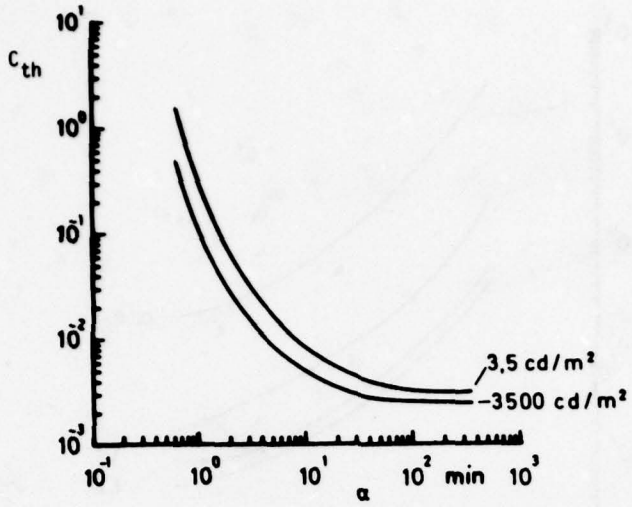


Fig. 7 Contrast threshold C_{th} versus diameter of objekt α (Blackwell)

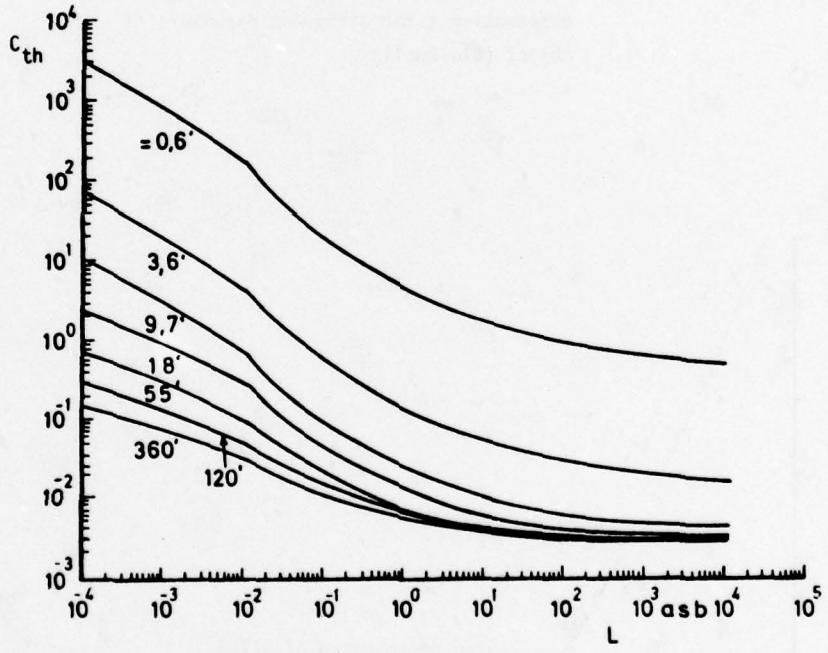


Fig. 8 Contrast theeshold C_{th} versus adaptation luminance L for different diameters of object (Blackwell)

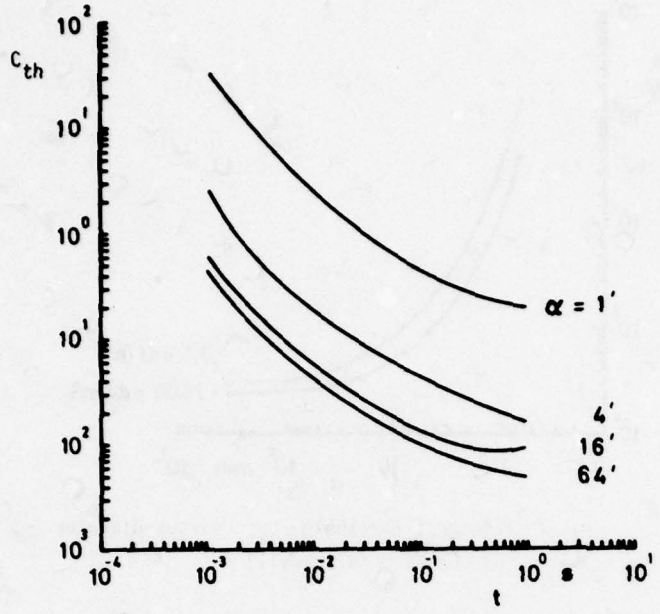


Fig. 9 Contrast threshold C_{th} versus time of observation t for different diameters of object (Blackwell)

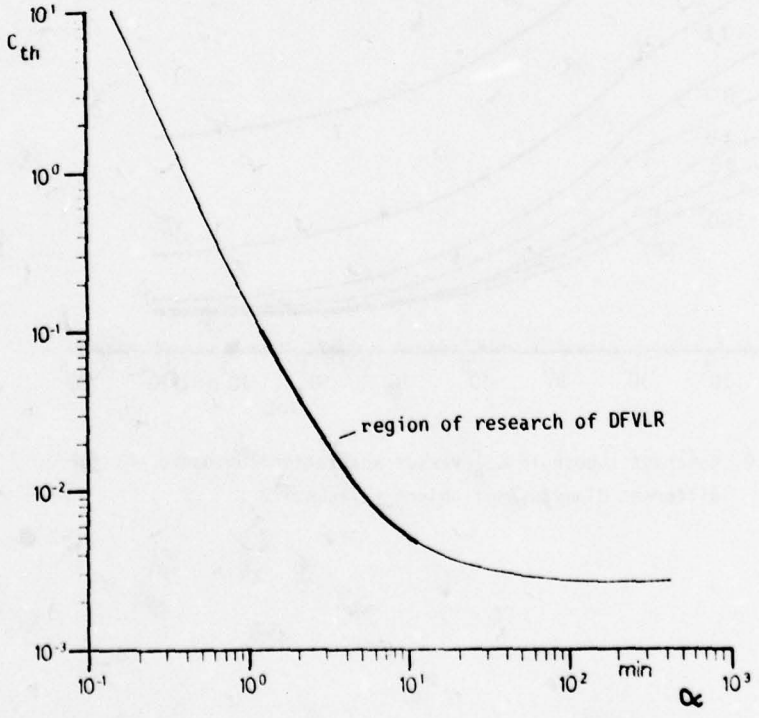


Fig. 10 Contrast threshold C_{th} versus diameter of object (Blackwell) and region of research of DFVLR

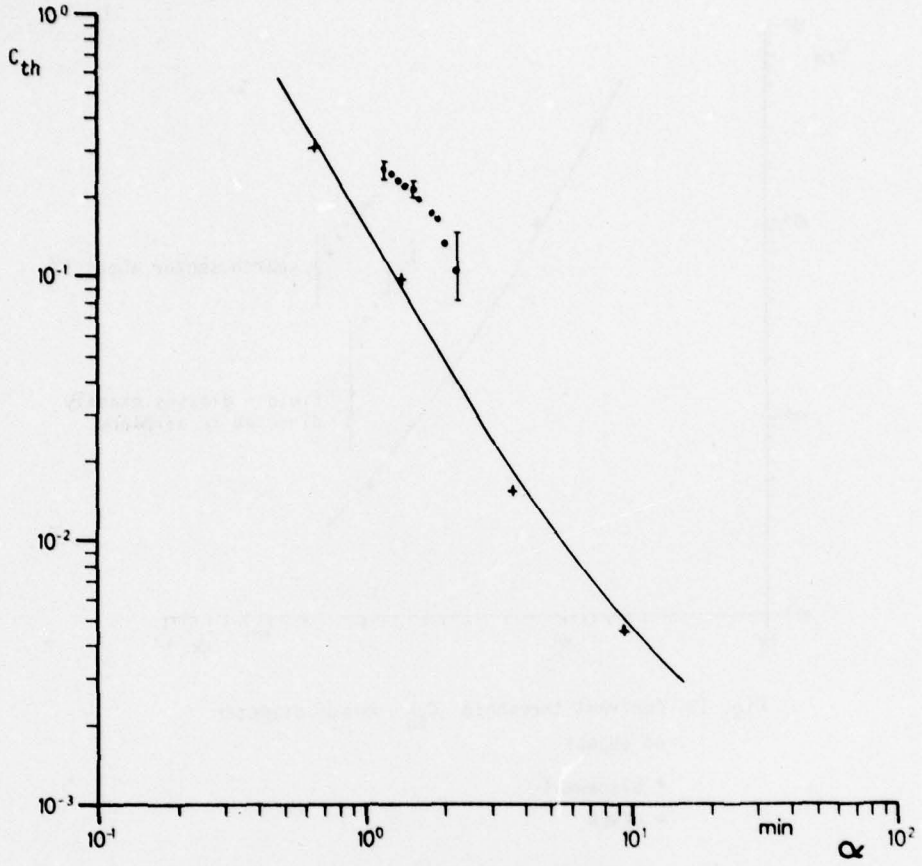


Fig.11 Contrast threshold C_{th} versus diameter of object α

◆ Blackwell

• DFVLR

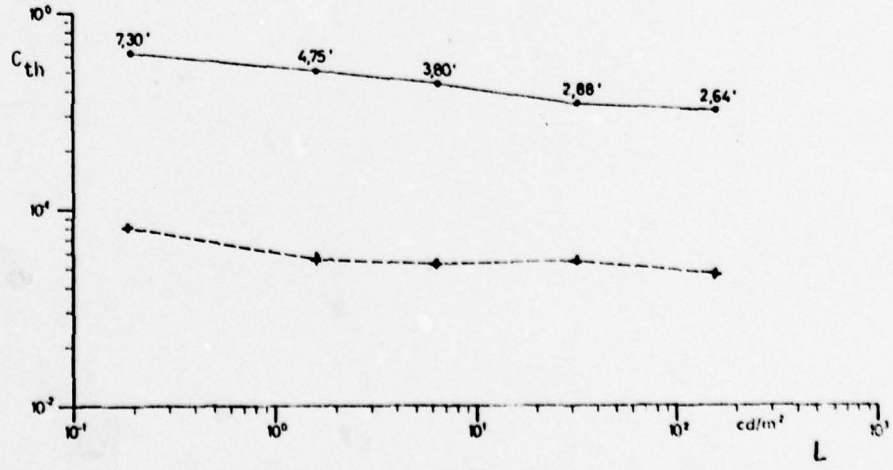


Fig. 12 Contrast threshold C_{th} versus adaptation luminance L

◆ Blackwell

• DFVLR

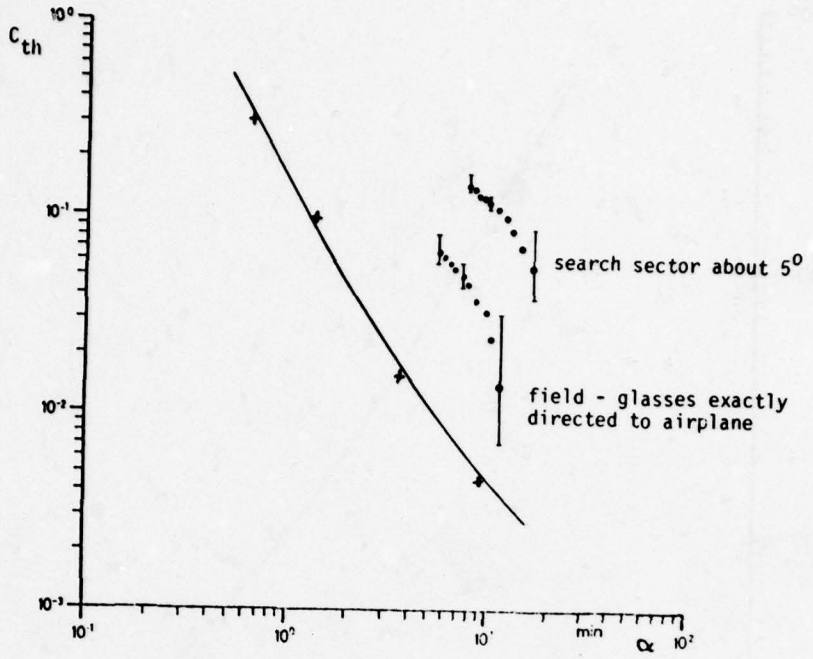


Fig. 13 Contrast threshold C_{th} versus diameter of object

✦ Blackwell

• DFVLR

DISCUSSION

PERDRIEL: (France)

I would like to ask the speaker if he has made an observation of objects in the air with an air-air perception. I believe that your study was made with a ground observer looking at an object in the air. This has some importance because air-to-air detection is better for a thirty-meter wing span aircraft. Maximum detection in clear weather lies at about 14 kilometers, while the values you gave us under the best visibility are about 10 kilometers. Were you able to make experiments of detection distance between two aircraft, for instance, and were you able to confirm the 14 kilometer range, which is still used as a reference point when one considers, in particular, the contribution of anti-collision lights?

HOFFMAN: (Germany)

Perhaps I don't understand.

PERDRIEL: (France)

Let me repeat the first part. I wanted to ask you if you had studied detection ranges between the eye of a pilot in flying aircraft and another aircraft at some distance still in flight. The studies you have made refer to detection range from a ground observer for an incoming aircraft. I think that it is important for the prevention of accidents to know that (for mid-air collisions) detection ranges for air-to-air visibility are about 50% greater than ground-to-air visibility, or air-to-ground visibility.

Hoffman: (Germany)

You have seen some information on the experiments that we have made during very large horizontal standard visibilities. Perhaps I must mention when you have on the ground a horizontal standard visibility, you have at 5 kilometers altitude perhaps a horizontal standard visibility of 20 kilometers. Therefore, we have also conducted experiments for standard visibilities at high altitudes. We can only approximate from our experiments the detection distance at high altitudes. I might say here also, we have made our experiments by observers who have only to look into the air to detect any aircraft. We have also made comparisons with, for example, helicopters, where there was a difference between the detection distance of the pilot versus special observers who only had to look for other aircraft. I must also say that one of our tasks was also to determine the relationship between detection range or visibility and atmospheric optical parameters and that with atmospheric optical parameters, we take into account the effect of turbidity of the atmosphere in the horizontal direction and also in slant-view direction, as well as several meteorological parameters. In answer to your question, I can say that these experiments also apply to observing air-to-air.

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ANALYSES OF MIDAIR COLLISIONS IN GERMAN AIRSPACE: METHODOLOGY AND RESULTS

by
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SUMMARY

The paper deals with theoretical studies concerning conflict detection and resolution in visual meteorological conditions by means of the "see and avoid" concept, and lessons learned from analyses of midair accidents in German airspace. The methodology is concerned with some supplementary aspects of the visual detection of an aircraft, the observation and extrapolation of its flight path, and the distance limits where an efficient manoeuvre can be initiated taking observation errors into account. Restrictions of a pilot's ability to detect an approaching aircraft caused by a small apparent size or unfavourable silhouette of that aircraft, and by opaque structures in his cockpit are discussed for horizontal turns and straight and level flight. Also treated is the apparent track of an aircraft on the windshield in front of the observing pilot. Based on this methodology, the features of five real midair conflicts in German airspace are demonstrated especially with respect to human factors.

1. INTRODUCTION

The existing ATC system within Germany is very effective in preventing midair collisions. In the four-year period, 1973-1976, the number of fatalities due to midair collisions was 20 (collisions between two military aircraft excluded). This number is much lower than the number of all transportation fatalities per day. However, with the continuing growth in aviation, an increase in midair collisions can be expected. Also, the advent of larger air carrier aircraft permits the fatalities per collision to increase substantially. Wide-bodied carrier aircraft with capacities of several hundred passengers present an ominous threat if one or two such aircraft are involved in a midair collision. Even if the size of an aircraft is small compared to the size of carrier aircraft, a collision can mean a catastrophe. The fuel capacity of modern military aircraft is so large that many people can be killed on the ground if a midair collision, with a glider for example, should occur and the military aircraft should afterwards crash into a crowded street. Therefore, the potential increase of midair collisions with catastrophic results indicates the necessity of new studies to verify current collision avoidance concepts.

Theoretical studies concerning conflict detection and resolution in visual meteorological conditions by means of the "see and avoid" concept have been undertaken for some years by the Institute for Flight Mechanics of the DFVLR at Braunschweig. Flight and ground tests on the acquisition of aircraft with respect to collision avoidance and special military tasks have been made by H.-E. HOFFMANN from the Institute for Physics of the Atmosphere at Oberpfaffenhofen who will present a paper during this meeting [1]. The theoretical and experimental collision avoidance studies are parts of a joint research programme for the German Ministry of Transport.

In addition, analyses of several real midair collisions and of one hazardous near midair collision have been accomplished by the Institute for Flight Mechanics as scientific support to the official investigations being made by Luftfahrt-Bundesamt, General Flugsicherheit in der Bundeswehr and district attorneys. The analysed conflicts include gliders, powered gliders, and high-performance civil and military aircraft.

The purpose of this paper is to give a brief review of our studies on real or simulated midair conflicts in visual meteorological conditions. In keeping with the theme of this symposium, attention will be focussed on human factors and on learning from a past experience in midair accidents or incidents.

2. THE RIGHT-OF-WAY AND THE USERS

In visual meteorological conditions (VMC) the flight visibility shall be at least 8 km (5 miles) or 5 km (3 miles) in most parts of airspace [2]. It is assumed that at least one aircraft is flying under visual flight rules (VFR). The second aircraft may fly under visual or instrument flight rules (IFR). Figure 1 shows the three most important conflict situations: head-on, converging courses and overtaking [2-4]. The "see and avoid" concept of visual collision avoidance is based on the early detection of the other aircraft and on an efficient evasive action taken by one or both pilots. This concept must provide the means which make possible the safe use of the airspace by all who desire to use it as a transportation medium with maximum flexibility and minimum restrictions. Pilots and aircraft flying in visual meteorolo-

gical conditions have a wide divergence of performance characteristics, e.g.:

- Pilots of light aircraft or (powered) gliders performing VFR flights for pleasure and nonbusiness purposes, perhaps after exhausting working hours. Their training may be inadequate for operating in a high density area; their health may be just at the limit for the prolongation of the licence.
- Pilots of military aircraft being highly qualified and well trained, in low-level high-speed VFR flights.
- Air carrier crews performing long-range IFR flights.
- Light aircraft or (powered) gliders, e.g. with insufficient ventilation, a high noise, temperature or vibration level, or a poor power plant.
- Single-seat high-performance military aircraft requiring a heavy workload of the pilot and enduring heavy "G" forces.
- Wide-bodied carrier aircraft with restricted load factors and angular accelerations, especially because of the passengers near the ends of the fuselage.

These items being obviously incomplete indicate that many operational, human and flight dynamic factors must be taken into account for analysing the "see and avoid" concept. More details are treated in the following chapters.

3. MIDAIR AND NEAR MIDAIR COLLISIONS

Five real midair conflicts are selected as examples for typical situations. Figure 3 shows the silhouettes of the aircraft in perspective during the critical phase; the sizes of the silhouettes are reduced approximately to the same observation range. As in one case the glider was circling, several aspects of the glider are shown. The operational factors of four conflicts are presented in figures 10 to 13. The following is a listing and brief description of each of the midair conflicts in generic terms:

(1) Near midair collision in 1975 near the intersection of two airways between

2 G-91 (single seat)	VFR straight and level flight, flight level 235 (nominal),
Boeing 737	IFR straight and level flight, flight level 240 (nominal),

High rate of closure, approximately head-on.

(2) Midair collision in 1976 between two aircraft approaching a navigation aid:

HFB 320 (executive jet)	IFR in straight and level flight, flight level 95, reduced airspeed.
G-91 (two-seat tandem)	VFR in a horizontal left turn, flight level 95, after leaving a Temporary Reserved Airspace, navigation training flight.

Low rate of closure, overtaking.

(3) Midair collision in 1976 between

Powered glider (two-seat abreast)	VFR in straight and level flight, 3500 ft,
4 F-4 Phantom	VFR in a horizontal left turn, 3500 ft, No.2 involved.

High rate of closure, at first overtaking, later on perhaps converging courses.

(4) Midair collision in 1977 between

2 F-104 (single-seat)	VFR in straight and level flight, 2400 feet. Right aircraft during radar training flight, involved. Left aircraft responsible for "see and avoid".
Glider (single-seat)	VFR, probably in straight and level flight, in a left turn during the last seconds, 2400 ft.

High rate of closure, converging courses. Glider has right-of-way.

(5) Midair collision in 1973 between

Mirage	VFR in straight and level flight.
Glider	VFR, circling (left).

High rate of closure; head-on, converging course, overtaking. Glider has right-of-way.

According to official reports, the meteorological visibility was better than 8 km (5 miles) in all five cases. Accident (3) between four military aircraft and a powered glider is also representative for collisions between high performance aircraft and light aircraft.

4. DETECTION

The problem areas associated with visual collision avoidance can be divided into four groups:

- Detection of the intruder aircraft
- Observation of the present and extrapolation of the future flight path
- Decision to continue the flight or to take action
- Initiation and performance of the evasive manoeuvre.

As mentioned above, the correlation between the maximum detection range of an intruder aircraft and the horizontal meteorological visibility or the brightness of the sky is treated in the paper by HOFFMANN [1] so that some supplementary aspects of the visual acquisition of an aircraft are sufficient in this chapter.

Figure 2 shows the field of view in the G-91 cockpit in straight and level flight and in a horizontal left turn. Many factors affect the pilot's ability to detect an aircraft which might be on a collision course with his aircraft. The aircraft's silhouette, size, position with respect to the horizon, the contrast between aircraft and background, haze, smoke, sun position, window configuration, and blind areas, e.g., by navigation bags, will affect the pilot's ability to detect the other aircraft. The accommodation of the pilot's eyes, his scanning techniques, and time sharing between the inside and outside of the cockpit have a significant effect on the probability of detection.

4.1 Silhouette and apparent size of the aircraft

There are several crucial questions that must be answered before a final conclusion on the detection can be made, particularly with respect to the apparent size and the silhouette of the intruder aircraft. The silhouettes of some aircraft involved in five typical midair conflicts are presented in figure 3. For the purpose of analysing midair conflicts, it is assumed that an apparent size in the order of 2 mm on a hypothetical windshield being 1 m away from the pilot's eyes is theoretically sufficient for the detection of the intruder aircraft unless the silhouette, the contrast etc. are unfavourable [6]. This threshold is comparable to the smallest lines on a slide-rule when observed at a distance of 0.3 m. Neglecting the different environmental conditions, it means that a 30 ft object can be detected at 2.5 NM (nautical miles). Furthermore, the threshold is compatible with the measurements by HOFFMANN for low flying light aircraft [1]. In addition to the computation of the apparent size and silhouette of the on-coming aircraft, the apparent position of the sun on the windshield is determined, since a small angle between the directions to the sun and to the aircraft can reduce the pilot's ability to detect a small target, especially if the windshield is not quite clean.

Figure 4 represents the apparent size of the circling glider and of the HFB 320 involved in the accidents (5) and (3), as observed by the pilots of the Mirage and the G-91. The apparent wing span of the glider is sufficient for detection at least 20 seconds (sec) before the collision, but the silhouette is very thin from -20 sec till -10 sec (figure 3). A temporary disappearing of a circling glider can easily be observed, particularly when the observer and the glider are approximately in the same level. The apparent length of the fuselage is larger than the threshold during the last 10 sec only. At first, the thin silhouette and the lack of contrast between the glider and the background, later on a short distraction from normal visual scan caused by cockpit duties or navigation requiring concentration may have resulted in the Mirage pilot's failing to detect the glider early enough.

Considering the HFB 320 accident (No.2), the wing span of this aircraft had a sufficient size at least 40 sec before the collision. However, the silhouette was unfavourable during this time because the G-91 pilot could observe the HFB 320 only from behind. The altitude of the sun was low and the angle between the line of sight and the direction to the sun small so that the performance of the pilot's eyes may probably have been reduced. The two-seat G-91 performed a navigation training flight and was approaching a navigation aid. This means an additional workload and an opportunity to make mistakes. For the temporary masking of the HFB 320 by a cockpit structure see chapter 4.2.

The G-91 pilots involved in the near midair collision with a Boeing 737 (accident (1), figure 10) did not see the Boeing 737 in spite of its large size because of a cockpit structure (chapter 4.2), whereas the Boeing 737 copilot detected both G-91 approximately 10 sec before the near miss although the apparent sizes of the G-91 were much smaller and their silhouettes unfavourable. The same yields for the apparent sizes of the four F-4 Phantoms and the powered glider from 20 sec till 10 sec before their collision (accident (3)), whereas the silhouettes of all aircraft involved were relatively favourable. The number of efficient crew members on board the four Phantoms may not be overrated as only one of eight members is able and responsible for collision avoidance in the head-on direction! As far as blind areas for the Phantom pilots are concerned see chapter 4.2.

The apparent sizes of the two F-104 and the glider before midair collision (4) were below threshold for a long time and their silhouettes unfavourable, particularly as the fuselage of the glider is rather thin. The pilot of the left F-104 was flying

behind the right F-104 so that he had to observe this aircraft very often. As the direction to the sun was not far away from the line of sight between the two F-104, the ability of the left F-104 pilot to detect the glider may have been reduced significantly. In addition, the glider was at least partially obscured by a cockpit structure (chapter 4.2).

HOFFMANN has accomplished a very interesting research programme, particularly with respect to the acquisition of head-on approaching light aircraft by observers on the ground. In addition, there are several crucial questions that should be studied in detail from the author's point of view, e.g., the detection range at medium or high altitudes, the influence of the relative position of the sun and the reduction of the pilot's ability to detect a target because of cockpit duties and affiliated accomodation changes. For some months, Deutsche Lufthansa, in cooperation with DFVLR, has been accomplishing a programme concerning the detection range of air carrier aircraft flying head-on on airways.

4.2 Blind Areas

For each midair conflict the apparent flight path of the intruder aircraft on the windshield is computed from the data being available, e.g., heading, indicated airspeed, bank angle, altitude and collision angle. The opaque structures of cockpits are determined by means of photos taken by the official investigators. A customary camera is used instead of the pilot's head so that a single photo offers the same view as a fictitious single central eye of the pilot. Figure 2 shows the field of view for one eye in the G-91 cockpit. If the horizontal length of opaque structures is shorter than the distance between both eyes, an aircraft being far away from the pilot is observable at least by one eye in principle [3, 4, 6, 10].

Some general features can be derived from figures 1 and 10 to 13 on the directions where an intruder aircraft can approach from; that are the horizontal angles β_1 and β_2 between the axes of the aircraft and the line of sight or equivalent angles in the cockpit reference system. If one of the aircraft involved in a collision is flying much faster than the other one (e.g., fighter/light aircraft), all possible collisions will approximately be head-on conflicts with respect to the pilot of the faster aircraft, whereas the pilot of the slower aircraft has to detect the faster one head-on, on both sides or backwards. Therefore, a pilot in a slower aircraft has a worse detection chance than a pilot in a faster one in many cases.

Before the near midair collision (1) between the Boeing 737 and the two G-91, the carrier aircraft was obscured by the right structure being 15 degrees away from the reference point of the G-91 cockpit (figures 2 and 10). As all the aircraft were probably flying in straight and level flight during the last minute, the apparent flight path of the Boeing 737 was not shifting to the right or left side but only a little from bottom to top because of the probably different real flight levels of the aircraft. The distance between both eyes is smaller than the effective width of the structure so that a small angle of view is masked at the same time for both eyes.

The HFB 320 (accident (2)) was obscured by the left structure in the G-91 cockpit when the G-91 was flying a horizontal left turn before the collision (figures 6 and 11). The pilot of the crashed F-4 Phantom (accident (3)) could not detect the powered glider since it was masked by an extended horizontal structure in the left upper edge of the Phantom cockpit during the last 30 sec (figures 6 and 12). The pilot sitting on the left seat of the powered glider could not sight the four Phantoms because the passenger sitting side by side with him was shadowing the Phantoms.

During the critical phase before collision (4), the visibility of the glider was strongly reduced for the pilot of the left F-104 (figure 13) by a structure being approximately 8 degrees away from the cockpit reference point and a little smaller than the distance between both eyes. Therefore, the target could be detected at least by one eye in principle. However, if a target is very small and the sky without any contour like a cumulus cloud, the eyes will in most cases accommodate automatically to the structure of the cockpit and a far distant target will not be noticed. Disregarding this human factor, some pilots apparently have a false sense of security. A possible reduction of the pilot's ability to detect the glider by mission requirements and the relative position of the sun has been treated in chapter 4.1. With respect to the glider, both F-104 were approaching from an unfavourable direction on the left side.

There are several crucial questions that should be studied in detail, e.g., the pilot's ability to detect a small target behind a window post by one eye without moving his head and the pilot's endurance to change the field of vision by moving his head. During a flight of several hours, the pilot cannot reasonably be expected to accept the last demand.

5. OBSERVATION

When the on-coming aircraft has been detected, there are several questions that must be answered before the pilot can come to a decision for an evasive manoeuvre:

- Is the intruder aircraft a glider or a powered glider whose engine is running?
- Is the aircraft at the same level?
- Who has the right-of-way taking operational factors into account?
- Does the approaching aircraft threaten the observing aircraft?
- How much time is available before the potential collision?

5.1 Powered glider

The first question makes an excessive demand on the observing pilot in some cases. As the propeller of a powered glider is relatively small, e.g., 1/10 of the wing span, the pilot can only distinguish at a very short distance, perhaps at half a mile, whether the propeller is running [6]. If not, the approaching glider has the right-of-way in all operational situations. A few seconds before collision (3) a member of the Phantoms' crews believed, for example, that a glider was flying head-on although the propeller was running in reality.

5.2 Estimation of equal flight levels

A reliable estimation of small vertical differences between aircraft in straight and level flight seems to be difficult or even impossible, particularly, if the rate of closure is high [3]. There is no line on the windshield indicating a constant flight level since the position of this line would depend on the altitude, the weight, airspeed etc. The horizon or the bases of haze and clouds are inappropriate as references, particularly at high altitudes. As represented in figures 2 and 6, the horizon is more than 2 degrees below the fictitious line indicating flight level 240. The nominal difference in altitude before near midair collision (1) was 500 ft. Although the Boeing 737 was nominally flying higher than the two G-91 (figure 7) and the Boeing copilot at first had the impression that both G-91 were flying lower than himself, the Boeing crew initiated a rapid descent some seconds before the near miss. Therefore, errors in judgement of the relative height by the pilots cannot entirely be excluded.

5.3 Limits between priority areas

Considering the three main operational conflict situations in figure 1 and the rules of the air, our attention is attracted by the difference between the sighting directions β_1 or β_2 on the one hand and the angle between the directions of flight on the other hand. The last angle is the criterion for the right-of-way in some cases during daylight, but it cannot be observed directly; this is contrary to β_1 and β_2, which are the criteria at night and correlated to the perspective or silhouette of the aircraft. The difference between these directions can become considerable, especially for comparable airspeeds [3, 4, 6].

Before near midair collision (1) (figure 10) the crew of the Boeing 737 had the impression that both G-91 were approaching approximately head-on, whereas the angle between the flight directions was lower than 150 degrees instead of approximately 180 degrees for the head-on case. This impression was probably based on the small angle β_2 being approximately 15 degrees which meant that both G-91 were approaching from 11.30 in the cockpit system. A limit between the head-on case and converging courses is not yet officially fixed.

Considering the situation some seconds before collision (3), the right-of-way of the Phantoms depended on the angle used as the criterion (figures 1 and 12). Provided that the angle between the flight directions had been used according to the rules of the air, the Phantoms would probably have overtaken the powered glider which then would have had the right-of-way. If the angle β_2 had been derived from the perspective of the powered glider and erroneously been used as the priority criterion during daylight, the courses would probably have converged and the Phantoms would have had the right-of-way. It must be emphasized that the pilots are obliged to come to a decision by means of operational parameters which they cannot observe directly in some important cases.

5.4 Collision criteria

After the detection of the intruder aircraft, the pilot has the task to observe its apparent flight path and to determine the collision risk by extrapolation of the apparent flight path. Two aircraft flying in straight and level flight will threaten each other if the line of sight is fixed with respect to the windshield and the distance decreases. This means that the angles β_1 and β_2 in figures 1 and 5 are constant. The

above mentioned conditions are not complete. In addition, oscillations of the observing aircraft around its axes are not allowed. If one or both aircraft are performing horizontal turns in a collision situation, many types of apparent tracks are possible on the windshield. A special case excepted the aircraft's "image" will move parallel to the horizon. However, the image can shift continuously into the same direction or change its direction, e.g., after an apparent stop or quasi stop lasting many seconds [3, 4, 6].

Figure 6 represents the apparent track of the HFB 320 in the G-91 cockpit before collision (2) and, in comparison, the apparent track of the powered glider (in the Phantom cockpit) before collision (3). The HFB 320 and the powered glider were flying in straight and level flight, the G-91 and the Phantom in a horizontal left turn (figures 11 and 12). Figure 8 shows a head-on collision between two aircraft in straight and level flight. If the aircraft is approaching at a lower flight level, as shown in figure 7, the aircraft's "image" will move to bottom, at first very slowly.

Considering human factors, an excessive demand is made on the pilots with respect to collision criteria. Only if both aircraft are flying in straight and level flight, the collision criterion may be simple enough for an average pilot flying for pleasure or nonbusiness purposes. Taking horizontal turns into account, only military pilots, who are well trained in air combat simulations, may probably be capable of analysing the real conflict situation. Unless the aircraft are approaching each other approximately head-on or from behind, a very high faculty of imagination is required for the evaluation of the real operational situation.

The evaluation of the future flight path of the intruder aircraft is complicated by observation errors. In figure 8, the "image" of an aircraft approaching in straight and level flight is considerably enlarged on the windshield because of observation errors. These can be due to the pilot's incapability to distinguish between far distant aircraft which are stationary or moving very slowly on the windshield, e.g., to the left or to the right side. In addition, small oscillations of the observing aircraft around its axes can deteriorate the observation and extrapolation process. An observation error circle around the "image" of the on-coming aircraft on the windshield results in a cone of possible flight paths whose diameter depends, among other things, on the distance between the two aircraft during the observation period. Two examples are shown in figure 8. The lower light aircraft is pinned to this presentation during the whole flight of the upper jet aircraft, unless the light aircraft is performing an evasive manoeuvre. Taking observation errors into account, an evasive manoeuvre of the light aircraft can be considered efficient and safe if the light aircraft leaves the flight path cone and gains an additional minimum distance from the cone, e.g., of 0.1 NM. This value is arbitrarily chosen, as no airspace user would like to answer the question which minimum distance he takes for safe. The diameter of the cone depends on the error model which is chosen for the observation of the "image" of the intruder aircraft on the windshield. Two models are treated by CALVERT and later on by the author [3, 7, 8]. The first model uses a threshold for the minimum apparent displacement which can be detected on the windshield by the pilot, the second one a threshold for the minimum apparent velocity. Flight test data, however, are not yet available to the author so that a final conclusion cannot be made on the error model. In chapter 6, a minimum displacement $\Delta\beta_1$ is chosen as a criterion.

5.5 Estimation of the available time

The time being available before a potential collision between two aircraft in straight and level flight depends on their distance and their rate of closure. Figure 5 shows two examples of collisions. The detection range d_A and the direction β_1 from aircraft (1) to aircraft (2) are equal in both cases, the angles between the flight paths are 90 and 45 degrees. As the small silhouette of aircraft (2) only represents a rather unknown perspective of the aircraft and the type of the approaching aircraft cannot often be resolved on time, the estimation of the aircraft's range is very difficult. The same yields for the estimation of the rate of closure since the increase of the apparent size of a far distant aircraft (2) is very slow and the true airspeed V_2 of that aircraft only partially influences the rate of closure. In figure 5, the time being available before the potential collision increases from 10 sec to 20 sec, the true airspeed V_2 decreases from V_1 to 0.7 V_1, that is 30 per cent instead of 50 per cent, and the apparent length of the fuselage increases from 0.7 to 1.0. Flight test data on the estimation of the distance between two aircraft and their rate of closure are not yet available to the author, particularly with respect to converging courses which are the most difficult problem. The author expects that the evaluation of these human factors is a crucial problem of the "see and avoid" concept.

Summarizing the observation process, several important questions should be studied in detail, e.g., the pilot's capability to resolve small differences between flight levels, to distinguish between aircraft being apparently stationary and aircraft moving very slowly on the windshield, and to estimate distances and rates of closure. In addition, the pilot's ability should be studied to produce an overall picture of a dangerous operational situation by means of the visual informations being available in the cockpit.

6. DECISION AND EVASIVE MANOEUVRE

After the detection of the intruder aircraft and the observation of its future flight path, the pilot must come to a decision whether he should continue his flight or take action. Regarding the decision process, two cases can be distinguished:

- The intruder aircraft was detected so late that only a spontaneous evasive manoeuvre is possible.
- The intruder aircraft could be observed for a sufficient time so that a well-considered action is practicable.

In the first case, a general inquiry made by Amt für Flugsicherung der Bundeswehr and Bundesanstalt für Flugsicherung showed that the type of a spontaneous evasive manoeuvre largely depends on the size and performance of the aircraft [6]. Pilots of large civil or military aircraft seem to prefer rapid descents, pilots of high-performance aircraft climbing turns, and pilots of helicopters right turns or autorotation. It is evident that a spontaneous evasive action can be detrimental and somewhat aggravate the degree of hazard.

Regarding near midair collision (1) between two G-91 and a Boeing 737 (figures 7 and 10), an aggravation of the hazard by initiating a rapid descent cannot entirely be excluded. During this manoeuvre several passengers, who had not fastened their seat belts, were injured. The vertical acceleration measured in the centre of gravity of the aircraft was not unusually high, as far as we may have confidence in the reliability of the simple flight recorder of the Boeing 737. However, the acceleration of the passengers due to sudden rotations of the aircraft around its pitch axis must be taken into account. This component is particularly high for passengers sitting near the end of the fuselage.

6.1 Efficiency of manoeuvres in ideal optical conditions

The efficiency of well-considered evasive manoeuvres depends, among other things, on the acceleration of the aircraft initiated by the pilot, on the time being available before the potential conflict, on the overall operational situation, and on the observation error model used [3-7]. The last influence is treated in chapter 6.2. Since only small accelerations are possible parallel to the primary flight path, lateral and vertical accelerations play a dominant role with respect to evasive manoeuvres. At a first approximation for manoeuvres lasting some seconds only, the lateral or vertical displacement from the primary flight path is propertional to half the manoeuvre acceleration and to the square of the time being available before the potential conflict. This means, e.g., that a lateral displacement of approximately 300 m ($\approx$1000 ft $\approx$ 0.15 NM) can be achieved by means of a horizontal turn lasting 10 sec; 2 sec are included for establishing a bank angle of 45 degrees. Neglecting observation errors, a descent lasting at least 8 sec (2 sec initiation) is necessary to achieve a minimum safety distance of 0.1 NM if passengers sitting near the centre of the aircraft are weightless during the descent. The rate of closure of two aircraft flying head-on at a true airspeed of 360 kts is 0.2 NM/sec. Therefore, if only one pilot detects the other aircraft, this pilot will have to initiate the "1 G" descent at least 1.6 NM ($\approx$3 km) before the potential conflict.

Regarding converging courses, a minimum safety distance of 0.1 NM cannot always be achieved for geometrical reasons by means of an "1 G" horizontal turn lasting approximately 8 sec. In the worst case, the occurrence of the midair collision is only delayed or advanced for a moment [4, 6]. Since this critical case is dependent on several parameters, the estimation of the efficiency of evasive horizontal turns will make a high or even an excessive demand on the observing pilot if both aircraft are at first flying on converging courses. An analysis of the affiliated operational situations in detail is beyond the scope of this paper and treated in [3].

In the course of an accident analysis, the minimum safety distance which could have been achieved by means of an evasive manoeuvre is computed taking several parameters into account, e.g., bank establishment, bank angle, and duration of the manoeuvre before the potential conflict. Afterwards, the time at which the intruder aircraft probably had a sufficient apparent size is compared to the last time at which an efficient manoeuvre could have been initiated theoretically. The period between these two moments is available for normal visual scan, detection, observation, decision, and distractions by cockpit duties, mission requirements, or navigation requiring concentration. Midair collision (5) (figure 4) represents a typical example. If the circling glider could at the earliest be detected approximately 13 sec before the potential collision because of its unfavourable head-on silhouette, a short distraction by cockpit duties lasting 6 sec, for example, would have prevented a well-considered evasive manoeuvre at a moderate "G" factor.

6.2 Influence of observation errors on efficiency

The purpose of an evasive manoeuvre in ideal optical and human conditions is to avoid the precisely observed flight path of the intruder aircraft or, perhaps more evident, the bullet of a precision rifle. Taking observation errors into account, the pilot must leave the cone of all possible flight paths of the other aircraft or the bullets of a shotgun. If the distance between the marksman and his target is short, there is not a large difference between a rifle and a shotgun. Therefore, observation errors influence the efficiency of evasive manoeuvres only insignificantly if the distance between the two aircraft is small during the observation period, whereas at long observation distances, the efficiency can crucially be reduced.

Figure 9 shows the efficiency of well-considered evasive manoeuvres performed by aircraft (1) as a function of the direction β_1 of the line of sight in cockpit (1) and the detection range d_A. The true airspeeds of both aircraft are 360 kts, the time for establishing a bank angle of 25 degrees is 4 sec, the minimum safety distance from the flight path cone 0.1 NM, and the threshold for the detection of a displacement on the windshield $\Delta\beta_1$ = 10 mrad (10 mm at 1 m). The data for the bank angle and bank establishment are not excessive and can easily be achieved by an air carrier aircraft. Regarding the head-on case ($\beta_1 = 0^o$) and a detection range d_A = 5 NM, aircraft (1) can perform a successful evasive right turn provided that its pilot initiates this action between the distance limits d_E = 4.25 NM and d_E = 3.25 NM; that is an usable range of 1 NM. If the manoeuvre is initiated above 4.25 NM, pilot (1) knows too little of the future flight path of aircraft (2); if d_E is below 3.25 NM, he does not have sufficient time available to leave the small cone plus 0.1 NM. For achieving the minimum safety distance of 0.1 NM alone, pilot (1) approximately needs 13 sec which is equivalent to a closure distance of 2.6 NM. If the bank establishment is reduced from 4 to 2 sec, then the closure distance decreases from 2.6 to 2.2 NM. Provided that the bank angle is increased to 45 degrees in addition, the closure distance further decreases from 2.2 NM to 1.6 NM. These few data very clearly show the influence which the different parameters may have on the lower limit of the usable range.

Regarding converging courses, the usable range is larger than in the head-on case which results from the operational situation assumed in figure 9. Since the detection range and the true airspeeds are assumed to be constant for all directions β_1 of the line of sight, the rate of closure is lower for converging courses than in the head-on case. If the visual meteorological conditions are near the limit or the silhouette and apparent size of the approaching aircraft unfavourable, the detection range may be 4 or 3 NM only. In this case, the total area being usable for an efficient turn is reduced so much in figure 9 that an efficient turn is impossible even in the head-on case. Particularly for a detection range of 3 NM, the usable area is limited to large angles β_1 of the line of sight. The upper limit of the usable area can approximately be raised up to the detection range provided that the observation error $\Delta\beta_1$ of the pilot including oscillations of the aircraft around its axes is considerably reduced. Obviously, the resolution of the conflict situation becomes much easier if the aircraft involved are flying at airspeeds below 360 kts, e.g., at 250 kts in a terminal control area (TMA) [3], or if excessive "G" factors are allowed during the evasive manoeuvre.

These studies on the efficiency of well-considered evasive manoeuvres have been accomplished on a purely theoretical basis. There are several crucial questions that must be answered by means of flight tests and laboratory research before reliable conclusions can be made. Some aspects, particularly concerning human factors, have already been mentioned in chapters 4 and 5.

7. CONCLUDING REMARKS

Fortunately the number of fatalities due to midair collisions in visual meteorological conditions has been low in German airspace during the last years. Consequently, a small sample of midair conflicts is only available for deriving trends and their relation to operational and human factors so that this overview of our theoretical studies and accident analyses is by necessity sketchy and incomplete. In spite of these shortcomings, some common features should be mentioned:

The detection range of aircraft presenting a small silhouette in some operational situations can become much smaller than the standard horizontal visibility. Then the "see and avoid" concept ceases to be operative at medium or high rates of closure. The midair collisions between high-performance military aircraft and gliders are typical examples.

Particularly in the cockpit of some high-performance military aircraft flying a horizontal turn or in straight and level flight, the intruder aircraft can be totally or partially obscured by opaque structures for many seconds. Disregarding these facts, some pilots apparently have a false sense of security. This applies to nearly all rates of closure.

At high rates of closure, an evasive action taken can be detrimental and aggravate the collision risk since a reliable estimation of the future flight path of the intruder aircraft is very difficult in the short time available for observation.

Several countermeasures against midair collisions in visual meteorological conditions are obvious. With respect to human factors of the "see and avoid" concept, an adequate initial training or advanced instruction should be accomplished. In addition, cockpit duties should be reduced as much as possible since a lack of vigilance for other aircraft, lasting five or more seconds for example, can considerably aggravate the degree of hazard provided that high rates of closure must be expected.

As far as the ATC system is concerned, a reasonable separation of the different users by means of restricted areas or times of activity should be considered, keeping the balance between flight safety and freedom of airspace for all civil and military users. At medium and high altitudes radar transponders should be used onboard the aircraft, where practicable, by which means a continuous or intermittent positive control is possible from the ground.

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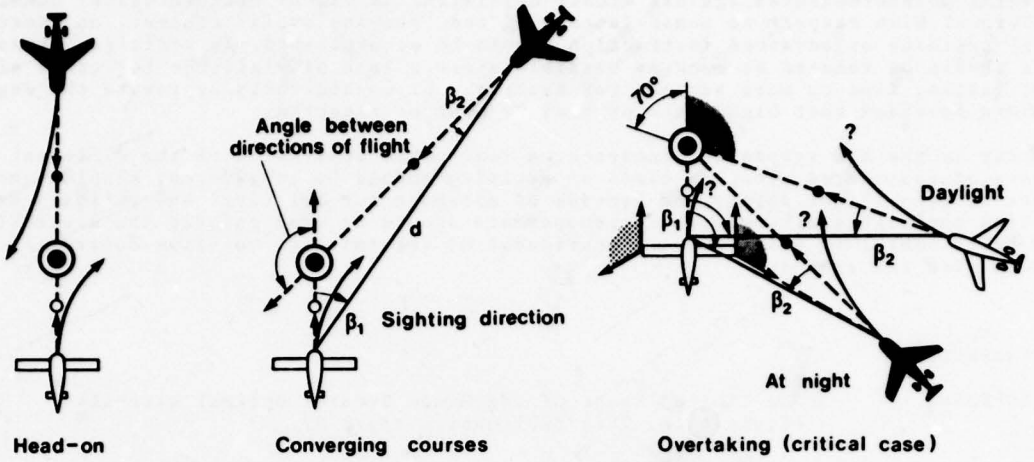


Fig. 1 Right-of-way in visual meteorological conditions.

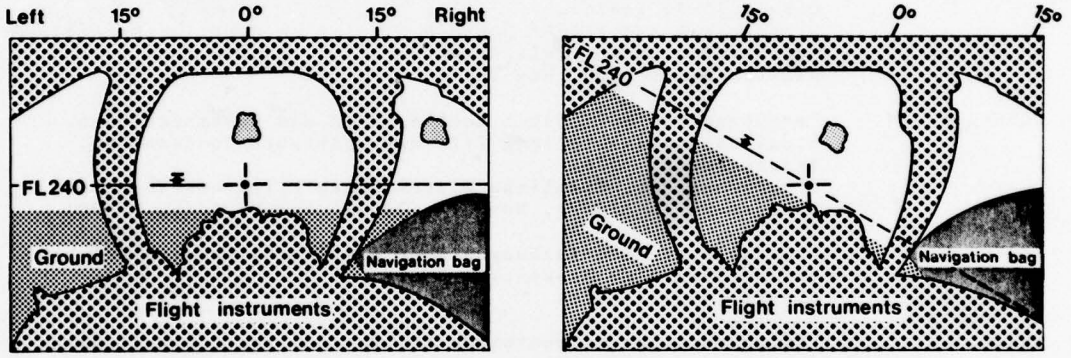


Fig. 2 Field of view in a G-91 cockpit.

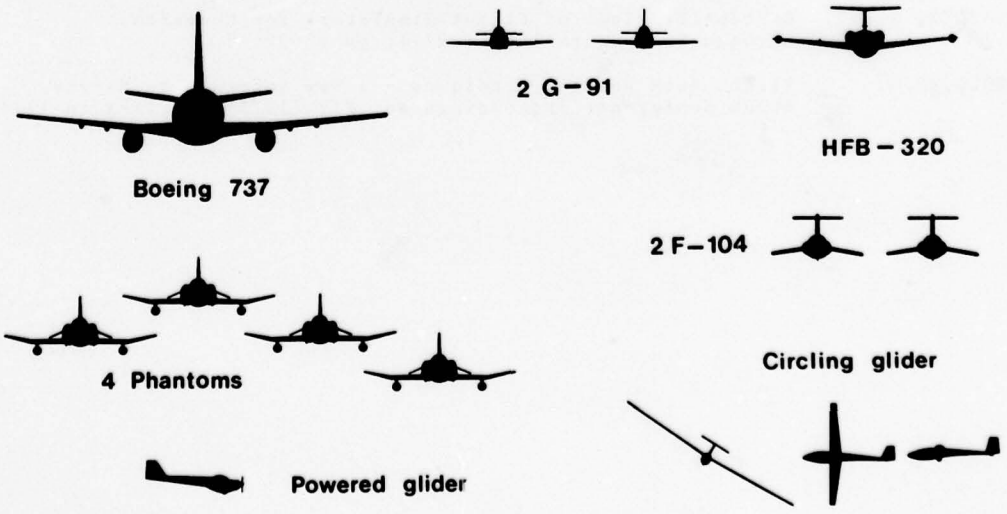


Fig. 3 Silhouettes of airplanes some seconds before the midair conflicts.

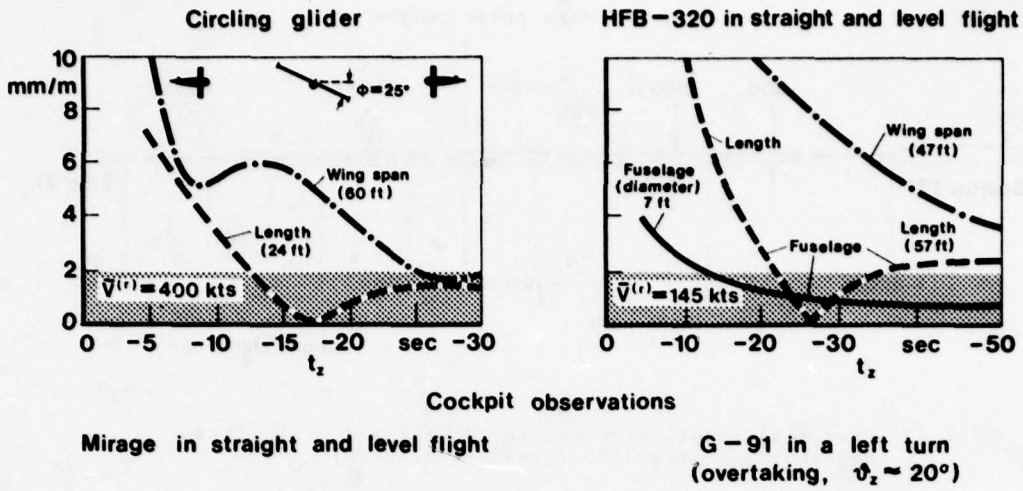


Fig. 4 Apparent size during a horizontal turn.

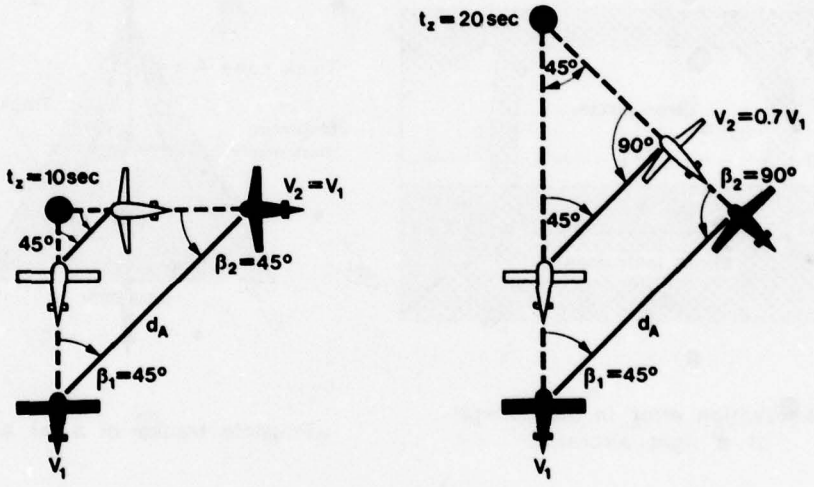


Fig. 5 Two different conflict situations for the same detection ranges d_A and sighting directions β_1.

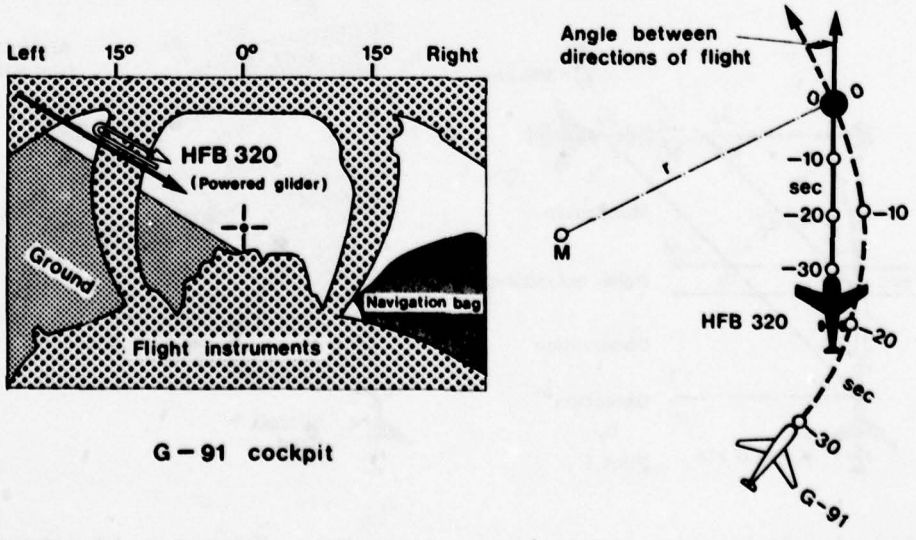


Fig. 6 Apparent track of an aircraft in straight and level flight on the windshield of an aircraft flying a horizontal turn.

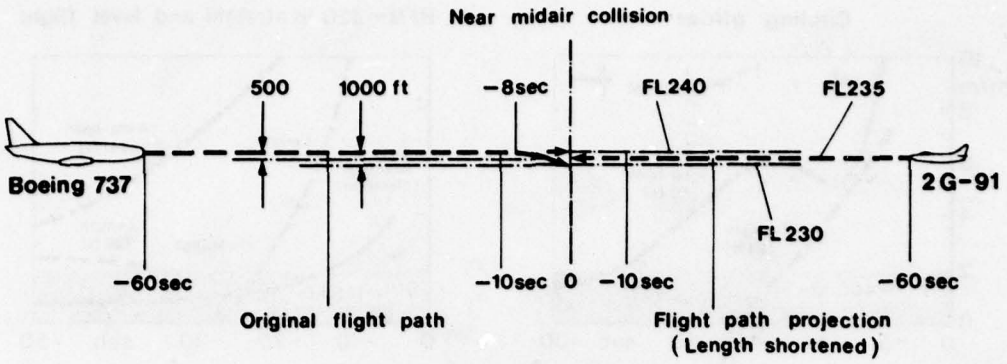
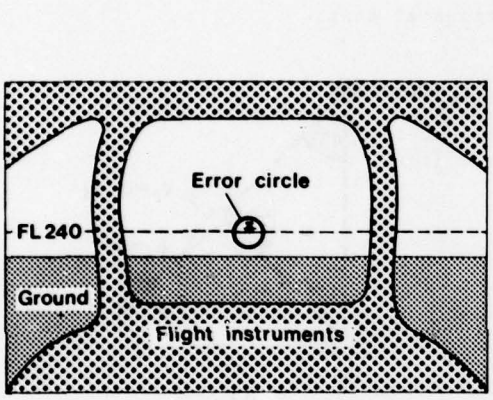
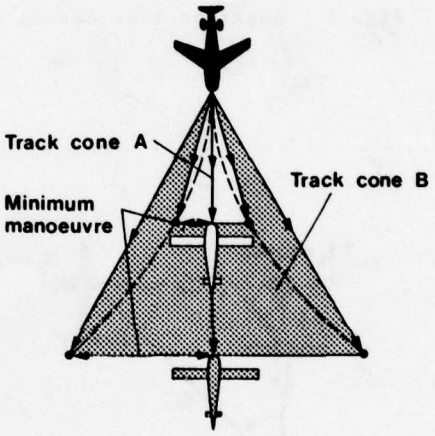


Fig. 7 Near midair collision between 2 G-91 and a rapidly descending Boeing 737. (See also Fig. 10)



Observation error in the cockpit of a light aircraft



Possible tracks of a jet aircraft.

Fig. 8 Incorrect observation of an apparent track.

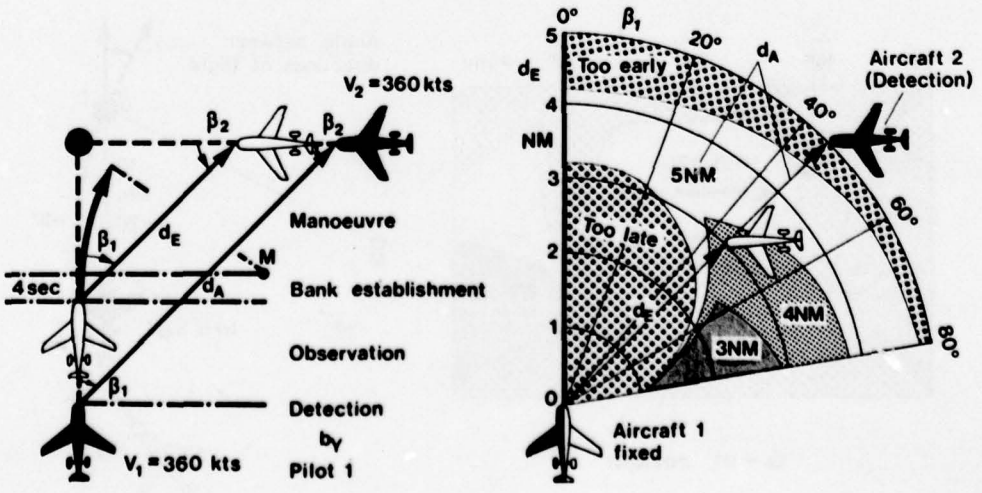


Fig. 9 Usable area for an evasive right turn. Observation threshold $\Delta\beta_1$ = 10 mrad (10 mm / 1 m). Bank angle ϕ_1 = 25 degrees, bank establishment 4 sec. Minimum distance between aircraft 0.1 NM.

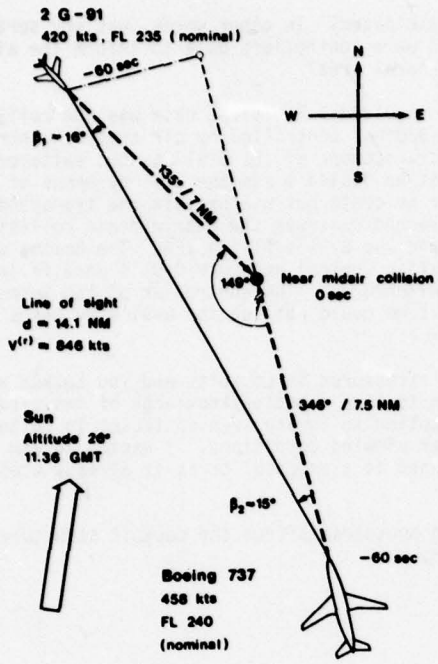


Fig. 10 Near Midair Collision
2 G-91 / Boeing 737.

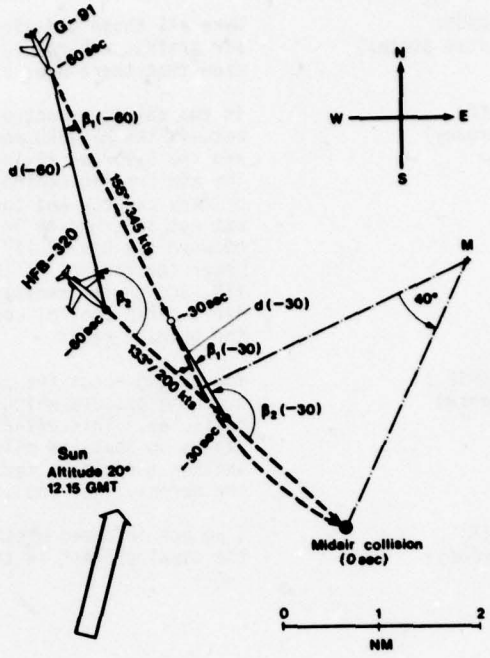


Fig. 11 Midair Collision
G-91 / HFB 320.

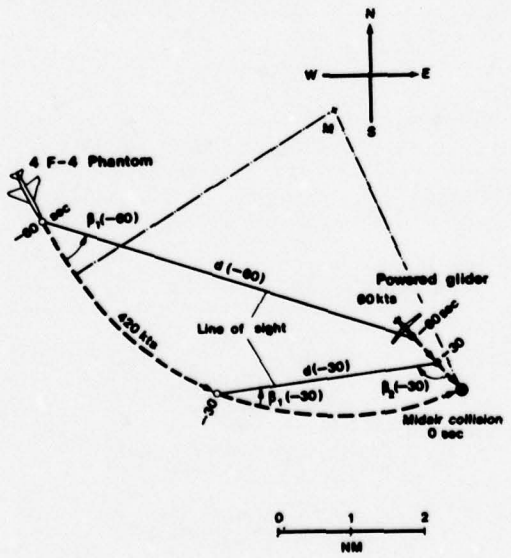


Fig. 12 Midair Collision
4 F-4 Phantom / Powered Glider.

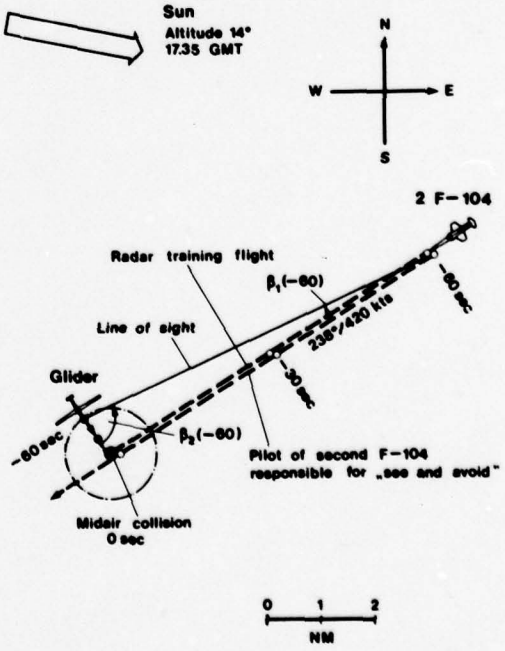


Fig. 13 Midair Collision
2 F-104 / Glider.
(Mirage / Glider similar)

DISCUSSION

JOHNSON: (United States)
Were all these mid-air collisions unanticipated? In other words, was any sort of air traffic control agency involved and were controllers able to inform the aircrew that there were aircraft in the general area?

WEBER: (Germany)
In two cases, a controlling agency was involved. The first case was the collision between the HFE-320 and G-91. The HFE-320 was controlled by air traffic control and the G-91 was flying VFR. But the transponder of the G-91 was not switched on. The air traffic controller reported that he couldn't see the G-91 by means of his primary radar. And the secondary radar he could not use because the transponder was not switched on in the G-91. The second case was the near mid-air collision between the Boeing 737 at 24,000 feet and two G-91's flying VFR. The Boeing was under the control of the German Air Traffic Control and both G-91's were flying VFR, and their transponders were not switched on. The controller of the German Air Traffic Control Center reported that he could not see the G-91's by means of the primary radar.

PERDRIEL: (France)
You talked about the problem of opaque structures in cockpits and you talked about a cinema process which made it possible to have a better knowledge of the visual obstacles. This offers designers the option to locate such obstacles in better places so that the pilot may have better viewing conditions. I wanted to ask you whether the cinema technique you mentioned is a proposal or is it already used in the aeronautical industry?

WEBER: (Germany)
I am not informed whether or not taking photographs from the cockpit structure is the usual process in the German industry.

PILOT INCAPACITY IN FLIGHT

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SUMMARY

Incapacity of any crew member of an aeroplane can have serious implications for the aircraft and occupants. However, in the case of the pilot, the outcome can be disastrous.

In transport aircraft the hazards of pilot incapacity are reduced by carrying more than one pilot. For the majority of the flight there is sufficient time to remove the incapacitated crew member from the controls and retain control of the aircraft. However, under certain critical conditions, (for instance at low level), this may not be possible; moreover, the pilot may slump forward and restrict the controls.

Various restraint systems were devised and these were considered in turn to determine whether the hazard presented by an incapacitated pilot could be avoided by their use. In addition, the incidence of pilot incapacitation was reviewed in both military and civil aircraft and the risk compared with other flight hazards.

It was concluded that the risk of pilot incapacitation is low and that the installation of novel complex restraint systems was not justified. The problem can be solved using existing restraint systems in transport type aircraft with certain changes to established cockpit procedures. Furthermore, it is recommended that aircrew training should include instruction on the hazards of both sudden and subtle incapacitation and the methods of detecting it in others.

INTRODUCTION

Incapacity of any crew member of an aeroplane can have serious implications for the aircraft and occupants. However, in the case of the pilot, the outcome can be disastrous.

In transport aircraft the hazards of the incapacity of one pilot are simply overcome by carrying more than one pilot. For most of the flight; that is, during the cruise, there is usually sufficient time to remove the suddenly incapacitated pilot from the controls and continue the flight. Under certain critical conditions near the ground, however, it may be impossible to do this. Furthermore, the incapacitated pilot may slump forward and foul or restrict the controls so much that the other pilot cannot control the aircraft safely. Special procedures should be considered to obviate this risk, and at the request of the Civil Aviation Authority the Royal Air Force Institute of Aviation Medicine has investigated possible methods to overcome it. This study was confined to transport aircraft, and improved techniques for the detection of impending incapacitation were not considered. This paper describes the investigation and the recommendations that arose from it.

Before the various methods of restraint are described and their individual merits discussed, the risk itself must be addressed.

Incapacitation of a crew member in flight is a rare event. Lane (1971) observed that the probability of incapacitation is one case in 8×10^5 flight sectors. Furthermore, the chances of an accident following an incapacitation is low; Lane (1971) calculated the probability to be 0.074.

Bennett (1972) reported the results of a survey of incapacitation affecting 5000 pilots. The most common causes in order were nausea, vomiting and abdominal pain (1042 cases), acute diarrhoea (450), earache and blocked ears (153), faintness (120), headache and "migraine" (118) and vertigo/disorientation (68). Forty five per cent considered that incapacitation had prejudiced the safety of the flight and 56% considered that there would have been potential threat to safety if adverse operational factors had coincided with the incapacitation. However, none of these reported incidents had caused an accident.

Rayman (1973) described an analysis of in-flight incapacitation in the USAF. In a five year period, of a total of 89 incidents there were 36 cases of loss of consciousness, 26 of disorientation, 19 of hypoxia, 4 of fumes in the cockpit, and 1 each of air sickness, hyperventilation, coronary disease and otitis media. Twenty four of the 89 resulted in fatalities in single seat aircraft. However, in 54 of the 89 incidents, the presence of another pilot (in multi seat aircraft) prevented accidents.

Raboutet and Raboutet (1975) reported on incapacity in French Civil Aviation. They described 17 cases on 24 years; 13 incidents were cardiac in origin and 11 were caused by myocardial infarcts. However, none of these cases caused any accidents.

Cardiac emergencies in flight were also reviewed by Rayman (1974) who listed 2 confirmed and 5 suspected cases of in-flight myocardial infarction in a 10 year period in the USAF. In an attempt to determine whether some of the 199 unexplained accidents in that period could have been cardiac emergencies, Rayman, after investigation, excluded 144 leaving only 55 that could have been caused by in-flight incapacitation. However, in those 55, there were no radio calls or ejections and he concluded that mechanical malfunction or pilot error were more likely than incapacitation.

In the US general aviation Fleet, Reighard and Mohler (1967) reported 37 fatal accidents arising from cardio-vascular incapacitation in the period 1959-1965. This represents an average of 6 cases per year and the incidence has remained relatively constant. Of the 1404 general aviation fatal accidents that occurred in the US in 1974 and 1975 only 13 (0.93%) were caused by cardio-vascular incapacitation. The mean age of the pilots concerned was 52 (range 33-68). However, 53% of 445 general aviation pilot fatalities showed signs of atherosclerosis at post mortem (Mohler and Booze, 1978).

In another study, Underwood - Ground (1978) found that 16% of military aircrew (mean age 29 years) had significant coronary atherosclerosis at post mortem while 24% of professional pilots (mean age 40 years) and 23% of private pilots (mean age 37 years) showed similar disease. A control group (mean age 37 years) had an incidence of 18%. There are no statistically significant differences either between any of these rates or from those of a similar study reported in 1963. These figures suggest that pilots do not suffer more from coronary disease than other groups and that the incidence remains constant.

In the civil transportation field, the incidence of in-flight incapacitation is no greater than that experienced by military aircrew, but the larger number of passengers carried per aircraft results in a greater number of fatalities per incapacitation. Buley (1969) reported that in the years 1961-68 there were 5 cases of crew incapacitation in civil aircraft which caused accidents involving a total of 147 deaths. In the same period there were 12 pilot fatalities in flight which did not cause accidents.

In the period 1961-72, only 9 cases of crew fatality in-flight in transport aircraft have been reported world wide (Flight, 1975) and of these 6 caused a total of 339 deaths to other occupants of the aircraft (Table 1).

In the same period (1961-72) there was a total of 463 reported accidents in scheduled air services and in these 12,794 persons died (Flight, 1975). This produces an average of 0.58 fatalities per 10^8 passenger miles for a total of 2.2×10^{12} passenger miles in those twelve years. In the same period, the deaths attributable to all possible cases of crew incapacitation were 339 i.e. 2.6% of the total.

In order to put these figures in perspective, over the last 6 years (1972-77) there have been 169 instances of air piracy and hijacking (Flight, 1978). In these, 877 passengers and crew have been killed out of a total of 10,096 fatalities from all causes. Thus, 8.7% of all fatalities were due to hijacking, which is more than triple that due to crew incapacitation for the earlier period. Air piracy has overtaken crew incapacity as a cause of death in air transport.

This brief survey of the literature shows that in transport aircraft, crew incapacity is uncommon, and accidents caused by crew incapacity are very rare, but in those few accidents many fatalities can occur. Clearly, any device or procedure that could limit such events is worth exploring.

A requirement can be stated for a system to preclude involuntary movement of either pilot which could hazard the aircraft. Movement of the control column, rudder pedals, engine controls etc must not be restricted, nor must they be operated inadvertently by the incapacitated man, especially when the aircraft is near the ground, as in the landing and take off phases of flight.

OPTIONS

In order to fulfil the requirement, many methods could be considered and some of these are described in increasing order of complexity.

(a) Four point restraint harness

A four point restraint harness consisting of 2 lap and 2 straps over the shoulder united at a central quick release fitting (QRF), if worn, would prevent inadvertent movement of the torso of an incapacitated crew member. (A pair of lap straps would not be sufficient.)

(b) Four point restraint with inertia reel

The four point harness suffers from the disadvantage that the restraint prevents the crew member from voluntary forward movement to reach distant controls and is thus unacceptable for most of the time in flight. To overcome this, the shoulder straps could be fitted with an inertia reel which allows the shoulder straps to extend under the action of a spring. The inertia reel incorporates a lock so that if the acceleration and/or velocity of the strap or the acceleration of the reel itself is excessive, as in crash impact, the reel locks and prevents the shoulder straps extending. The inertia lock is usually set to respond to accelerations greater than $+1.5G_x$. The involuntary movement of the torso of an incapacitated pilot is unlikely to accelerate the shoulder strap to exceed that level, thus the inertia lock mechanism alone would not meet the requirement. A study of simulated incapacitation by Harper et al (1969) found that the inertia reel was completely ineffective in restraining the torso of an incapacitated pilot. However, for the critical stages of flight, e.g. below 1000' AGL, the inertia reel could be locked. Inertia reels can also be locked at will in an intermediate position.

(c) Increased shoulder strap tension

If the locked shoulder straps proved too restrictive, the reel device could be altered so that a greater spring retracting force or increased friction could be applied at will to the shoulder straps so that voluntary forward movements would be possible (at some effort), but involuntary movement would be prevented. Bice (1971) estimated that 50N (10 lbf) would be sufficient and Reader (1976) showed that 53N (12 lbf) would restrain the involuntary torso movement of all aircrew but would not inhibit voluntary movement. In practice, the increased restraint would be selected at critical phases, and released in cruising flight. There is little danger of the increased restraint being selected inadvertently, as the crew would soon become aware of it. However, the selection does require action on the part of the crew and could easily be overlooked.

(d) Automatic shoulder strap tension

If automatic control of this increased spring tension were required, for example to ensure that the extra restraint was applied whenever the aircraft was below 1000', it could be arranged that the undercarriage, landing flap or some other aircraft system would, when selected, automatically increase the shoulder tension. This would remove the necessity for the crew member to select the appropriate setting,

but would introduce the hazard of malfunction of the relevant aircraft system miscontrolling the shoulder strap system.

(e) Retractors

A powered system to move the incapacitated crew member physically would also meet the requirement but with more attendant complications. The force could be applied by means of a restraint harness tensioned by springs, compressed gas or pyrotechnic devices. All these systems would require initiation by another crew member when incapacitation was detected. To ensure that the restraint harness was not displaced by the force of retraction, a negative G or tie down strap from the central QRF to the seat would be required.

(f) Moving seats

An alternative method utilizing similar principles would be to move the crew member's seat away from the controls. This would also facilitate emergency treatment, but would be more complex to install.

(g) Airbags

Another method of applying forces to the incapacitated crew member would be by means of air bags stowed in the adjacent cockpit console and inflated by compressed gas. Detailed attention to design would be essential as inadvertent actuation would be as disastrous as incapacitation, and the action of the inflating bag could cause more restriction to controls than an incapacitated crewman.

(h) Other systems

The arm rests of the crew seat could be powered to retract and grasp the pilot's torso, but the forces required could be injurious. It would be disastrous if the system operated inadvertently and the system could fail to meet the requirement if it were activated after the crew member had moved beyond the limit of the movement of the arm rests. Net restraints could be stowed in the appropriate cockpit consoles and deployed to restrain the incapacitated crew member. Again the system would be complex, the risk of inadvertent actuation high and the crewman could move beyond the net's sphere of influence.

It is difficult to conceive of a realistic system whereby the last four methods could be activated automatically as the incapacitation arose. Sensors demanding input from the conscious pilot to inhibit activation would either require additional action on his part or have an unacceptably long time delay before activation.

DISCUSSION

As fatalities caused by pilot incapacitation in transport aircraft are so rare, the more elaborate methods described above could never be judged cost-effective.

Only methods involving systems already installed in current transport aircraft could be used, but changes in crew procedures or training could be considered.

These considerations champion the simpler systems presented earlier. A four point restraint harness system incorporating a lockable inertia reel is installed in most, if not all, crew seats. Utilization of this system would involve no installation costs. If both pilots physically locked their inertia reels and tensioned their shoulder straps (if adjustment is provided) at take-off and when flying below 1000', this would remove almost completely the risk of physical obstruction of the controls. Below 1000' aircraft would be established in the landing pattern and the crew would be unlikely to need to move significantly. Each pilot would have to be responsible for checking the locking action of the other pilot and checks, as appropriate, would have to be introduced into crew procedures.

It is arguable that altering the inertia reels in aircraft to exert the higher retraction force as discussed under option (c) is likely to be cost effective. If the shoulder harness were always fitted, adjusted and locked when flying below 1000' or on take-off, the risk to passengers from crew incapacitation would be greatly reduced, as fouling of the controls would be impossible. Therefore, option (c) would offer little improvement in flight safety but would relieve the crew of the need to unlock their inertia reels to lean forward below 1000'; rather more a convenience than a definite requirement.

The cost of altering all inertia reels in transport aircraft would be high and unlikely to be justified by the improvement in convenience to the crew. However, in aircraft where there is a need to move forward repeatedly to reach inaccessible controls on the approach or on take-off, the convenience of option (c) could be worthwhile.

It would be desirable if all crews were made more aware of the dangers inherent in pilot incapacity. Special training in simulators or with the use of films could demonstrate the brief time available for crews to recognize incapacitation and take the appropriate action. The task of the crew could be widened to include positive checks on physical and mental state of fellow crew members. Incapacitation is not always a sudden catastrophic event; nor is it, in itself, easily recognisable. Often it arises as a subtle change and this could well have occurred in the last accident listed in Table 1.

In addition to the many procedures that have to be completed during the approach, landing and take-off phases of flight, a formal verbal check amongst all crew members might be used to detect early symptoms which could lead to incapacity, and so prevent some of the hazards of sudden incapacitation.

RECOMMENDATIONS

As a result of this study, the following recommendations are presented:

(1) Below 1000' AGL and on take-off, all pilots of civil transport aircraft should wear lap and shoulder harness, correctly fitted and adjusted. The inertia reel device, if fitted, should be set to the locked position.

(2) Checks should be introduced into crew procedures at the appropriate phase of flight to ensure that this action is not overlooked.

(3) The training of aircrew should include instruction on the hazards both of sudden and of subtle incapacitation in flight, and the methods of detecting it in others. The action to be taken if it occurs should be practised.

(4) Consideration should be given to the introduction of a formal verbal check at appropriate stages to detect symptoms which could be hazardous at later and more critical phases of flight.

(5) Procedures to avoid the more likely types of incapacity, e.g. gastrointestinal disorders, disorientation, barotrauma etc. should become part of the regular continuation training of all airline crews.

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TABLE 1. FATAL CREW INCAPACITATION (PRIME CAUSE OR POSSIBLE)

Date	Aircraft	Carrier	Location	Type of Flight	Fatalities		Occupants		Remarks
					Crew	Pax	Crew	Pax	
May 24 1961	DC-4 (VH-TAA)	TAA	Queens-land	Freight	2	-	2	-	Heart attack
Dec 14 1962	L-1094H (N6913C)	Flying Tigers	Holly-wood	Freight	3	2	3	2	Heart attack
Jan 15 1966	DC-4	-	Columbia	Pax	2	56	2	64	Heart attack after take-off
Jan 28 1966	CV-440 (D-ACAT)	Luft-hansa	Bremen	Pax	4	42	4	42	Stall at low level, possibly after pilot incapacitation.
Apr 22 1966	Electra	Ameri-can Flyers	Ardmore Oklahoma	Pax	5	78	5	93	Heart attack
Aug 5 1966	DC-8 (PH-DCD)	KLM	Tokyo	Pax	1	0	11	53	Captain died during approach. Co-pilot landed aircraft
Dec 8 1966	CV-440	-	Oslo	No pax	1	0	3	0	Co-pilot collapsed onto controls at 50' on approach
Mar 13 1967	Viscount (ZS-CVA)	South African	East London	Pax	5	20	5	20	Possible heart attack (crashed into sea)
Jun 18 1972	*Trident* (G-ARPI)	*BEA*	*Staines*	*Pax*	9	109	9	109	Heart condition is listed as "underlying cause"

Pax = Passengers

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GEOGRAPHICAL DISORIENTATION AND FLIGHT SAFETY

by

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SUMMARY

Geographical orientation is the psychological process whereby the aircraft pilot maintains an awareness of his position in relation to geographical points. The antithesis, geographical disorientation is a common occurrence in flight, the consequences of which vary in seriousness from delays in reaching destinations to aborted flights, empty fuel tanks and catastrophic collisions with high ground. Man has limited guidance mechanisms and relies primarily on vision and memory for navigation, supplemented in flight by aids such as compasses, radios and maps, providing information that cannot be sensed directly. There is no good evidence for an innate sense of direction in humans. Inadequate and inaccurate visual information, errors of interpretation, false hypotheses and expectancy, and system-induced errors, such as poor pilot-controller communication, may lead to a state of geographical disorientation. Case studies of individual accidents and incidents have indicated that in many respects geographical disorientation in flight can be as insidious, compelling and as stressful as spatial disorientation. Geographical disorientation may precipitate spatial disorientation and vice versa. In severe cases, where the realisation of the error is sudden, there is evidence of panic and disorganisation of behaviour leading to loss of control of the aircraft. Preventative actions that may reduce the incidence of geographical disorientation include better training and pre-flight planning, improved awareness of the problem, elimination of system induced errors, and improved navigation aids, including maps and charts.

INTRODUCTION

Geographic disorientation has been cited as a contributory factor in two recent "pilot error" mishaps involving RAF aircraft investigated by psychologists from the RAF Institute of Aviation Medicine. One of these mishaps resulted in loss of the aircraft with both the pilot and navigator ejecting safely. The other ended in a safely executed emergency landing with the aircraft on its last reserves of fuel.

Case Study No 1

The pilot, an experienced instructor, was acting as a target for air-to-air low-level cine gunnery practice by students over the Bristol Channel. The weather was good with visibility at 35 kms and a 15 kt wind from the north west. While flying a race-track pattern he overcompensated for the wind effect and instead of drifting towards the Welsh coast he unknowingly moved slowly upwind towards Ireland. Eventually he saw a coastline which he assumed to be St Annes Head in SW Wales but which was in fact the SE tip of Ireland. On reaching the fuel state for return to base he received a steer of 100° for recovery which he acknowledged correctly. He then turned onto a heading of 010° rather than 100°, towards his base in relation to the distant coastline, which he still assumed to be SW Wales. On closing on the headland he realised that he was geographically disorientated and called for assistance. When told he was over southern Ireland, he turned onto the correct heading for base, jettisoned his external fuel tanks, and when within range because of a shortage of fuel he flamed out his engine and glided towards his destination. He then relit the engine and carried out a glide landing with the engine at idle.

Case Study No 2

On their second crew solo flight, a pre-instrument rating test sortie, the crew experienced a single, followed by a double, aircraft utilities hydraulic failure. While carrying out emergency drills for a GCA recovery on the down-wind leg of a right-hand race-track pattern, the aircraft's speed dropped unnoticed to below 170 knots. Warned by the navigator, the pilot increased speed in time to prevent a stall. During this incident, and unknown to both crew, the aircraft changed heading from 070° to approximately 110-120° magnetic, taking the aircraft across and south of the runway centre line. At the end of the down-wind leg, the pilot called Air Traffic for the heading of his final turn onto the runway centre line. Expecting to be told to turn right, he was told to turn left onto a heading of 250°. The pilot asked for confirmation that he needed to turn left onto 250°. This was confirmed and the pilot acknowledged that he had received confirmation. Immediately after his acknowledgement, the aircraft was observed on radar to make a tight left turn. Thereafter, the aircraft began to lose height with uncontrollable roll and yaw to the left. The pilot was unable to regain control and at 3,000 ft both aircrew ejected safely and were picked up by coastguard. The aircraft crashed into the sea. On questioning after the accident, the pilot did not clearly recall his exchange with Air Traffic nor did he realise his geographical disorientation. He claimed that he had tried to turn right onto the runway centre line.

Both of these mishaps involved pilots who had misinterpreted their positions. In the first case study, the magnitude of the error was great, approximately 70 kilometres, but the pilot eventually realised his error and made a successful recovery. In the second case, the error was smaller, less than 20 kilometres, and the pilot did not recall being disorientated, but the incident was followed by a nearly fatal crash. A number of specific questions need to be answered. Firstly, why did the experienced instructor acknowledge the steer of 100° and then turn onto a heading of 010°? Secondly, why did the inexperienced pilot claim that he had tried to turn right, after he had acknowledged the confirmation that he needed to turn left? Thirdly, could the confusion caused by doubt about the aircraft's position have led to the final loss of

control of the aircraft? More generally, how common is geographical disorientation, what is its relationship with spatial disorientation, and can anything be done to prevent it? To answer these questions we need to examine the process by studying its known causes and consequences.

TOWARDS A DEFINITION OF GEOGRAPHICAL DISORIENTATION

In the research literature, geographical orientation is considered to be a special form of spatial orientation. According to Howard & Templeton (1), the study of human spatial orientation concerns those aspects of human behaviour which are determined by the angular position of the body (or head) in relation to any stable external reference system. They include "geographical orientation of the body" in an eight part classification of human orientation behaviour (Table 1). Positions, objects and directions on the earth's surface constitute the stable external reference system for geographical orientation. Rotation about a person's own body axis changes his geographical orientation in relation to objects on the earth's surface. It may also be changed by linear movements, depending on the direction of the movement and on the significance of the distance moved.

TABLE 1 - A CLASSIFICATION OF HUMAN ORIENTATION BEHAVIOUR*

1. Judging angles.
2. Judging direction (e.g. inclination, compass direction)
3. Setting a point to eye level (horizontal).
4. Gravitational orientation of the body.
5. GEOGRAPHICAL ORIENTATION OF THE BODY
6. Egocentric orientation - setting a line parallel with the body axis.
7. Egocentric orientation - setting a point to the median plane.
8. Relative orientation of body parts.

* Adapted from Howard, I.P. and Templeton, W.B. (1).

In terms of skills and abilities, Lichte et al (2) use the term "geographic orientation" to mean the ability to maintain a sense of direction, a sense of one's position in the geographical environment and a sense of the pattern of the physical and cultural features of the surrounding world. Two classes of geographical orientation skills can be distinguished, namely:

1. Tasks which involve the ability to maintain a sense of direction when moving about in strange surroundings, without prior intellectual knowledge of the spatial position of particular objects, such as the ability to walk in a straight line.

2. Tasks which do require intellectual knowledge about spatial positions such as drawing a map, pointing north or travelling to a destination.

Each of these tasks can be analysed in terms of the role of visual, vestibular and kinaesthetic factors, personality and memory.

One can also distinguish between geographical orientation in relation to directly sensed objects and in relation to objects outside the immediately sensory environment. Gibson (3), for example, has differentiated two types of locomotion:

1. Locomotion oriented directly toward the goal guided by the sight of the goal object.

2. The act of going to an object or space beyond the range of vision.

In aircraft navigation, geographical orientation is mostly concerned with the latter. Most writers have preferred to think of geographical orientation as an integrated process in which the immediate visual world is extended, perhaps within a topographical schema or "mental map", to include positions and objects that cannot and may never be seen. Both Lichte et al (2) and McGrath (4) accepted the following summary of the process of geographical orientation:

"Oriented persons start with something given (through information, perception, etc) and immediately use this to apply imaginary co-ordinates to the perceived field; this perceived field is then extended in the imagination to include a larger area (as large as necessary at the moment). Thereafter the oriented person maintains his sense of direction and his geographical orientation by (a) being continuously aware of his movements and position with respect to the geographical co-ordinates, (b) being aware of the spatial relations of newly perceived regions to the familiar regions, or (c) some combination of both. He becomes so highly practiced in this skill that very little attention is given to the process and often he is hardly aware of it."

For the present purposes, geographical orientation will be treated as the process whereby the aircraft pilot maintains an awareness of his position and direction in relation to aspects of both the immediate (e.g. obstructions, relief) and distant (e.g. waypoints, destinations) geographical environment. The process of maintaining geographical orientation in flight involves skills and abilities and the performance of tasks, some of which may require constant monitoring, and others which may be sufficiently well-practiced to be performed automatically without conscious attention. The antithesis, geographical disorientation, will be treated as the process whereby the pilot loses his sense of position and direction in relation to important features of the geographical environment. A total loss of geographical orientation is unlikely to occur under visual flight rules (VFR) meteorological conditions as the pilot should always be aware of his position in relation to the immediate topography through information directly available to the senses. On

the other hand, under instrument flight rules (IFR) conditions, the pilot may remain orientated towards compass directions and to his destination without knowing his exact position in relation to the immediate topography or to obstacles that are a hazard to flight safety.

ACCIDENT STATISTICS

Navigation errors associated with geographical disorientation always reduce operational efficiency and occasionally cause serious accidents. In 1975 there were 661 fatal accidents and 3,496 non-fatal accidents in US General Aviation (5). A lost/disorientated pilot was cited as a cause of 43 of these accidents and as a contributory factor in a further 20. A further 189 accidents were caused by pilots who became lost because they continued VFR into IFR weather conditions. In total, geographical disorientation was a contributory cause in 252 (6.1%) of accidents. During the same period, "spatial disorientation" (i.e. gravitational disorientation), as distinct from geographical disorientation, was cited as causing 109 accidents. It was never cited as a contributory factor.

Falkenberg (6) reported an analysis of 154 pilot error accidents within the German Federal Armed Forces for the years 1967-1970. Misinterpretation of geographical position, one of 41 error categories distinguished, was identified as contributing to 4 (2.5%) of the accidents. "Misinterpretation of attitude" was cited as a factor in 20 (12.3%) of the accidents. The most frequently cited cause, "false incomplete normal procedure", was responsible for 36 (22.2%) of the accidents.

Cases of geographical disorientation are sometimes included in studies of spatial disorientation. A US Army study of 1520 pilot-error helicopter mishaps (accidents and incidents) in the period 1971-72 and 452 pilot-error fixed-wing mishaps in the period 1969-71 is reported by Ricketson et al (7). Here, geographical disorientation was treated in the same category - "disorientation/vertigo" - as other forms of spatial disorientation. "Disorientation/vertigo" was cited as a factor in 75 helicopter mishaps and 11 fixed-wing mishaps. "Navigation error", a separate category, occurred in 20 helicopter mishaps and 7 fixed-wing mishaps. Disorientation/vertigo accounted for 12% of the common factor variance and involved 6% of the helicopter cases. In fixed-wing mishaps, disorientation/vertigo accounted for 10% of the common factor variance and 6% of the individual cases.

Further quantitative data on the occurrence of disorientation and vertigo (false sensations of rotation) were obtained by Clark and Graybiel (8) from interviews with 137 jet pilots. Almost all had experienced vertigo caused by confusion of attitude and motion, but 47% also reported experiencing geographical disorientation during incidents of vertigo. Here, geographical disorientation was treated as a by-product of vertigo.

The most extensive analysis of geographical disorientation statistics is reported by McGrath and Borden (9). In the 5 year period 1958-62, the US Armed Forces lost 82 aircraft destroyed and had at least 122 aircrew killed in accidents caused by geographical disorientation (Table 2).

TABLE 2 - US MILITARY ACCIDENTS CAUSED BY GEOGRAPHICAL DISORIENTATION (1958-62)*

	Aircraft Destroyed	Men Killed
Army	12	8
Navy	26	57
Air Force	44	57
Total	82	122

* Adapted from: McGrath & Borden (9).

Civilian statistics for the 3 year period 1959-61 showed a total of 343 accidents with 41 fatalities due to geographical disorientation under VFR conditions. A further 613 accidents and 365 fatalities resulted from civilian pilots who became lost because they continued VFR into IFR weather conditions. In total, geographical disorientation was a contributory cause of 6.7% of all general aviation accidents in the 1959-61 period. Analysis of 118 of military aircraft accidents that resulted from geographical disorientation revealed that 52% resulted in collision with terrain, 31% caused the aircraft to be abandoned and 12% forced an emergency landing.

Aircraft collisions with terrain or other obstacles are usually catastrophic. When geographical disorientation is involved, often the pilot is unaware of his navigation error, believing his position to be elsewhere. IATA statistics for the period 1963-66 showed that 34.5% of all passenger deaths were caused by accidents involving high ground. Approximately 150 accidents occurred in each of these years, of which approximately 9% were collisions with high ground that had resulted at least in part from errors in navigation. A detailed study of eleven of the high ground accidents involving navigation error during this period indicated that the envelopment of the ground in cloud was the main common factor and three were due to continuance of VFR into IFR weather conditions (10). The 1975 US General Aviation accident statistics show that "Terrain-High Obstructions" was the most frequently cited cause or related factor in fatal accidents (15.16%). Collisions with the ground (or water) in which the aircraft was in controlled flight accounted for 212 (4.9%) of all accidents (5). This comparatively, new accident category, known as Controlled Flight into Terrain (CFIT), implies an unawareness of the aircrew of the impending collision and hence some degree of geographical disorientation (11).

Similar conclusions can be drawn about accidents involving collisions with wires. During the period 1969-74, 104 wire strikes were recorded in the UK involving civilian aircraft. Approximately 20% of these

accidents were fatal. Between 1964 and 1972 helicopters of the British Army Air Corps recorded 56 wire strike accidents of which approximately 10% were fatal. In wire strikes, as in collisions with high ground, failure to anticipate and avoid obstructions are indicative of unawareness of the location of the obstacles and hence inadequate geographical orientation in relation to these features.

Geographical disorientation does not always result in aircraft accidents and most non-serious occurrences are unrecorded. Some indication of the high frequency with which civilian aircraft become lost can be gained from Flight Assist Reports. Re-orientation by calling air traffic control for assistance accounted for 88% of FAA Flight Assist Reports in 1962. McGrath and Borden (9) suggest that this is probably a conservative estimate as flight assists for lost pilots were so commonplace that up to 50% went unrecorded. In order to assess the full extent of the problem in military operations, McGrath and Borden (9) examined the records of 959 low altitude attack training missions conducted under visual flight rules. Analysis showed that 10% of the missions failed completely because the pilots got lost and 17% involved disorientation and subsequent recovery, finally arriving late at the destination. Of the 126 pilots who had flown 6 or more missions, 80% got lost on at least one mission and 50% became geographically disorientated on at least 23% of their missions. In other words, there were large individual differences, but the problem was a general one and not confined to a small number of disorientation-prone aircrew.

Analysis of trends in geographical disorientation statistics are complicated by differences in classifications and the inadequate way in which occurrences have been recorded. One would anticipate that the proliferation of navigation aids in modern aircraft and the improvement of area navigation systems should have reduced the incidence of geographical disorientation, at least among civilian passenger transport and military aviation. The slight reduction in the US general aviation accident figures between the 1959-61 period and 1975 provides only scant support for this hypothesis (Table 3). Unfortunately, McGrath and Borden (9) only report absolute numbers of US military accidents for the 1958-62 period and thus comparisons with the FRG military data reported by Falkenberg (6) are meaningless. On the other hand, Ruffell-Smith's data (10) on the frequency of high ground collisions in 1963-66 (9%) is probably comparable with the NTSB CFIT figure for 1977 (4.94%), indicating a slight reduction in the frequency of accidents but not necessarily in the number of fatalities.

TABLE 3 - ACCIDENTS DUE TO GEOGRAPHICAL AND GRAVITATIONAL DISORIENTATION

	Geographical Disorientation	Gravitational Disorientation	N
US General Aviation All accidents. 1975 NTSB statistics	252 (6.1%)	109 (2.6%)	4,157
US General Aviation All accidents. 1959-61 From: McGrath & Borden (1963)	856 (6.7%)	-	12,776
German Federal Armed Forces Pilot-error accidents. 1967-70 From: Falkenberg (1973)	4 (2.5%)	20 (12.3%)	154

Few useful conclusions can be drawn from this analysis of accident statistics. The information comes from a variety of sources in the guise of numerous classifications including CFIT statistics, data on "spatial disorientation", navigation errors, VFR-IFR transition problems and ATC Flight Assist Reports. Taken together, they indicate that geographical disorientation is probably still a common occurrence in flight, that it is a more serious problem in some aircraft operations than in others, for instance in low altitude attack training and helicopter nap-of-the earth flight, that most occurrences are soon recognised and present only a temporary problem soon resolved for instance, by calling for an ATC flight assist, and that a few occurrences remain undetected by the aircrew and result in collisions with obstacles and high ground, usually with catastrophic consequences. More useful conclusions could be drawn from detailed studies of data on specific aircraft operations, such as McGrath and Borden's (9) investigation of low altitude training records, but inevitably the results are difficult to generalise to other roles.

RESEARCH ON GEOGRAPHICAL ORIENTATION

The Development of Geographical Orientation Ability

Interest in the process of geographical orientation in humans dates back to the early 1900s. The first experiments were mostly concerned with children, on whether or not a sense of direction is innate and on how geographical orientation abilities develop and should be taught (Lichte et al (2)). There is no good evidence for a special "magnetic" sense of direction in humans. Remarkable feats of navigation have been reported in primitive societies but these can all be accounted for by the use of visual cues, some quite subtle, and by information stored in memory, without implicating a special sense e.g. (12). This does not mean that there are no inherited differences in orientation aptitude. Malán (13) found that identical twins were more alike in their geographical orientation ability than fraternal twins. He concluded that the ability to orient is to some extent inherited, meaning that some people are more readily able to learn to orient themselves than others. It could also mean that twins are more likely to be taught geographical orientation skills in the same way.

Mental Maps

Studies of geographical orientation in humans have mostly been concerned with the ability to point in a given direction and draw maps e.g. (14). The study of mental maps or topographical schema reproduced by drawing has continued to interest some researchers, particularly planners e.g. (15). The major weakness with this work concerns the relationship between the ability to draw maps and the ability to navigate and maintain geographical orientation. One can reason that the better the mental map established say in pre-flight planning, the easier and more accurate the subsequent navigation, but this relationship has not been tested empirically. It would account for the reduced probability of geographical disorientation in familiar terrain. Reproducing mental maps may involve a completely different set of skills and abilities than maintaining geographical orientation in flight. The most significant conclusion from these studies is that there are consistent individual differences in orientation ability measured in this way.

Skills and Abilities

Attempts to identify the modifiable skills and stable perceptual attributes involved in geographical orientation have met with mixed success. Whereas for 75 college students performance on a pointing task correlated highly (0.51) with the spatial visualisation test in the Guildford-Zimmerman Aptitude Survey, Clarke and Malone (16) found no relationship between pointing responses and spatial visualisation or spatial orientation when 242 naval aviation cadets were subjects. Findlay et al's (17) study of the skills involved in land navigation emphasises the importance of location skills such as direction estimation and terrain visualisation from map contour lines rather than compass skills. Powers (18) also studied land navigation skills and demonstrated the value of training for improving geographical orientation performance in the field. Most of the available evidence (e.g. (19)) seems to indicate that performance on spatial tests is relatively unaffected by training and that the concepts of spatial ability - spatial pattern, spatial orientation and spatial visualisation - are reasonably well developed at an early age (e.g. (20)). A recent study by Hill and Burns (21) confirms this by showing that the ability to visualise terrain slope from contour maps was not improved by land navigation training whereas other skills less dependent on spatial ability were affected, such as object interpretation.

Studies of Navigation Performance

Studies of geographical orientation in aircraft are mostly concerned with assessing navigation performance and IP, LZ and target detection probabilities under different operational conditions with different navigation systems. A number of systematic measurements of unaided helicopter low altitude navigation performance have been reported (e.g. (22,23)). An extensive series of experiments on unaided navigation performance in simulated low altitude high speed flight are summarised by McGrath (24). These studies were mainly concerned with the effects of cartographic variables on performance, including the effects of map scale, information content, colour coding and place names. They also compared the visual utility of terrain features as checkpoints with map compilation selection rates and the apparent utility of features judged from their appearance on maps. The results consistently demonstrated the importance of map design factors for successful geographical orientation. Ruffell-Smith (10) concluded that all of the CFIT accidents he studied might have been prevented if the maps used by the crews had better terrain representation.

Most of the experiments on geographical orientation in humans have been summarised by Lichte et al (2). McGrath (4) and Howard and Templeton (1). McGrath (4) lists the following conclusions about geographical orientation that may reasonably be drawn from this research:

1. Geographical orientation is not an innate skill.
2. Geographical orientation is not mediated by some unknown sensory mechanism. Vision is the primary source of orientation information.
3. There are large individual differences in geographical orientation abilities. Gross errors made in estimating direction to distant places are rather common.
4. When the directional orientation of large groups of subjects has been studied, large constant errors have often been noted.
5. Attempts to predict individual differences in orientation by identifying measurable correlates of these differences have been generally unsuccessful.

THE ETIOLOGY OF GEOGRAPHICAL DISORIENTATION

Investigations of the etiology of geographical disorientation are often characterised by anecdotal reports of individual cases intended to indicate the types of situations some pilots have experienced e.g. (25),(9). Systematic studies of geographical disorientation are rare because the process is a subjective phenomenon and it is difficult to manipulate pre-conditions under controlled experimental conditions.

Vestibular and Kinaesthetic Cues

Howard and Templeton (1) summarised a number of studies in which attempts were made to induce geographical disorientation by blindfolding subjects and rotating them passively, with vestibular cues predominating,or actively, with both vestibular and kinaesthetic cues present. Passive rotation without kinaesthetic cues generally caused greater disorientation but the effects of variations in kinaesthetic and vestibular sensitivities were not well known. These studies have little relevance to aircraft navigation where only visual cues are likely to have a significant effect on performance.

Clinical Studies

Research on clinical disturbances of geographical orientation is also discussed by Howard and Templeton (1). The possibility that vestibular dysfunction may lead to a greater probability of geographical disorientation cannot be ruled out and needs to be checked. Slight persistent asymmetries in vestibular

"tonus" could be responsible for consistent veering tendencies that have been observed in some individuals. Lesions in the parietal lobes of the brain are most commonly implicated leading to deficiencies of spatial ability and topographical memory. Aphasia may also cause geographical disorientation when the patient has difficulty in describing locations. The conclusion that disorientation may also involve a pathological inattention to backgrounds was suggested by the finding that performance by a brain-damaged patient on a route finding task was correlated with performance on a conditional-reaction task in which the background of the stimuli had to be taken into account. The implications of these findings for normal functioning are unclear because of the general lack of theoretical discussion. Yet they do serve to underline factors that may lead to geographical disorientation in normal individuals, i.e. underdeveloped spatial ability, poor organisation and retrieval difficulties in memory for topographical information, inadequate verbal representation and naming responses, inattention, and field-dependency effects.

Operational Factors

Vision is the primary source for providing cues for geographical orientation. Operational factors that change the visual information available for unaided aircraft navigation are likely to affect geographical orientation performance. The reduction and degradation of visual cues at night and in unfavourable meteorological conditions make visual navigation more difficult and geographical disorientation highly probable unless instrument navigation procedures are followed, or position-sensing equipment is fitted (inertial, radio, doppler navigation systems) or ground mapping sensors and displays are used such as radar, infra-red, low-light TV, and image intensification goggles. Geographical disorientation during visual navigation is commonly associated with flight in military aircraft at low altitude because of the high angular velocities of terrain features, reduced field-of-view, oblique perspectives and terrain masking. The high probability of geographical disorientation in single-seat aircraft in low altitude flight at high speeds has necessitated expensive equipment fits to automate the navigation task. At present, few helicopters are fitted with navigation systems because of high costs. Low cost, high resolution, reliable systems are becoming available which are likely to be adopted in the next generation of helicopters.

Problems of navigating existing helicopters by unaided visual reference and map reading are discussed by Wright and Pauley (26) and Barnard et al (27). The latter lists sixteen different causes of geographical disorientation in low level helicopter operations, ranging from poor quality and out-of-date cartographic information to workload and attentional factors. Seventeen different techniques for reorientation were used by helicopter pilots. The most common procedure was to retrace the route to the last known position. The requirements for a systematic evaluation of future helicopter navigation systems are described by McGrath (28).

Disorientation can be experimentally induced in studies of aircraft navigation performance by varying the navigation information available to pilots such as from equipment and maps. McGrath et al (29), for instance, studied the occurrence of speed control errors in simulated low altitude flight by deliberately introducing discrepancies between the aircraft's observed position and its planned position. Under laboratory conditions, speed control inversion errors occurred more often when the pilot was attending mainly to his position than when he was attending to his elapsed time. It is not known how common speed control inversions are on operational missions. Simulators provide a safe environment for manipulating variables and inducing navigation errors that might otherwise endanger lives under operational flying conditions. However, the removal of the threat to flight safety reduces the psychological severity of the disorientation experience and affects the kinds of responses that are likely to occur. Cine-film simulation of low altitude missions restricts the pilot's control over the route flown and limits his ability to divert from the planned route. Television monitor/terrain model systems allow route variations but practical limits on the size of models mean that the pilot soon becomes familiar with the topography of the area flown. Computer-generated terrain imagery, when it becomes available, will provide the desired flexibility but it will undoubtedly sacrifice some degree of pictorial realism.

Statistical Studies

The statistical data already referred to, has identified continuance of VFR into IFR weather conditions as a major cause of geographical disorientation in general aviation and CFIT accidents. Lack of pre-flight planning is probably another main cause. McGrath and Borden (9) included inclement weather conditions as one of six major problem areas that lead to geographical disorientation in military aviation, namely:

1. Visual References. Poor selection, detection and identification of checkpoints.

2. Navigation Procedures. Inefficiency in reckoning procedures, failure to adhere to flight plan, and faulty control of the aircraft.

3. Aeronautical Charts. Chart inaccuracies, misreadings and misinterpretation of cartographic information.

4. Weather Conditions. Unfavourable winds and poor visibility.

5. Pre-flight Procedures. Inadequate or inaccurate planning.

6. Cockpit Instruments. Faulty design and positioning of instruments and malfunctions leading to misreading.

Three sets of data on the frequency of these causes of disorientation showed a consistent pattern (Table 4). Visual referencing problems - misidentifying or missing checkpoints - were always first in the problem hierarchy whereas weather conditions and pre-flight procedures played much less dominant roles. Visual referencing caused the greatest difficulty in low altitude flight where the visual field is limited in area, dynamic with high angular velocities, oblique in perspective, and masked by terrain.

TABLE 4 - CAUSES OF GEOGRAPHICAL DISORIENTATION AS INDICATED BY THREE DIFFERENT STUDIES*

	Study 1 135 Navy low-altitude training missions	Study 2 108 critical incidents in general military aviation	Study 3 Opinions of 305 US Army pilots
Visual references	46%	36%	33%
Navigation procedures	19%	23%	23%
Aeronautical charts	16%	14%	12%
Weather conditions	8%	16%	7%
Pre-flight procedures	6%	8%	16%
Cockpit instruments	5%	4%	9%

* Adapted from McGrath and Borden (9).

Individual Differences

As noted earlier, there are large individual differences in the frequency with which pilots became geographically disorientated on low altitude attack training missions. Consistent individual differences have also been found in performance on direction pointing tasks. In aircraft navigation, individual differences in proneness to geographical disorientation are most likely to be due to differences in the ways in which pilots interpret and utilise navigational information. McGrath and Borden (9) found that pilots conceive of their navigational position in different ways. A total of 56 pilots were asked to report the kind of conceptual reference they used during aircraft navigation. Many of the pilots (40%) thought of their position in relation to their aeronautical chart, i.e. moving over the map. Others, conceived of their position in relation to the real terrain below them (28%) or used a temporal reference where they are positioned as a point in time rather than in space (22%). A small minority (19%) conceived of their position in relation to a mental map. In practice, most individuals probably rely on a combination of these references. Mental maps are probably the least reliable conceptual reference for accurate navigation and over-dependence on them is likely to lead to the greatest probability of disorientation. The effects on geographical orientation of using different conceptual reference systems have not been investigated.

Automated Navigation Systems

The merits of different conceptual reference systems have implications for the design of aircraft navigation displays. In theory, the earth reference of the display should be compatible with the pilot's conceptual reference. Experimental evidence suggests that most pilots conceive of the earth as the fixed component of the navigation system. Hence, it has been argued that in map displays, the map should be the fixed component against which the aircraft should move (30). This philosophy has guided the design of altimeter and altitude displays but most map displays have a moving map-fixed aircraft symbol format to enable the "view-ahead" of the aircraft to be maximised and held constant (31). At present, in aircraft fitted with moving map displays, the pilot needs to carry a hand-held map enscribed with route plan and tactical information. This is used as the primary visual reference and the position indicated on the map display is used to confirm and update the aircraft's position in relation to the flight plan. Undoubtedly, the provision of moving map displays has significantly reduced the probability of geographical disorientation in low flying aircraft but there is no evidence that disorientation has been caused by confusions concerning the display movement relationships.

System-induced errors are an avoidable, but seemingly inevitable consequence of semi-automated navigation procedures. Weiner (11) reviews a number of recent CFIT accidents which were the result of system-induced errors. He makes the point that CFITs are not caused by single factors but are system generated. Pilot-controller communication problems are a good example of system failure which may cause geographical disorientation. Others include flight-deck workload, crew co-ordination, warning devices, noise-abatement procedures, and government regulations. In military aircraft, inertial navigation systems with associated moving map displays automate the task of position monitoring and provide the pilot with valuable guidance cues for navigation and weapon delivery. The value of these systems is determined partly by their accuracy and reliability and partly by interface and system management considerations. Problems are being experienced with equipment installed in current military aircraft because of the unacceptable head-in cockpit time needed for in-flight data entry, particularly for pilots of short stature. CFIT accidents have occurred under circumstances in which the pilot may have had his head down in-putting new co-ordinates or updating the system's accuracy. Most of these problems can be resolved by simplified controls and displays located close to the normal line of sight, e.g. a "chin-up" digital keyboard and associated alphanumeric display.

PSYCHOLOGICAL FACTORS

One of the most frequently reported findings from case studies of geographical disorientation is that errors, even large ones, tend to resist detection and persist, perhaps for as long as several months, despite

information clearly inconsistent with the incorrect orientation. The compelling nature of geographical disorientation was noted by Binet (32) and Peterson (33) who described the experience as an "illusion". They reported that it was often initiated by inattention or distraction when making a turn, and that it was often as large as possible, the real world being rotated by 180 degrees. If the incorrect orientation occurred before entering a new region it often persisted for months or longer despite knowledge of the true directions.

McGrath (4) reports that a disorientated aircraft pilot may find the illusion so compelling that he may become absolutely convinced that his instruments are wrong. McGrath and Borden (9) quote the following example:

> "On a night training mission over highly familiar terrain the instructor pilot mistook the lights of one city for those of another 100 miles away. He became incredulous of his VOR reading and concluded that his radio was malfunctioning. He soon became totally disorientated in an attempt to fix his position. Fuel was exhausted before he could reorient, forcing him and the student pilot to abandon the aircraft."

Incidents such as the above are symptomatic of the same psychological process that led the inexperienced pilot in the second case study, reported in the introduction to this paper, to apparently disregard the Air Traffic instruction to turn left, and that caused the experienced instructor in first case study to transpose the steer of 100^{o} to 010^{o} magnetic after acknowledging that he had received it correctly and to perceive the distant coastline as South Wales rather than as somewhere else. Essentially, they are all examples of the disorientated pilot making the information which he is receiving from the world fit his perceived model of the world rather than building his model on the information available. Information inconsistent with the model can either be ignored, filtered out and not attended to, or processed and rejected as inaccurate, such as a "malfunctioning" radio, or simply misperceived. The steer of 100^{o}, for instance, was clearly sensed and read back correctly, and yet still perceived as meaning 010^{o} because the pilot was expecting to hear a heading near to north.

Our perceptual model of the world is the outcome of an interaction between information directly received through our senses from the outside world and the internal information stored in memory in the form of expectancies and preconceptions of what past experience has taught us ought to be there. These built-in expectancies play a major part in forming our perceptions when sensory information is inadequate or ambiguous. But even when there is plenty of sensory information we still tend to be selective and reorganise the information so that what we perceive conforms more to what we expect than is justified by the sensory evidence. Most of the time what we expect conforms to the reality. Inappropriate expectancies or false hypotheses are normally modified or rejected when an opportunity arises for them to be tested by checking against information sensed directly, such as compass indications and pre-planned checkpoints. They are likely to persist when there is little opportunity for an adequate test either because the sensory evidence is sparce, for instance, in barren terrain, or lacks uniqueness like roads in build-up areas, or because the evidence is insufficiently strong to challenge the hypothesis, for instance, when doubt exists about the serviceability of equipment. False hypotheses are particularly resistant when they are extremely probable and when they have been held for a long time. In such cases they can be retained despite a mass of evidence to the contrary. False hypotheses are also likely to be retained and acted upon when the individual is distracted, particularly after a period of stress or high anxiety.

It has also been noted in the literature that the conflict of cues for a disorientated pilot may produce marked nervousness, confusion, stress and even vertigo (2),(4). McGrath and Borden (9) quote the following example from a US Army accident report:

> "Pilot became disorientated in flight without realising it. He was about to land at what he thought was his destination, when he suddenly realised it was the wrong airstrip. He became so shaken and confused by this sudden realisation that he crash landed the aircraft."

Emotional reactions to the experience of being lost in flight vary. McGrath and Borden (9) report responses by 45 military pilots to the question "How did you feel when you realised you were disoriented" referring to a specific critical incident. Only 16% reported "Little or no concern". 11% reported that they were confused or bufuddled, 27% reported embarrassment, 35% reported moderate anxiety and 11% reported extreme concern and fright.

As already discussed, the facts of perception in general suggest the presence of powerful organising tendencies which show great resistance to re-organisation. Thus, when the disorientated individual finds that the sensory evidence does not agree with his preconceived model, he becomes greatly disturbed and may actually disbelieve what he sees. These reactions are similar to those normally associated with gravitational disorientation. On the other hand the subsequent precipitous breakdown and disorganisation of behaviour, leading to the loss of control of the aircraft that often follows severe vertigo, seems less likely to occur during the stress of geographical disorientation because we are more familiar with its effects - it happens during land navigation - and because our coping responses are better learnt. Furthermore, gravitational disorientation results from false sensations from the vestibular receptors, which can be highly distracting, as well as from visual misperceptions, whereas geographical disorientation is primarily a problem of visual misperception. Some sources suggest that geographical disorientation may be caused by vertigo (8), and others suggest that vertigo may be caused by geographical disorientation (2). These conclusions rely on anecdotal reports of individual cases rather than on controlled scientific research. Accurate knowledge of the vertical is a prerequisite for geographical orientation and it is not unreasonable that geographical disorientation should be a byproduct of vertigo. But apart from an indirect effect of geographical disorientation causing information overload and inattention to attitude cues, it seems unlikely that geographical disorientation, arising from visual misperception, could lead directly to gravitational disorientation and the misperception of vestibular information. In the second case study, when the disorientated pilot lost control of his aircraft, the accident was probably caused by a combination of the pilot's inexperience and his struggle to resolve the conflict of information about his position, both of which could have lowered his capacity to cope with the events that followed.

PREVENTION

The available evidence gives little grounds for expecting that selection procedures based on tests of spatial abilities can reduce the incidence of geographical disorientation. Training in pre-flight planning, orientation and re-orientation techniques probably offers room for improvement, but this should be based on systematic research on the optimum operating techniques, conceptual reference systems etc.

In principle, automation of navigation functions should reduce the frequency and seriousness of geographical disorientation. Geographical disorientation is unlikely to be eliminated entirely as long as the pilot has a system monitoring and executive decision-making role. Improvements in the resolution and reliability of future navigation systems such as laser gyroscope inertial navigation systems and the NAVSTAR Satellite Global Positioning System, will undoubtedly increase the operator's confidence that the aircraft's position actually is where the system says it is. But even with such advanced systems, disorientation could still result from inadequacies in the ways in which the position information is conveyed to the pilot. Pilot-controller communication problems are a good example of a system induced error that can cause geographical disorientation. The design of the interface between the man and the navigation equipment is a crucial factor. CFIT accidents have occurred in military aircraft because pilots have had to spend too much time head-down in the cockpit inputting new co-ordinates and updating system accuracies. Ergonomic solutions have been proposed such as "chin-up" digital keyboards and associated alphanumeric displays.

Achieving an integrated and meaningful display of navigational information is vitally important. A pictorial display of the aircraft's position in relation to a moving map seems to be the most preferred form of conceptual reference system. Advanced forms of map displays now show the map image combined with a cathode ray tube image in which a variety of navigational information can be integrated with the map including radar, route plan and tactical information. Improvements in the display of cartographic information can also be made such as in the greater use of colour coding, in the representation of relief and obstructions, and in the selection of features for portrayal on the basis of their appearance from the aircraft.

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DISCUSSION

HARTMAN:
(United States)

A very interesting paper. I found it to be extremely relevant to some of the questions we have had in the United States Air Force. Perhaps you would discuss the following question. Brief periods of disorientation have occurred to pilots engaged in aerial combat leading to misjudgments of ground clearances. What factors could have caused these brief periods of disorientation?

TAYLOR:
(United Kingdom)

Aerial combat is a high workload environment and periodically places major demands on the pilot's limited information processing capacity. Maintaining an awareness of geographical orientation relies on continuous, though not necessarily conscious, monitoring of positional and directional information. This task, whether consciously attended to or not, must occupy some information processing capacity. In order to prevent information overload during periods of particularly high demand, the aerial combatant will tend to focus his attention on the performance of tasks most relevant to his immediate needs, namely aircraft control and maintaining visual contact with his adversary. Information not of immediate relevance such as the aircraft's position in relation to geographical features, will tend to be ignored. Inattention to positions and directions during turning maneuvers is a common cause of geographical disorientation. At the end of a difficult maneuver an incorrectly oriented or confused pilot may misperceive features on the ground even when operating in highly familiar terrain. A familiar airfield, for instance, may suddenly appear unfamiliar if seen unexpectedly or if approached from an unusual direction. Reorientation will occur when the disoriented pilot has the opportunity to test his false hypothesis against good positional and directional information, such as approaching high ground or compass indications.

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HUMAN FACTORS IN PRODUCTION AND PREVENTION OF AIRCRAFT ACCIDENTS DUE TO DISORIENTATION IN FLIGHT.

by

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SUMMARY.

A certain number of aircraft accidents occurring especially in phases of flight with no visibility or in flight by night can be caused by or associated with "disorientation in flight". This is often due to illusory phenomena, vertiginous states, etc. induced by abnormal stimuli of the sense organs concerned with equilibrium and spatial orientation and by defects of agreement among the diverse perceptions which contribute to spatial orientation.

To prevent and reduce those flight accidents occasionally due to spatial disorientation, which are tied to the human factor and whose causes can, therefore, be influenced and corrected, it is very important that the pilot has exact knowledge of the possible illusory phenomena which can occur in flight, the awareness that they can be anticipated, and finally that timely actuation of adequate preventive measures allows one to avoid loss of orientation during the various conditions of flight.

For that reason the most frequent circumstances and conditions should be examined which can facilitate spatial disorientation in the pilot favoring the mental conflict which originates when there is sensorial incongruity between erroneous sensations coming from the vestibular apparatus and/or the proprioceptors and inadequate visual information. This applies to fixed-wing as well as rotating-wings aircraft.

The possible measures necessary to prevent those various conditions contributing to or facilitating disorientation in flight, or neutralizing them whenever they are already in effect, are then discussed.

It is very important that these conditions be brought to the attention of flight personnel and, especially, to student pilots so that they - along with adequate and accurate training in instrumental flight under expert instructors and simulator training - can give the pilot a well-grounded faith in his own flying capabilities under all flight conditions.

Carrying out the above-mentioned measures and diffusion of this knowledge in the aeronautical field are to be considered useful and indispensable means of preventing aircraft accidents due to the human factor and for the realization of increasingly greater and more efficient safety in flight.

INTRODUCTION.

In the aeronautical field a certain number of aircraft accidents occur during night flying or flying in zero visibility. In the cases in which no specific technical causes have been found, it can be inferred that "disorientation in flight" caused the accident or was a contributing factor, especially since its effects are so grave as to induce in the pilot instinctive reactions not adequately dominated consciously or by a quick check of the instruments on board.

Since that state of disorientation is often caused by illusory phenomena, vertiginous states, etc. induced by abnormal stimulations of the sense organs controlling equilibrium and spatial orientation, and by defects in the agreement among the diverse perceptions that contribute to orientation in space, it is very important to know and quickly actuate adequate preventive measures which avoid the loss of spatial orientation during the various conditions of flight.

ORIENTATION AND DISORIENTATION IN FLIGHT.

The problem of orientation is much more complex in flight than on the ground because during flight one can be influenced by a variety of accelerations which act according to non-habitual combinations and patterns when compared with terrestrial experience. Of the

three common and most important sources of orientation (eye, mechanoreceptors, vestibular apparatus), only the eye can be trusted, especially in flight, to provide a true picture of body orientation in space on the condition that the eyes receive adequate information from the outside world or from the instruments on board.

The organs of static balance (utricle, saccule), those of dynamic balance (semicir cular canals) and the other proprioceptors (skin, joint, muscular, tendinous receptors), on the other hand, not only are not trustworthy, but it is possible for them to relay in formation to the brain which is misleading.

For that reason, when one of the three above-mentioned sensorial paths is excluded as, for example, in the case of the most important pathway - sight - during a flight with zero visibility, an exact evaluation of orientation is not possible. In fact, in some cases perceptions may be considered exact when, in reality, they are inexact, in which case one encounters true illusions.

There are two types of such misleading sensation which arise in the organs of balance : misleading gravity sensation associated with the otolith organs, and misleading sensations of rotation originating in the semicircular canals.

The first one, i.e. the misleading gravity sensation or "oculogravic illusion" (or "somato-gravity illusion") may be defined as a false perception of tilt induced by stimul ation of the otolith organs by linear accelerations. For example, during a forward linear acceleration, there exists the force of gravity acting downwards (body weight) and also an inertial force associated with the forward acceleration, which can be considered as pushing the pilot's body back in his seat ($+G_x$). These two separate forces are interpreted as a single resultant force tilted backwards from the vertical. At the conscious level this resultant force is considered as being vertical, from which derives a false impression of the aircraft pitching up.

During a sudden deceleration the opposite illusion occurs, i.e. a false sensation of the plane varying its trim into a dive.

If the pilot acts basing himself on these sensations an accident can occur, for example, by pushing stick forward during overshoot. Thus it is necessary to refer to the instruments on board to determine the correct attitude and to act accordingly.

An analogous misleading sensation can occur when flying blind since, during a turning maneuver, the pilot has the feeling of climbing instead of turning. In fact, his body is pushed strongly against the seat by the inertial force associated with the head-feet centrifugal acceleration ($+G_z$) generated when turning. This force, combining with the force of gravity acting downwards, gives a resultant which, at the conscious level, is interpreted falsely as a climbing maneuver. The natural reaction could be to push the stick forward in order to put the aircraft back in horizontal flight.

The opposite sensation of descending can occur when flying blind and coming out of a turning maneuver. The tendency is to pull back on the stick. In addition, when flying blind the inclination of the aircraft during a horizontal turn generally is not correctly perceived by the pilot. In fact, a force is exerted on the otoliths (and on the airplane) which is the resultant of the vertical component (force of gravity) and the horizontal component (centrifugal force) ; that is, a stimulus is exerted on these organs of static balance which has the same direction (apart from the greater value) of that caused by the force of gravity when the subject is on the ground in a vertical position. The otolithic apparatus sends information to the brain that the body is subject, as normally occurs, to the force of gravity.

This, however, is the genesis of the erroneous illusion that one has when, having initiated a turn with the eyes closed, and then opening them, one is induced to judge the panorama below as non-vertical rather than to judge as non-vertical the position of one's body.

Another erroneous sensation which is a possible cause of disorientation in flight is that which can occur whenever the upper surface of a cloud bank is inclined rather than horizontal (the usual case) with respect to the horizontal and is used as a false reference for the attitude of the aircraft. The pilot can become disoriented if he aligns the plane with this false horizon.

In addition to the misleading gravity sensations associated with the otolith organs, misleading sensations of rotation originating in the semicircular canals can occur. For ex ample, during a prolonged rotation, however, when a constant angular velocity is reached and maintained, no sensation of rotation can be detected. During such motion the relative movement of the endolymphatic fluid in the semicircular canal ceases and the natural ela sticity of the cupula causes it to return to its resting position. Thus, although the body may be turning at a high rate there is no longer any information about rotation coming from the semicircular canal itself.

In addition, a fallacious sensation of rotation can occur immediately after the rotation has ceased. This false sensation is caused by the successive flexion of the cupula in the opposite direction by the inertial movement of the endolymphatic fluid in a direction contrary to the initial movement whenever the rotational motion is quickly slowed down or interrupted. In the last case, one has the sensation of rotating to the right when the plane is rotating to the left and vice-versa. The pilot, induced by the false sensation of rotating to the right (when, in reality, the aircraft is in rotation to the left), is brought to tighten the turn even more to the left, and vice-versa when the rotation occurs to the right. Tightening the turn in this case forces the aircraft into an even tighter spiral.

These vestibular inaccuracies and errors can occur in varying degrees and in all three planes, and with various combinations. For example, the misleading sensation of falling forward, with the consequent tendency to pull back the stick (this worsens the situation in a spin), occurs when an aviator carries out angular movements of the head during the execution of a tight turn. In that case the vestibular apparatus is subjected to two diverse angular forces in two planes perpendicular to each other (that of the passive rotation caused by the turn, and that of the active rotation caused by the voluntary movement of the head). The resultant of these two accelerations, called "Coriolis acceleration", is capable of producing a vertiginous state which can be the cause of flying accidents.

In practice, the dizziness from the Coriolis effect occurs during and at the end of a rotation around a determined axis when the subject's head is passively or actively flexed forward rapidly or extended backward or inclined to one side in a manner to bring into the plane of rotation another pair of semicircular canals. It follows that to prevent the Coriolis effect and other analogous dizzy sensations, it is opportune to make the maximum use of ocular mobility for the scope of reducing head movements to a minimum.

An analogous state of dizziness and malaise can be generated in the pilot when he is subject with his aircraft to repeated subliminal angular stimulations during navigation in turbulent air. The subliminal stresses, being of limited entity and taking place very slowly, do not reach an excitable threshold in the labyrinth and, therefore, are not perceived by the pilot. The pilot soon loses completely his evaluation of the true vertical because of the loss of "zeroing" of his balance apparatus. This can be regained only when visual contact with fixed reference points situated outside of the aircraft will have eliminated the conflict between the instrument indicators on board and the subjective evaluation of the pilot's own vertical position.

The logical consequence of that which has been discussed up to this point is that the pilot, when flying in zero visibility, will always have recourse exclusively to his instrument presentation, which will provide a reliable visual information again. This will avoid generation of false sensations of orientation due to the exclusion of one of the most important pathways which allows us to determine our position in space, i.e.sight. The pilot must consciously and selectively exclude for the evaluation of his spatial orientation those indications that come to him from the labyrinth and the muscular, skin and joint receptors.

Not doing so creates sensorial incongruities between erroneous information coming from the vestibular apparatus and the inadequate visual information. There are many situations capable of originating a state of mental conflict so strong as to render the subject incapable of continuing to believe in the instrumentation on board.

Such situations, which during flight can cause disorientation and thus contribute to the genesis of aircraft accidents, are found above all during instrument flying ; especially in haze the pilot passes continuously from his instrument presentation to information he receives directly from the outside world and which often are inadequate and erroneous because of the limitations and inaccuracies of the vestibular apparatus and of the other receptors. The inexperienced pilot who doesn't know or understand the problem could, at this point, lose faith in the instruments on board, be subject to the conflict generated between observation of the instrumental data and the picture which he has formed subjectively in his mind, and become disoriented.

NIGHT AND FORMATION FLYING.

Other situations which facilitate flight disorientation can occur during night flying in which there are frequent illusions caused by the false interpretation of visual information.

Confusion of ground lights with stars can occur ; that is, lights on the ground or on ships are taken for stars (this happens when one leaves a cloud bank and finds himself "on top" on a dark night with no moon) and the pilot has the erroneous sensation of complete inversion, i.e. to be flying upside-down. This causes the tendency to put the aircraft

into very unusual flight attitudes so that the ground lights are kept above the airplane : this can cause a flight accident.

Another phenomenon which can occur especially during night flying at high altitude is that in which the moon and the stars appear below the true horizon. If the pilot, suddenly looking outside during straight and level flight, sees the moon below his plane, he has the immediate sensation of inverted flight. From this arises a conflict so typical in disorientation accidents which he can easily solve by looking at the instruments. Yet so often the pilot forgets to make this obligatory check and performs an immediate change of attitude of the aircraft.

Thus even in night flying at high altitudes, false visual sensations which are potential factors of disorientation can occur due to the altitude. Therefore, aviators should remember that owing to the curvature of the earth, the actual horizon as seen from an aircraft becomes progressively depressed below the horizontal as altitude increases. At very high altitudes, a considerable part of the sky becomes visible below the horizon line. This can lead to confusion if the pilot forgets that some stars and the moon can be seen below the aircraft. It also means that at these altitudes, if the tip of one wing is aligned with the horizon, the other will be considerably above it.

During night flying a false perception of altitude can also occur as a consequence of the pilot not noticing an error in the aircraft's trim. The angular depression of single isolated light observed on the ground from the cockpit changes with the height and with the distance during straight and level flight.

In addition, during flight on a very dark night with no visible stars or horizon, the problem is similar to that which has been described when flying in haze and indeed may even be worse if the cockpit illumination is very low. The visual cues from any source are minimal and the information from the vestibular organs and from other mechanoreceptors impinge on the nervous centers quite strongly. This condition can be overcome by increasing the intensity of the cockpit lighting thereby re-orientating with a familiar environment.

Other frequent visual illusions during night flying are the so-called oculo-rotary and autokinetic illusions. The first, also called the "oculogyral illusion", plays a non-indifferent part in the onset of the so-called "flyer's vertigo", and is caused by particular involuntary movements of the eyeballs as a consequence of slight angular accelerations of the aircraft which, if the pilot is in the dark, cause apparent oscillations of the surrounding objects.

The "autokinetic illusion", also called "Carpentier's illusion", is due to small spontaneous and un-noticed oscillations of the eyeballs which begin when an individual in the dark observes a small static light. It consists of false impressions of movement ; that is, in apparent movements of an object in the visual field of the pilot when all visual reference points of the perceptive framework are insufficient or completely absent. This illusion is particularly dangerous during night flying in formation when the other aircrafts are following the formation leader observing his wings or tail because it can cause corrective attempts by the pilot which are useless, if not dangerous. In this case the phenomenon is more complex because the luminous point observed is undergoing real movements which can be reduced or accentuated by the illusory movements.

Other conflicting situations which facilitate disorientation can occur during formation flying. In fact, each pilot flying in formation maintains a determined position and so remains orientated in relation to the constantly changing position of the flight leader. The pilot is therefore unable to maintain a reliable and updated mental picture of his spatial orientation in relation to the earth's surface and it is normal for him to experience a strong impression which is in contrast with the true attitude of the aircraft in space.

Other factors can facilitate disorientation in flight such as the sudden and large pressure changes in the middle ear, the so-called "alternobaric vertigo" or "pressure vertigo". A stimulus on the receptors of the semicircular canals can arise during ascent or descent with consequent sensations of vertigo, rotation and disorientation sometimes accompanied by visual disturbances. This is another reason for not flying when the ears cannot be cleared satisfactorily, due to phlogistic and catarrhal phenomena of the Eustachian tubes because of otosalpingitis, rhinopharyngitis, etc.

Another condition capable of facilitating disorientation in flight is the after-effects of alcohol. The immediate effects of alcohol on the ability to orientate are well-known. After an excess of alcohol, however, the effects may be delayed for many hours and be of a nature and entity such to compromise the pilot's individual capacity for orientation, especially during instrumental flight. This is only one of the many reasons why flying and alcohol are incompatible [NASA, 4].

DISORIENTATION IN FLIGHT ON HELICOPTERS.

Thus the problem of spatial disorientation is very important. During flight on fixed-wing aircraft the pilot is subject to the conflict between his own sensorial evaluations and the information supplied by the instruments. This conflict may induce him - if his critical faculty has not been sufficiently trained or if it has been compromised by fatigue - to commit manoeuvering errors due to the failure to correct the aircraft's attitude in situations that call for completely anti-instinctive maneuvers.

In the case of rotary-wing aircraft the problem of disorientation in flight is, for helicopter pilots, far more serious than in conventional fixed-wing aircraft, since accelerations may occur simultaneously among all three of the aerodynamic axes of the vehicle. In these conditions it is possible for the pilot to experience more frequently environmental and coenesthetic situations which are ambiguous from both the visual and the vestibular standpoint, so that the interaction of sensorial information frequently leads to conflicts which can only be solved by pilots well and continuously trained.

At times, however, the conflicts can contribute to the origin of accidents in flight. In fact, the necessity of rapid passages from visual to instrumental flight, the existence of isolated light sources during the night and the continuous observation of the instrument panel during certain vibration cycles can provide sensorial reference data incorrect from the visual point of view. This permits the onset of other erroneous sensorial stimuli further favoring the above-mentioned conflicting situations.

CONCLUSIONS.

After having discussed the possible causes of illusory phenomena, of vertiginous states, etc. which can favor loss of orientation in flight, the prevention of flight disorientation remains to be discussed.

Concerning this it must be remembered that many of the preventive measures have been mentioned from time to time. In any event, the pilot's exact knowledge of all of the above-mentioned possible illusory phenomena which can occur in flight and the awareness of their predictability are prerequisites useful to reduce their consequences.

It has already been stated that disorientation only becomes dangerous when the sensory incongruity causes a mental conflict which is so strong that an individual is unable to continue to believe in the instruments on board. Awareness of this potential hazard means that the aircrew who experience these sensations during flight both understand their importance and know how to overcome them.

From this point of view the following measures are very important for the prevention of aircraft accidents due to disorientation in flight :

a. the achievement of a correct even though anti-instinctive domination of one's organs of balance through accurate training for instrumental flight using the link-trainer on the ground and training in flight under expert instructors ;

b. the consequent acquisition of a well-founded confidence in one's own ability to fly using only the instruments on board under all conditions of flight.

Concerning helicopters in particular, the adoption of the above-mentioned countermeasures valid for preventing the various forms of disorientation in flight (temporary increase of luminance level of the cockpit instruments during some critical flight maneuvers, adequate changes in cockpit instrumentation including reduction of the area of instrument scan and incorporation of a flight director system in helicopters, reduction of extreme head movements, etc.) can be very useful and effective in counterbalancing and reducing the occasions of flight disorientation and in preventing possible accidents. It is also necessary to recommend that all known disorientation countermeasures be emphasized in basic and advanced helicopter training, with special reference to those situations which are peculiar and particularly troublesome and fatigueing during helicopter flight.

In that manner and with these means a significant contribution can be given to the prevention of aircraft accidents caused by the human factor and to the achievement of increasingly greater and efficient flight safety.

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BETWEEN INCIDENT AND ACCIDENT!

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SUMMARY

In the evolution of an aircraft occurrence, combined stress often plays a significant role. This paper presents conceptual models of how a combination of stress-inducing factors can lead to the "no man's land" between normal operation and incident; between incident and accident. The models are primarily for presentation to aircrew when discussing stress.

INTRODUCTION

A careful human factors review of recent Canadian Forces aircraft occurrences confirms that a combination of stresses have played a significant role in the causation of these accidents. Even though the verdict may be "pilot error", it is implicit that there are background reasons why a pilot displayed degraded judgement, carelessness, inattention or poor technique. It is reasonable to investigate and enumerate the combination of stresses after an aircraft occurrence with the view of recommending methods of identifying the stressors and then reducing them in the hope of reducing the occurrence rate.

The stresses to which the pilot is subjected while flying are threefold. First is physical stress, which are the classical aeromedical problems (e.g. hypoxia, gravito-inertial forces, vibration). The second is cognitive (intellectual) stress, usually related to cockpit workload which, when it becomes excessive, affects the pilot's operational efficiency. Lastly is affective (emotional) stress, when the input to consciousness is seen as threatening to the individual's safety, self esteem, or satisfaction of desires. Affective stress is not always harmful as seen in the anxiety-provoked "gearing up" of the pilot to deal with an emergency. Intense or chronic emotional stress can seriously interfere with performance capability as seen in the phrase "the troubled pilot seldom returns" (4).

This paper presents conceptual models of combined stress and its effect on flying. The models have been used to present the topic of stress to aircrew (especially flight safety officers). The feedback after presentation has been quite positive. Aircrew seem to be able to grasp easily the concepts especially if concrete examples are given. Often worthwhile questions on the topic are forthcoming after the presentation.

STRESS - DISEASE MODEL

"Stress is the nonspecific response of the body to any demand made upon it" according to Selye (6). Stress is a normal phenomenon, is needed in life and is always present. "Complete freedom from stress is death" (6). Selye points out that the mechanism of adapting to stress is the same for a cell, an organ, an organ system, an individual, or a society. This adaptation mechanism has become known as the General Adaptation Syndrome (GAS) and occurs in three stages - (1) the alarm reaction; (2) the stage of resistance; and (3) the stage of exhaustion (Figure 1).

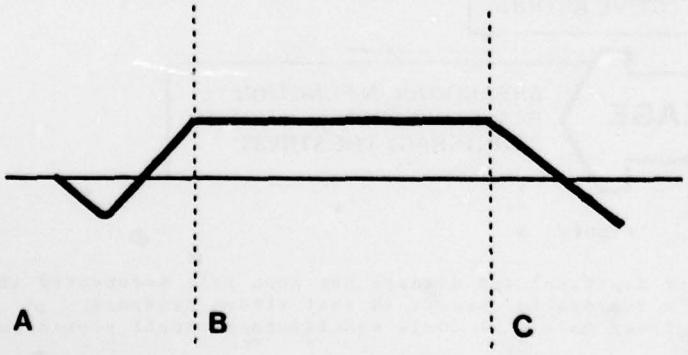


Figure 1

The three phases of the general adaptation syndrome (G.A.S.)

A. Alarm reaction. The body shows the changes characteristic of the first exposure to a stressor. At the same time, its resistance is diminished and, if the stressor is sufficiently strong (severe burns, extremes of temperature) death may result.

B. Stage of resistance. Resistance ensues if continued exposure to the stressor is compatible with adaptation. The bodily signs characteristic of the alarm reaction have virtually disappeared, and resistance rises above normal.

C. Stage of exhaustion. Following long-continued exposure to the same stressor, to which the body had become adjusted, eventually adaptation energy is exhausted. The signs of the alarm reaction reappear, but now they are irreversible, and the individual dies.

The Selye model can be modified to produce a disease model, applied at the level of the individual. In this model, stress is a force or pressure acting on a person to compel him to act. If the action to remove the stress is ineffective the model moves on to a stage of distress, which is defined as a stage when the stress is so severe or so prolonged that the person has difficulty acting appropriately. In the states of either stress or distress the individual is seeking relief from that state, that is, he is seeking a state of ease (Figure 2). If the action to achieve that state of ease is ineffective the result is a breakdown in function and a state of disease. Disease is defined as a breakdown in function resulting from failure to counteract the stress (Figure 3).

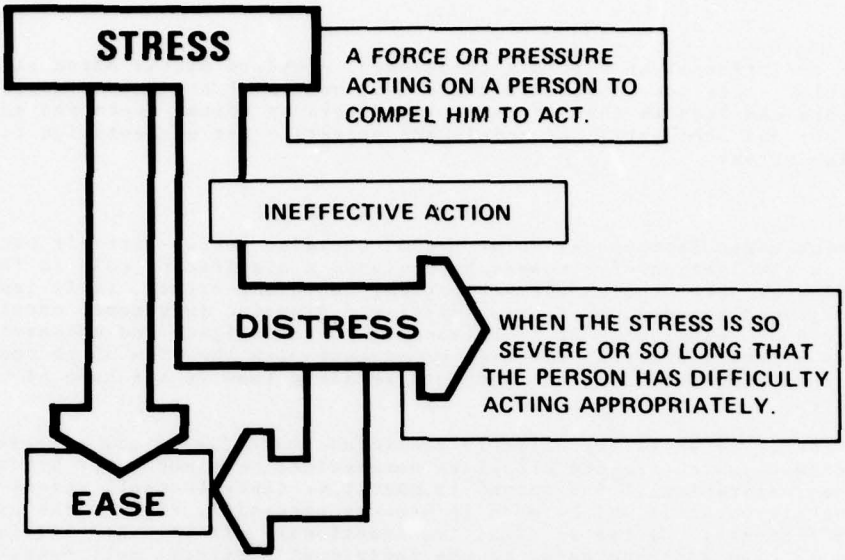


Figure 2

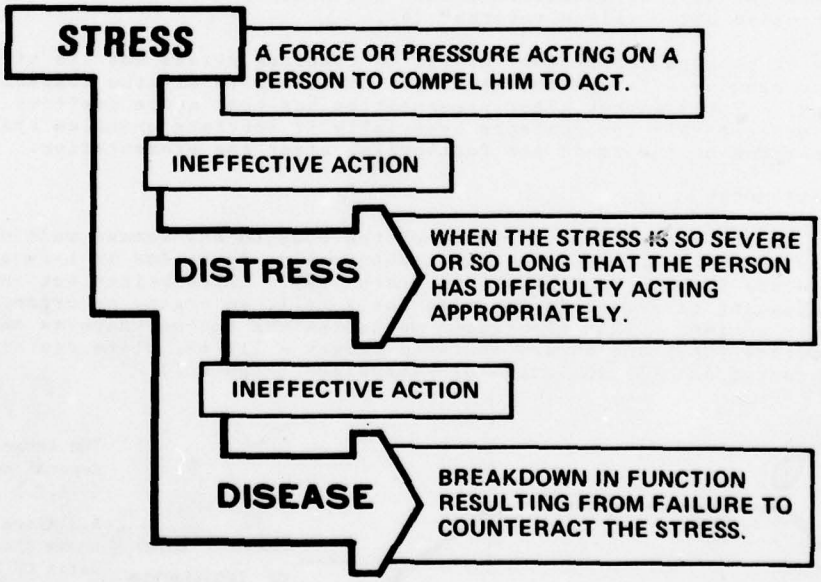


Figure 3

The relation between stress (or distress) and disease has been well documented (6). Less scientifically proven but still a reasonable concept is that stress produces "accident behaviour". In the above stress model, we could substitute accident proneness for disease.

EXPLOSIVE MODEL

Basic flying stresses exist in any air operation to a greater or lesser degree. A few of the more obvious ones are in Table I. All these stresses contribute to fatigue as well as remind the aviator that he is not on the ground and that he has a job to do. These ordinary flying stresses are more than compensated for by effective training and experience (Figure 4).

Table I

FLYING STRESS FACTORS

Height
Pressure changes
Acceleration - "G"
Motion
Turbulence
Low Humidity
Glare
Vibration
Noise
Cold
Heat
Inactivity
Uncomfortable personal equipment
Red lighting

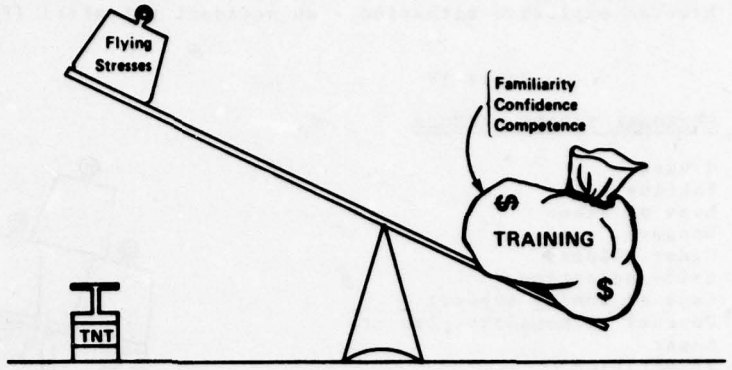


Figure 4

In flying, various influences are exerted by the aircraft, the flight conditions and the level of training and experience. Some of these "anxiety factors" are listed in Table II. Still an explosive situation should not exist (Figure 5), although some disorganization of mental activity to a greater or lesser degree probably will occur. This may include channelling of attention, over-concentration on a single instrument and acceptance of a reduced standard of performance.

Table II

ANXIETY STRESS FACTORS

Level of training
Level of confidence
Unfamiliar aircraft
Unfamiliar route
Unfamiliar airport
Poor runway conditions
Poor weather
Low fuel
Malfunctioning navigation equipment
Low altitude
IFR and night flying
Fear of losing face
Lack of confidence in aircraft design

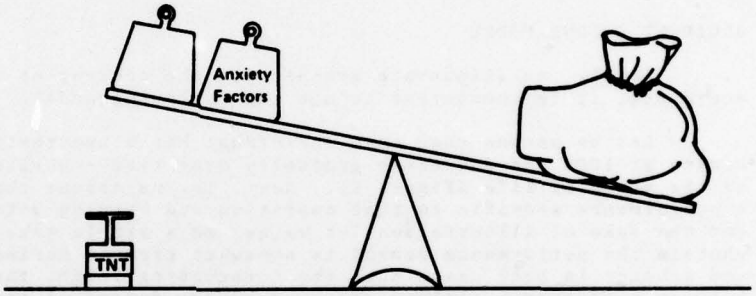


Figure 5

If in addition to one or more of these "anxiety factors", an emergency occurs (Table III), the level of anxiety is bound to rise still further. Training and experience should still be adequate to permit effective dealing with such situations singly or even with more than one at a time (Figure 6).

Table III

EMERGENCY STRESS FACTORS

Control/trim malfunction
Engine failure
In-flight fire or explosion
Mid-air collision
Birdstrike
Ditching
Loss of formation leader
Disorientation
In-flight incapacitation

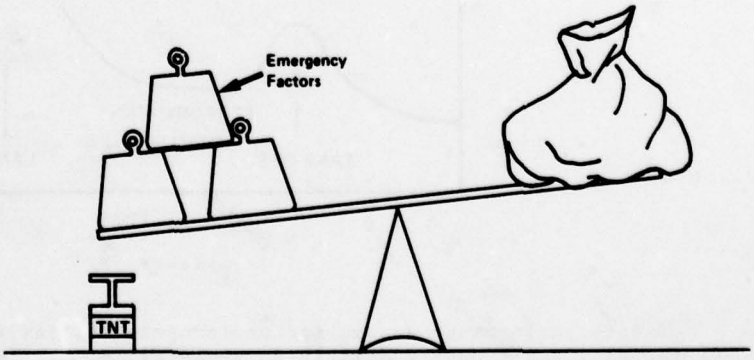


Figure 6

Under these circumstances, the aviator must rapidly process incoming information, weigh the alternatives, and initiate the necessary and, one hopes, appropriate action to save himself and if possible, the aircraft. It is at this point that "personal factors", as listed in Table IV can tip the scale into an accident situation. If the flyer has already burdened himself with one or more personal factors before even getting in the aircraft, his ability to evaluate and act appropriately, especially but not solely under emergency conditions is significantly degraded. Putting all these factors together we

have an explosive situation - an accident potential (Figure 7).

Table IV

PERSONAL STRESS FACTORS

Hunger
Fatigue
Loss of sleep
Hangover
Minor illness
Self-medication
Lack of family support
Unusual personality elements
Anger
Frustration
Worry
Over-sensitivity
Guilt
Memories of horrifying sights

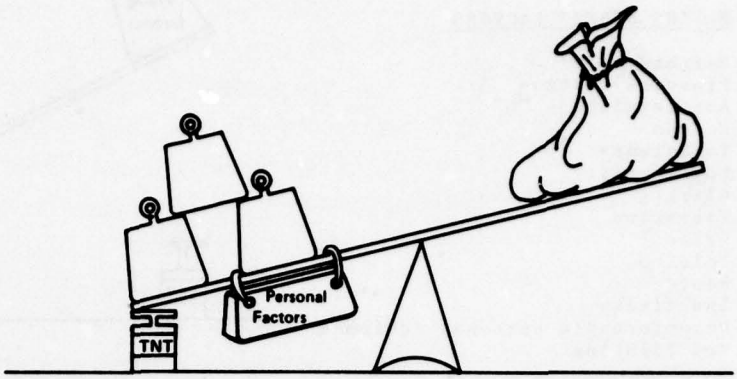


Figure 7

It is important to notice that the stress factors listed in Tables I, II and III have been decreased to a minimal point through aircraft and equipment design, procedural development, training and experience. Thus, it seems that the one group in which we have the greatest potential for improvement is that of the personal stress factors (Table IV), which are often self-imposed and therefore amenable to individual control.

ACCIDENT - ZONE MODEL

Lastly, to illustrate graphically the concept of combined stresses in relation to accidents, it is convenient to use the following model.

Let us assume that each individual has a hypothetical performance ability, which begins at 100% and decreases gradually over time - whether that time be hours of a day or the years of life (Figure 8). Next, let us assume that every flying operation requires a performance specific to that operation and varying with the different stages of flight. For the sake of illustration let us assume a simple take-off and landing operation wherein the performance demand is somewhat greater during landing than during takeoff and greater in both cases than the intervening flight time, (Figure 8). The difference between performance ability and performance demand at any particular time is the margin of safety for that flight operation.

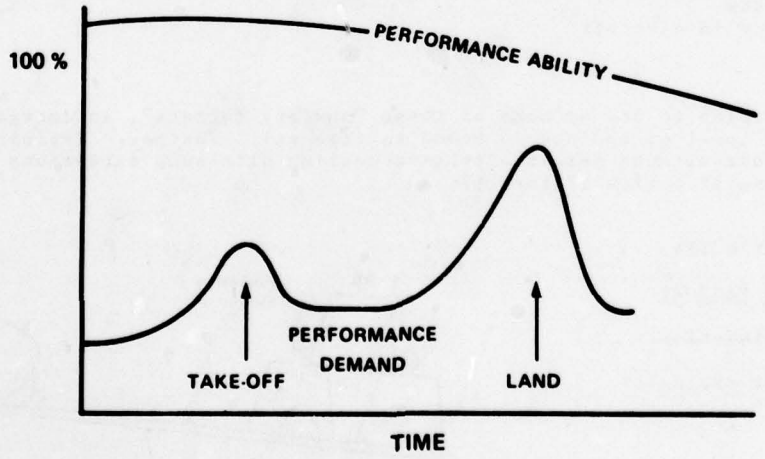


Figure 8

Both performance demand and performance ability are variable (Figures 9 & 10). For example, experience and training would elevate performance ability while hypoxia and alcohol would decrease it. Likewise performance demand can be increased by many factors (eg. IFR, low fuel, malfunction). The exact quantitative effect of these stressors cannot be measured. But whatever the quantity of each individual stressor, the overall effect of the combined stresses is at least additive and perhaps synergistic.

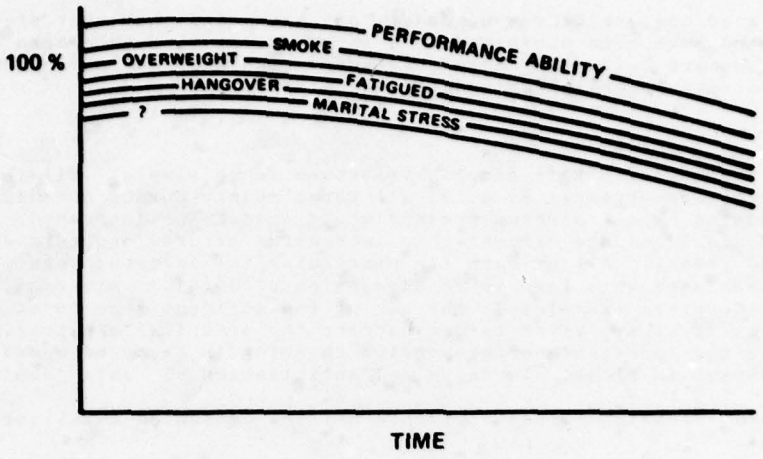


Figure 9

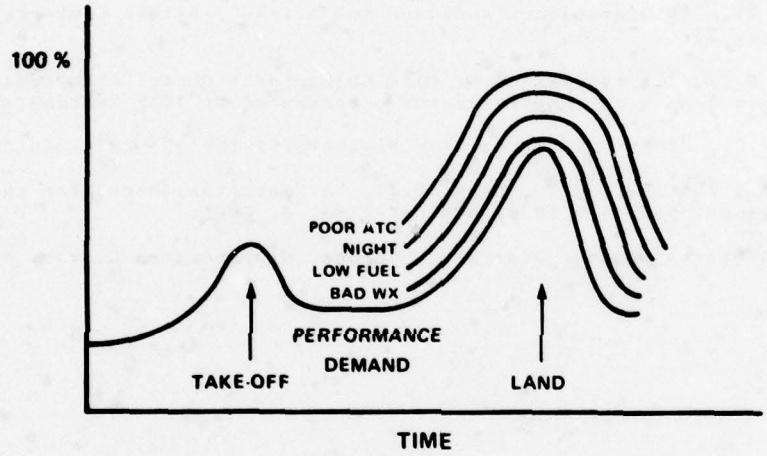


Figure 10

If the performance demand exceeds the available performance ability then we are in the "accident zone" - the area of operation where we find the incident and accident occurring (Figure 11). The difference between incident and accident is often a fine line. It may be a fraction of an inch, or of a second; a bruised face that was nearly a lost eye; or the misread altimeter that was taunting death. Whether an incident could have been an accident is related to training, experience and most often good (or blind) luck. Thus it is possible to explain why on one particular occasion an accident occurs when on many previous occasions an operation had been undertaken without accident or incident, when, seemingly, circumstances were identical.

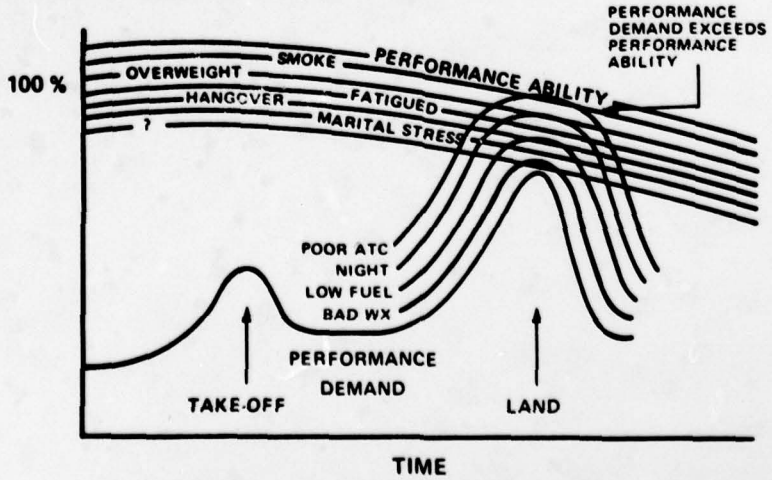


Figure 11

Bearing in mind the accident zone model, and accepting that most of the increases in performance demand have been minimized to a large extent through modern technology and good training, we are left with those stressors which decrease performance ability. Therein lies the potential for improving accident statistics.

CONCLUSION

The models presented in this paper have proven to be simple, well-received presentations of combined stress. By using all three models during one discussion, the chance of comprehension by all aircrew present would seem to be increased. The accident zone model has especially seemed effective in increasing aircrew understanding of the concept of combined stress. All or part (in particular the accident zone model) of this presentation has been used as a lead-in to discussion of specific stresses, eg. fatigue, alcohol, smoking. Concrete examples of the use of the accident zone model in recent aircraft occurrences is always given to demonstrate the practical application of the model and emphasize the importance of preventive thinking in terms of personal lifestyle; preflight preparedness, in-flight alertness and anticipation of "safe" decision-making.

Several recent Canadian Forces accidents will be presented as illustrating the accident zone model.

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ROUND TABLE DISCUSSION

As is our custom, we will have a round table discussion. I have prepared three questions and have asked tnree of our speakers take one each and discuss it briefly, after which perhaps the audience will have an opportunity to challenge, contribute, or whatever.

Question #1. Do we have an appropriate definition of "human factors" in relation to accident investigation?

Question #2. It does not appear, at least in the United States Air Force, that the research community is sufficiently involved in human factors aspects of aircraft accidents. Are there fruitful areas for research? Is there a reasonable chance for a payoff?

Question #3. Is it likely that we can reduce the number of accidents where human factors aspects are an important element? Is that possible, and if so, where should we concentrate our efforts?

As you will recognize, these questions deserve either very short answers or very long answers. The three discussants are Dr. Zeller, Dr. Johnson, and Dr. Reader.

ZELLER (U.S.): The first of those questions dealt with the definition of the term "human factors." I have the impression that we are either making progress or about to be abolished, because this is the third time within the past three weeks that I have been asked to address this question. Once to a university group, once to a combined military group, and the third time, today. In looking at the term "human factors," I think that we should look at the context in which it grew up. Perhaps we could use an analogy, for example, the attempt to define some other term such as medicine. I didn't look it up, but if you will look in a dictionary, I am sure that you are going to find a number of definitions. One of them is going to be a substance, one of them is going to be a discipline, and there will undoubtedly be some other terms. I think that any of you would be hard-pressed to delimit the concept of medicine with a definition that included the specifics. To pursue a further definition of aerospace medicine, I think you would find it difficult to delimit in terms of how it varies from pediatrics even now, certainly from clinical medicine, internal medicine, psychiatry. The term is one that is generally accepted because it represents the application of a broad area of behavioral and particularly biological science toward a specific end which is the treatment of people. Now, let's get back to human factors. Human factors grew up in the era of the systems concept. It is a fairly recent term and it was developed specifically within the man-machine context. It was developed because there was no specific term or no specific science that covered all the kinds of things that were important in this relationship--psychology, physiology, anthropology, and social sciences. Yesterday, in that list of five "P's" that I gave you, I suggested some of the elements. I do not think that was complete. As a matter of fact, I can think of two more at the moment. Another "P" is political, which certainly changes perceptions. And another, not a "P," is religion, or the spiritual values, which also changes perceptions. So, as medicine deals with the application of a great variety of sciences to the treatment of the ill, and certainly that is very broad, because there is preventive medicine, so the term "human factors" is a term that deals with those characteristics of the human being that are important in understanding behavior in a man-machine relationship. I would suggest that this definition is not rigid, that it will change, that items will be dropped, that others will be added, that it is a dynamic definition. We would do the field of human factors a great disservice by trying to force it into rigid limits at the current state of our ignorance.

HARTMAN (U.S.): One of the things that concerns me in my group at the School of Aerospace Medicine, one of my objectives in the program we are initiating, is to get the strongest possible interdisciplinary team organized to attack the problem of human factors in aircraft accidents. I think the accident boards are reasonably well staffed and have available to them--the boards who actually do the investigations--the option of calling on many different kinds of consultants. They do this routinely, but I am not sure as I look around the NATO community that all of the disciplines involved in and supporting aerospace medicine are being employed to the maximum extent possible, in research and as consultants, on the problems of human factors accidents.

We will move on now to the second question.

JOHNSON (U.S.): The next question deals with research involvement. It does not appear, at least in the United States Air Force, that the research community is sufficiently involved. Are there fruitful areas for research? And, is there a reasonable chance for a payoff? I'll try to make my answer fairly short. I think, as relates to the appearance of the involvement of the research community, that we would have to commit an error which is often counciled against, and that is, to answer a question with a question. I might say, "By whom does it appear that the research community is not sufficiently involved? And, where is that involvement lacking?" On behalf of the researchers, I might say that it may be difficult to play two roles at once. Number one, to be a researcher, and number two, to be a crusader at the same time. So for those of us who are crusaders, it might be very easy to say that the researchers are not sufficiently involved. For the researcher, it might be difficult to do basic research, and yet stand on the corner or on the soapbox and do the crusading. I would rather suggest that maybe there is not sufficient dialogue and exchange between the people who are doing the research and the people who are crying for more involvement and more safety products from the research effort. Are there fruitful areas for research? I think the obvious answer to that is "Yes." I think that the fruits of the research would depend upon whether we rely upon retrospective studies or prospective studies when we design our research projects. As I sat through the first two days of this meeting and looked at the models and analogues for evaluation of biodynamic response, performance, and protection, it became very apparent that much of this is based on retrospective studies. We have had accidents, we have had machines that fail, we have had failure of equipment. Because of that and the catastrophic results of an accident to man, we must do more research. I think, on the other hand, that there are areas in which we have not had a great number of fatalities or unfortunate experiences which would well dictate areas of research. For example, as I mentioned in my presentation, man now has a flying machine which can take him into areas which exceed his physiological limits. Let me give one example. The modern-day fighter can go above 50,000 feet, yet we have no pressure jerkin or emergency pressure suit available to the fighter pilot. Now, shall we as a research community, wait for ten canopies to blow off at 55,000 feet or for 13 pressurization systems to fail and

three people die before they can descend to the appropriate altitude, before we develop an emergency pressure suit? Or, could we, as a research community, instead foresee and acknowledge that this problem is present because men are now making excursions into these altitudes? I don't know how many people are aware of the fact that every day somebody takes his airplane up to 50,000 or 60,000 feet. Momentarily, perhaps, but it is happening. As I said, we do not have a long list of unfortunate occurrences, but I think it is this kind of excursion into these kinds of areas that are going to be happening more and more frequently. Eventually, we are going to have some fatalities. I would hope that the research community would become involved now in this one area, for example. Another example, we need a lightweight helmet. In the advanced fighter aircraft community, with the kind of G forces that man is able of exerting and subjecting himself to, we have a crying need for a helmet that weighs on the order of 1 1/2 to 2 pounds. But, instead, we see helmets getting heavier, because we are adding flash-blindness protection, we are adding optical devices, and so forth. All of these are adding more weight to the helmet. But the fact is that the man who will be doing aerial maneuvering in a combat situation with a high-performance fighter needs a piece of equipment which will lessen the strain on his neck muscles. This will allow him to have more mobility of his head in the combat environment. I am not aware that the research community is focusing on this. It appears that oftentimes we must have a series of misfortunes before the research community focuses in on a problem area. The last part of my question. Is there a reasonable chance for a payoff? I think that when we identify the problem and put the appropriate effort into solving the problem before it becomes acute, yes, there is a payoff. We save lives, we prevent injuries, or we at least reduce the magnitude of the injury that may occur.

MOONEY (Canada): I'd like to comment on the specific issue of a get-me-down-jerkin with counterpressure breathing. This, in fact, has been developed at the Defense and Civil Institute of Environmental Medicine (DCIEM) where I am working. We now have a system that can get us down from 80,000 feet. It is, in fact, going out for industrial research contracting now and will be available commercially, we hope, within a year or so. As to the more general question, I'd like to say that there should be perhaps more effort put into increasing the competence of pilots rather than dealing with their failures. This is one area where in fact there hasn't been much human factors input. We should put more effort into increasing pilot skills and seeing that the pilot really knows his 12 pages of emergency procedure by heart every time he goes flying. That kind of effort is likely to have a high payoff.

JOHNSON (U.S.): How do you get the research community involved in developing more emergency procedures for the pilot to learn? Is that really a research community problem?

MOONEY (Canada): Perhaps not, but it is a job for an expert of some kind. I'm not sure that it is really a research community question, but it certainly requires someone with expert knowledge, and I should think that someone with the psychologist's training undertaking that task could do a good job of it.

HARTMAN (U.S.): I believe we are ready for question number three. The question will be discussed by David Reader.

READER (U.K.): My question was, to remind you, "Is it likely that we can reduce the number of accidents where human factors aspects are an important element, and if so, where should we concentrate our efforts." The answer to the first part is certainly "yes." You've heard this week (and more importantly, yesterday afternoon and this morning) that human factors play a very important role in the majority of accidents. We should concentrate our efforts, I believe, in five major areas: (1) Investigation. Bob Taylor gave you a very good expose' of what you can learn from an investigation. I feel this is an aspect of current investigations which is not practiced widely in the NATO community. I believe it should be. Accident investigators are often too close to the problem to see the particularly pertinent aspect which should be focused upon. Specialists should be used for this procedure. (2) Communication. Having found what the problems are, everybody should be made aware of them. (3) Training. Once you know what the problems are, it is not sufficient to tell aircrew about them. They must receive simulated and actual training of those particular aspects of human factors failures which could befall them. Bob Taylor's picture this morning of the "hidden" cow is a very good example of perceptual problems. Once you see how you can be fooled by a picture, you are not fooled the second time. However, it is a difficult thing to put across in a lecture. Lectures, demonstrations, simulator practices should be used for training. (4) Specification. Having decided what your problems are, you should then "specify" them out by changing the specifications in designs of both aircraft cockpits and equipment. You should take out those particular aspects of design which have led to failures in the past. Colonel Johnson's plea for a lightweight helmet can easily be managed if you can define the advantages and risks of a heavy helmet and the advantages and risks of a lightweight helmet. Having done that, new helmets can be developed because you, in the specifications, will establish the compromise, the acceptable risk. You decide what you want. Having gone through investigation, communication, training, and specifications, my last item is (5) Construction. You decide what the problems are, you tell people about them, you "specify" them out, and you make sure the manufacturer will produce what you have asked for. This means you must write down clearly and exactly what you feel the problems are. I'd like to commend to the NATO community here a very useful document which has been specified by the U.S. military authorities. I believe the number is Mil Spec 1472B, which concerns itself with human factors designs principles. This is a compendium of information about those aspects of design which manufacturers should take into consideration to exclude problems which have happened in the past. This is a user document, I think, to broadcast to all. So, to summarize, we should concentrate our efforts in five major areas: investigation, communication, training, specification, and construction.

STANGROOM (U.K.): I was very interested that in your selection of items, you completely left out selection procedures. Perhaps you were thinking of that as a part of training. To my mind, initial selection is one of the most important factors and one in which, in NATO perhaps, we haven't given enough attention. We all fly very similar looking airplanes with very similar performances. We all have very different ways, it appears, of selecting pilots. In fact, some nations seem to have no particular method at all. Instead, they rely on someone else to do it for them. So, I wonder if you have any comment on how important initial selection is, and in that selection process, how important psychological factors are.

READER (U.K.): I deliberately omitted selection because this is a most impossible problem to grasp. How are you going to select pilots at an early stage of their training, or even before they have started

training? How do you identify those pilots who will, in fact, become human factors liabilities later on? The last speaker in this conference showed you that many human factors problems can be overlaid on the pilot without his knowledge or without his own voluntary act. I'm not quite sure, in fact, how you can exclude those problems by selection. Certainly, a medical examination can exclude the medical possibilities of human factors error. As we have heard today, the majority of the problems which have occurred in the human factors area are not ones of selection, but ones of operation.

ZELLER (U.S.): Another facet of the answer to your question is as follows: Psychologists in general certainly can "select" in people for almost any function. Within the USAF, we have a series of research projects underway that have the code name "Hasty Glue," which is aimed at selecting people ahead of time to perform as pilots. There are several limitations to this. An important one is that we don't really know what a pilot is. We haven't a clean, clear definition of the specifics of what makes a combat-ready pilot in terms of psychological characteristics. In spite of these limitations, on a purely statistical basis, we can and have followed people, although we have not selected on this system. The attrition we have observed would suggest that, in fact, we can do this, but this is an area going back to Colonel Johnson's problems. It certainly offers great potential, but at the moment is in it's infancy. It would seem that this is a good place for some research to be carried on.

JOHNSON (U.S.): In response to the selection question, I also have a comment. I think that we are not without a selection process that would work, at least in many phases. If we look historically at aviation medicine or medical involvement in aviation, we find some procedures even in the initial examinations that are rendered to the applicant who wishes to go into the occupation of flying. There is a considerable amount of selection even at this early stage, using factors like experience, education, and to some degree training. Furthermore, I think the applicant's performance on the initial application for flying includes some selecting in or selecting out. If we talk about aviation training as it relates to the military setting, most training programs are about a year in length and a great deal of selecting in or selecting out occurs during that year of training. Maybe what you are suggesting is that it should be more formalized, and that perhaps specific time periods be identified at which you would say this person will or will not make a safe as well as a good pilot. I think also maybe many of us sitting here are thinking of the pilot in terms of the fighter pilot. As we know, there are many different aspects of piloting the aircraft that are utilized in military aviation. You have the helicopter pilot, the transport pilot, the long-range bomber pilot, the fighter pilot, the pilot who is the teacher, the flight instructor pilot. So, I think we have to be more specific in talking about selecting pilots. We need to specify what particular kind of pilot when we talk about selecting in or selecting out.

I have one other comment for Dr. Reader. I would add a sixth factor and that would be the selling of the summary of these five items that you listed. As we all know, there are fiscal restraints, there are political restraints, and I think that after doing your five things, we must sell the appropriate agencies on the fact that what we have produced as the result of investigations and research is worthy of being implemented.

HARTMAN (U.S.): As you can see, the question on selection provoked a considerable amount of comment. Perhaps the Aerospace Medical Panel might consider either a session in this general area or perhaps some other mechanism for having the views from the aviation medicine community made available to the remainder of AGARD and NATO.

CHEVALERAUD (France): I would like to give some clarification of the word selection. I agree there is a need to add a sixth point to the five which were already mentioned and which we all endorse. Let me say that I am both a Doctor and a Psychologist. We generally speak, in medical terms, of selection as "fitness" or "unfitness." In other words, this selection process appears to be based on physiological and physical criteria. To be specific, we consider that applicants should be eliminated who do not have all of their bodily functions or organs completely intact. In addition, we also attempt to eliminate applicants who may have psychopathological difficulties in the future. That appears basically the medical standard in selection. But when we consider selection in the psychological arena, we no longer take this approach. We deal with the probability of success in a training course; so, therefore, the approach is totally different. Now, we all recognize that aircraft have changed. Therefore, we should also make changes in the selection process. Not only in selection per se, but also changes in the method of standardized investigations that we must also apply. I would like to bring up a very recent example. In France, we have recently correlated the EEG data with data received from the training schools. Note that the EEG data were not pathological data. We found interesting results which suggest that medical selection could perhaps be performed rather differently from the way it is done today. My point is to explain that selection is also undergoing changes. We no longer base ourselves exclusively on psychometric tests as in the past. In particular, we all know that data processing by the pilot is the thing of today, and therefore it is along these lines that our efforts should be directed. We should get rid of selection in the old sense of the term. Selection is undergoing great changes and, therefore, everything should also be adapted to the new selection processes.

HARTMAN (U.S.): That is a very provocative point and one that calls for a considerable amount of debate. New techniques--I think we need them. Selection in the process of changing--I agree. Throw out the old--I want to think a little about that. However, this is only a personal opinion. I think with this last comment by my French colleague, we will terminate the round table discussion.

REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's Reference	3. Further Reference	4. Security Classification of Document
	AGARD-CP-254	ISBN 92-835-0241-8	UNCLASSIFIED

5. Originator Advisory Group for Aerospace Research and Development
North Atlantic Treaty Organization
7 rue Ancelle, 92200 Neuilly sur Seine, France

6. Title HUMAN FACTORS ASPECTS OF AIRCRAFT ACCIDENTS AND INCIDENTS

7. Presented at the Aerospace Medical Panel Specialists' Meeting held in Paris, France, 6–10 November 1978.

8. Author(s)/Editor(s) Various — Edited by B.O.Hartman*

9. Date June 1979

10. Author's/Editor's Address Various

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USAF School of Aerospace Medicine
(AFSC)
Brooks AFB, TX 78235, USA

11. Pages 100

12. Distribution Statement This document is distributed in accordance with AGARD policies and regulations, which are outlined on the Outside Back Covers of all AGARD publications.

13. Keywords/Descriptors

Human factors engineering
Aviation accidents
Aviation safety
Collision research
Pilots (personnel)

14. Abstract

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AGARD Conference Proceedings No.254
Advisory Group for Aerospace Research and Development, NATO
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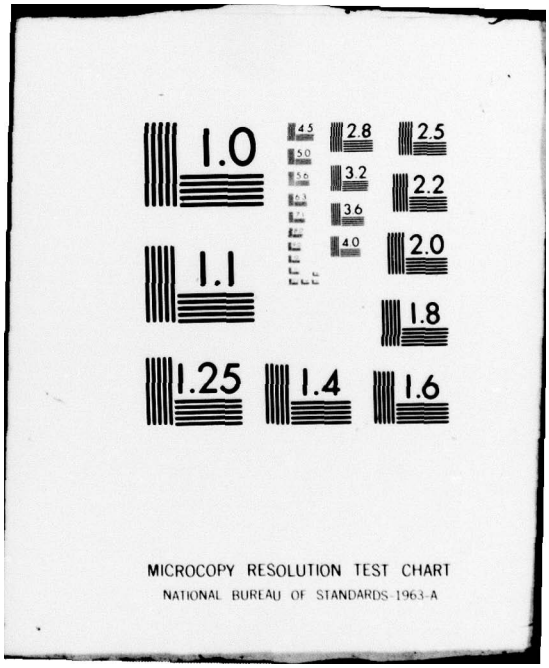
AD-A073 812 ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT--ETC F/G 1/2
HUMAN FACTORS ASPECTS OF AIRCRAFT ACCIDENTS AND INCIDENTS.(U)
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Printed by Technical Editing and Reproduction Ltd
Harford House, 7–9 Charlotte St, London W1P 1HD

ISBN 92-835-0241-8