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Call for Papers

The 1982 ISASI International Seminar will be held at the Dan Hotel in Tel-Aviv, Israel, during the period October 11-16, 1982. The Seminar will be devoted to three basic themes:

First Day: "The Investigation of Avionics and Electronics Failures"

Second Day: "The Investigation of Composite Material Failures"

Third Day: "Investigation Cases of Special Interest during the Past Year"

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Authors wishing to present papers are invited to submit a 200-300 word abstract to:

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From the Mail

After reading "The Editor's Cornered" in the Forum Spring 1981, Volume 14, Number 1, I feel that I should share with you some of my feelings on the adequacy of accident investigation by the government investigators, particularly those ground installations for which the government is responsible to install, maintain, and operate. As you may be aware, these ground based systems comprise at least 50% of the total system used by most aircraft to navigate from point A to point B. The remaining 50% of the total system is in the aircraft installation, and the ability of the crew to use it.

The FAA is charged with the responsibility of planning, installing, maintaining, operating, and certifying all air navigation facilities that are used by air carriers. This responsibility within the FAA is shared by the Air Traffic Control, Flight Standards, and Airway Facilities divisions. Aircraft Engineering is involved only in investigating the air frame and related components of the aircraft for airworthiness.

The FAA is the sole investigatory body for the investigation of FAA airway facilities that might be involved in, or have contributed to, an aircraft accident. This provides some interesting aspects to the investigation of aircraft accidents.

The NTSB uses the FAA findings in their published reports of the cause of the accident. However, the NTSB does not publish the actual FAA technical findings of facil-

THE JEROME F. LEDERER AWARD

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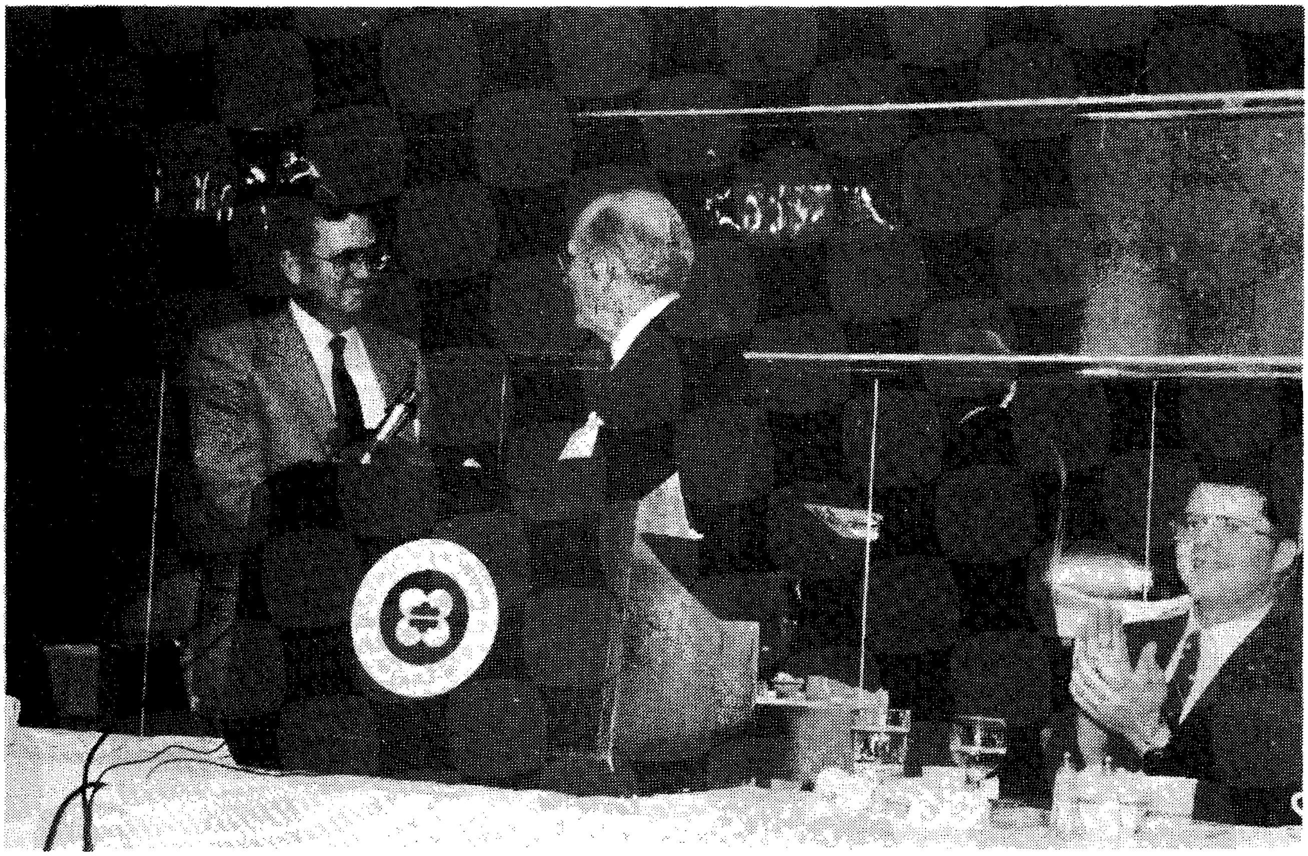

Dr. Robertson has used his extensive experience in accident investigation and crash research to develop improved techniques for investigation which he has taught to over four thousand students in courses on Crash Survival Investigation and in other safety related areas. He has developed new methods and equipment, resulting in crashworthy fuel systems for aircraft and racing cars. His extensive record of publications has served to share this knowledge with the entire safety community.

These contributions, through example and leadership, have encouraged and aided others to achieve technical excellence in accident investigation.

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Photographs by Robey J. Green and Ira J. Rimson

Methodological Biases Which Undermine Accident Investigations

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Strongly differing opinions about accident causation among conscientious, well-intentioned accident investigators frequently arise in accident investigations. These differences can complicate investigations, frustrate investigators, undermine the credibility of investigators' work in the eyes of the public and others, and delay or misdirect safety improvements. This paper explores reasons why these differences occur. It is a status report of ongoing research into accident investigation theory, principles and practices in support of advanced accident investigation courses conducted for the University of Southern California.

The research findings reported here indicate ways to reduce controversy about accident investigations, and improve their contribution to our nation's well-being. The purpose of this paper is to share my findings in the hope they will lead to an improved accident investigation methodology that encourages meticulously disciplined, harmonious "win/win" accident investigations, regardless of the subsequent interests of the parties.

The research findings and conclusions reported are solely the author's, and do not necessarily reflect the views of the University, the National Transportation Safety Board or any other organization with which the author is or has been affiliated. The author accepts all responsibility for the contents and conclusions reported.

Is There Really An Investigative Problem?

It seems wherever one looks these days, one sees evidence of controversy about accident investigations. The Summer 1981 ***forum*** reports on such a controversy between two investigative bodies in New Zealand.[1] The international journal of insurance and risk management reports that the UK Department of Trade has issued a strongly worded report disagreeing with Spanish investigators' report of the Dan Air crash last year.[2] In the USA, ALPA continues to take issue with a National Transportation Safety Board report of a 1978 accident.[3] During research efforts, differences of opinion cannot be conclusively resolved with one of the more highly respected aircraft accident investigation data bases available.[4]

Controversy is not confined to aviation. At least four reports of the Three Mile Island nuclear plant accident were published, each presented differing views.[5] Jurors relate to me their personal uncertainties in arriving at accident case decisions. Litigation abounds. Investigators quarrel. Students bring frequent examples of controversial conclusions from accident investigations to my classes. I regularly encounter views about how accidents should be investigated and reported that are very different from my own - even among ISASI members. Jerry Bruggink and I, for example, were unable to reconcile our different professional views before he retired. One author describes 20 different analytical approaches in a new accident investigation book.[6]

Every experienced investigator recognizes that differences exist. In my view, their consequences can be significant - in terms of investigations, administration of justice to individuals and organizations, money that changes hands, and even public confidence in the results of investigations. Investigations can stretch out. Investigative costs can escalate. Recommendations for corrective action can be delayed or misdirected. Blame or fault can be laid on the wrong persons. Licenses or reputations can be unfairly jeopardized. One party may inappropriately have to bear the accident costs. These are no small matters to the individuals directly involved!

Why can't investigative differences be reconciled more easily? Is it solely a matter of the money or reputations at stake? Or is there some technical problem that ISASI members could attack to overcome these differences?

My research suggests that ISASI members can do something constructive, if we will recognize why the differences exist, and act in concert to overcome them.

Summary of Findings

My research findings lead me to conclude that most differences arise because:

1. Investigators unconsciously base their investigative methods on methodologies adapted from their academic disciplines or previous work experience; this leads to highly individualized, personalized investigative methodologies;
2. Adaptations of an individual investigator's methodologies lead to differences in "tests" for technical truth used by each investigator in accident investigations;
3. Differences among tests for investigative "truth" make it hard for investigators to work together, and lead to differing conclusions by each investigator;

4. The lack of commonly accepted investigative truth tests allows each investigator to incorporate untested descriptive and judgmental materials into an accident report, increasing the potential for subsequent disagreements.

These findings highlight the need to develop a generally acceptable investigative methodology with methods for testing technical truth during investigations.

Today no mechanism exists to delineate, report and evaluate the differing methodologies used in accident investigations. Thus investigators have no basis for picking a "best" methodology, and few incentives to improve their own until they personally get caught up in a controversy. By that time, it is often too late—the battle is raging, often with us in the middle.

Let's look at these points one at a time. But before we do, let's make sure we are working with a common perception of at least one term:

What Is A Methodology?

Until I differentiated methodology from method during the research, I didn't really appreciate the significance of some of the things that were happening. Recognition of the issues we will explore in this paper depends in part on awareness of differences between "*methodologies*" and "*method.*"

Let's consider the term "*methods*" first. As you consider the findings, think of method as being a regular, disciplined and systematic procedure for accomplishing a task. A method is a technique. During an investigation, investigators use different "methods" or techniques to interview witnesses, calculate flight paths, examine debris, read out data from records, and even to structure the participation of other investigators. Method emphasizes procedures according to an underlying, detailed, logically-ordered plan.

Methodology, on the other hand, has a broader context. A methodology is a *system* of *principles, practices* and body of *procedures* (methods) applied to a specific branch of knowledge - determining in large measure how that branch of knowledge is practiced. A methodology is an overall approach to a field. The term "methodology" was selected for this paper because the subject of my research is the broader systemic approach to the accident investigation field, rather than individual procedures or methods.

The Origins of Modern Investigative Methodologies

As I became conscious of the methodological differences in accident investigations, I began looking for the reasons they existed. I observed that most investigators got into the accident investigation field through other fields. My own experience encompasses engineering, management and consulting. Some accident investigators have been or still are pilots. Some, engineers. Some, lawyers. Some, psychologists. Some, policemen. Some have safety experience. However, I have yet to meet the first investigator who decided to become an accident investigator and then engaged in a course of study with accident investigation as its major academic discipline.

Each of us has brought to the accident investigation field our previous academic or work disciplines. That background is unique to each of us. The different methods we developed through our academic pursuits and work or other experiences were the methods we felt comfortable adapting to investigations. As we continued our investigative work, we developed a body of investigative methods that, taken together, constitute our personal investigative methodology. When one examines the methodologies at work in investigations, at least six distinctive general methodological approaches can be observed.

Six General Accident Investigation Methodologies

The six methodologies or bodies of methods are listed below. Each methodology has characteristics and uses truth tests that are distinctive from all the others. Although the classification does not result in completely exclusive classes, the categories help understand investigative disagreements. The methodologies, in the order I recognized them, are:

1. "common sense,"
2. safety,
3. engineering,
4. statistical,
5. adversary, and
6. symbolic modeling.

Let's look at each, in terms of what it is and the truth tests it imposes.

1. The catch-all "common sense" has been used to describe the unstructured methodology for investigations that have been observed among some investigators. My first experience with highway accidents typified this approach. If the explanation of the accident "made sense" it was acceptable. It incorporated Kipling's six faithful servants (who, what, when, where, how, and why), and the apparent nature human tendency to try to order events sequentially when we try to remember something.

Technical truth is judged in the investigator's mind as s/he "reconstructs" the accident sequence.

2. The observed "safety" methodology was difficult to delineate. Much of the safety field has been dominated by H. W. Heinrich's philosophy since the 1930s. That philosophy is based on the "unsafe act" and "unsafe condition" approach to "prevention of accidents." My observations of investigations conducted by safety personnel suggested this dichotomous view on several occasions, especially in industrial accident investigations. The search for unsafe acts and conditions and their elimination to prevent future accidents explicitly drove the investigative efforts. It is a cause oriented, "single fix," retrospective approach. This methodological approach seems less prevalent, but still present, in general aviation investigative work today (pilot error, equipment failure), and it dominates much of the industrial safety field, especially among smaller concerns.

Technical truth is tested either against some coding standards, or ex-post-facto by how the investigator judges what happened against what the investigator considers "normal."

3. In a high technology environment, I next noted engineering methodologies drove accident investigators. Engineers were interested in the application of empirically-derived principles to the design, construction and operation of a working, productive facility or system. Observations of engineers' efforts in accident investigations suggests they are more interested in understanding how the accident occurred than whose fault it was and the "cause." Their methods reflect engineering approaches to studying the behavior of related components involved, and learning from these relationships how to produce better products.

The engineers' test for technical truth is "did it work" reliably the next time (or the familiar fly-fix-fly approach). Ergonomics, crashtesting, and operational factors efforts seem to be examples of investigative work based on engineering methodologies.

4. The statistical methodological approach to investigation has been observed, too, most extensively in the highway field. It seeks data from accidents that can be used to hypothesize causes and causal factors. It can be detected when forms are used during investigations and in the secondary statistical analysis work performed on accident data, both intended to confirm investigators' hypotheses. The goals of statistical inquiry are the identification of determinant variables, and from their isolation, the prediction and control of phenomena. The statistical methodology influences in large measure the data sought during light aircraft investigations, for example, and looks for "technical truth" after the investigation is concluded.

The statistical methodological approaches deal primarily with technical truth in terms of statistical tests of probabilities of factors present as "experimental" results. Human factors investigations, psychological autopsies, and biorhythm investigations seem to be examples of this methodological approach.

5. My observations in the aviation accident investigation field suggest that most major accident investigations—whether for accident prevention or other purposes—are driven by "adversary" methodologies. This methodological approach can be observed most clearly in two processes: the US "party system" of investigations, and the commission-type inquiries used in some countries. The influence of legal concepts, principles and rules of procedure and form of the final work products is dominant. In practice, the two processes seem to rely heavily on the adverse interests of parties to the investigation to bring hypotheses to light, rebut adverse views and present the strongest technical evidence for a favorable determination of "cause," or blame. During the research, it has also been noted that the principal effort during the processes was directed at determination of "cause(s)" and their elimination. During discussions with investigators, the terms fault and blame was often used. The many common points of the investigative proceedings and legal proceedings are readily recognized by anyone who has studied or practiced both. In view of government's role in the development of these processes, the similarity should not be a surprise.

Technical truth is reached through the adversarial development of relevant evidence from which reasoned conclusions are logically drawn.

6. My observations also suggest another methodological framework that is quite advanced in some fields. My term for that methodology is symbolic modeling. Mathematics and music probably are the most advanced examples of this methodological approach. Symbolic representations that permit recording, study, analysis, understanding, replication and manipulation of phenomena are their goals. Fault trees are another, more frequently encountered example of this methodological approach in the safety field. Symbolic modeling has been observed in accident investigations but was not generally considered a separate OVERALL methodology. For reasons that have been detailed in an earlier paper‡ my view is that it should be treated distinctively as an overall methodology. It demands a finite beginning and end to the investigation and an ordered display of the accident mechanism that facilitates information exchanges and problem resolution.

Technical truth is developed by logically linking the flow of events among concretely defined accident elements (actors) in a timed-matrix format. In investigations, the logical events flows are temporarily and spatially tested in the matrix, as soon as it is acquired.

There, briefly, are the 6 general methodologies that seem to be driving accident investigations. I have seen them all exerting influence on accident investigations and accident reports. I have seen as many as four present in a single investigation. Ted Ferry, in his new book, has a list of 20 different methods for analyzing accidents.

The Impact on Truth Tests

Each methodological approach involves differing sets of assumptions, concepts, principles, "laws," and procedures (methods) to arrive at the scope and technical truth about an accident. When more than one methodology is present in the investigation of the same phenomenon, we begin to encounter trouble because each methodology calls for differing

- accident scope, to which technical truth will be applied;
- investigative methods, used to arrive at the technical truth;
- accident data, sought to establish the technical truth;
- truth tests, applied to the investigative data to establish the actual scenario for the accident; and
- the likelihood that investigator's conclusions or assertions are reported as facts.

Are these differences important? My answer is an unequivocal YES. My research indicates that their importance lies in the different investigative demands they impose on each investigator. If you are working within a symbolic logic framework which provides a "win/win" investigative environment leading to understanding of the accident, imagine your frustration in trying to get cooperation from another investigator who is working within

- an engineering framework, looking for engineering or debris testing proofs or

- an adversary framework, looking for fault or culpability or
- a safety framework looking for a cause or unsafe condition to correct to prevent similar accidents, or
- a statistical framework looking for "all the facts" for later analysis and use.

Forty-four reported reasons for investigating accidents were previously reported.[8] Since February 1980, five more have been identified by some of my students. Many reasons are incompatible, as just shown. Disagreements arising from these cross-purposes, however, are merely symptoms of the methodological differences which unintentionally bias investigators.

The Impact on Investigative Reports

As my research continues, and I understand more clearly these differing methodological frameworks and truth tests, and the differing demands they impose on investigators, another—and possibly more important—question has emerged. Why do we need so many investigations of the same accident? After all, the accident only occurred one time, in one way in which everything involved had a probability of 1—it happened. Why are so many different purposes involved, and why are so many investigators and investigations needed? I have seen one accident in which 7 independent investigations were conducted. Why couldn't one investigation serve the needs of everyone involved?

One breakthrough in my research occurred as I worked with the truth tests to try to distinguish between "observed data" and "interpreted" data (investigator's conclusions) reported on accident investigation forms. One day, I suddenly realized that a single "time" reported on an accident form was an investigator's conclusion since a finite time period had actually elapsed during the accident. This led to the realization that much of the time investigators record their interpretation of the actual data, rather than the VALUE-FREE observations from the evidence. Much of the recorded data were investigator's conclusions—subjective personal judgments representing interpretations by the investigator. As the enormous significance of this distinction began to take shape, a lot of problems began to be understandable. If each investigator used different test criteria for making these judgments, reproducibility suffered. Discussions with investigators disclosed that—except in large accident investigations—the TECHNICAL truth of these CONCLUSIONS was UNTESTED!

Three grave problems began to dawn on me:

1. In the absence of rigorous truth tests, we were dealing with a lot of subjective investigator's opinions on the forms, which meant that we were looking at and arguing opinions rather than "fact";
2. "Observed data" about the accident were indiscriminately blended with the investigator's subjective opinions about the nature of the accident being reported;
3. Uncertainties were almost never reported, even in some major accidents, allowing speculative assertions to pass unchallenged;
4. Users of these kinds of reports were basing their work on UNTESTED opinions that, when tested, were fatally flawed in at least one respect-the absence of time relationships among events.

To sum up these problems simply, investigators were reporting arbitrarily selected data, blending it with untested subjective opinions or assertions, not mentioning the uncertainties in their reports, and then sending this information on its way to unwary secondary users! Any wonder arguments ensued?

From there, the search became more direct. The reasons for this state of affairs could be traced directly to the underlying investigative methodologies, their associated individualized "truth testing" techniques, and the general acceptance of these uncritical "truth tests" by secondary users. Greatly simplified, Common Sense accepts "sensible" explanations as true. Engineers regard something that can be tested and made to work as representing adequate truth. Statisticians rely on validation with probabilistic truth tests. The pure adversary methodology tends to recognize the "winner's" arguments as the most likely to represent the truth. Symbolic modelers regard logical, tested and displayed sequences as "truthful."

These realizations suggested that if the methodological differences can be recognized and resolved, a single truthful accident investigation report might not be a hopeless IDEAL. If methodological differences can be reconciled, and "truth tests" agreed upon, an "ideal" single accident report to serve all subsequent purposes might become a reality.

What Next?

This leads to my last point. My research suggests that investigators initiate consideration of the development of TWO types of accident investigation reports.

The first type of report would be a DESCRIPTIVE accident report, in which the accident mechanism or scenario is described to the level of detail possible by the surviving evidence. The mechanisms would best be described by a graphic flow-chart display. Narrative reports would be optional.

My experience with this methodology shows me that an entire set of accident events sequences could be developed cooperatively by anyone willing to make all available data available, capable and willing to support the investigation effort to its conclusion, and willing to accept a common INVESTIGATIVE METHODOLOGY. The investigative effort would allow investigators to use data acquisition methods currently in use. However, these efforts would be disciplined by an overall investigative framework with technical truth testing methods that would-at a minimum-

1. Force the organization and relevance testing of data as quickly as it is acquired, so known data and data gaps or uncertainties become visible quickly to all participating investigators;
2. Provide accident events-flow truth testing methods during investigations;
3. Compel use of agreed-upon events-flow truth testing methods by all participants during the investigation;
4. Require systematic structuring of anyone's speculations to avoid wild goose chases during the investigation;

5. Delay the proposing of hypotheses to the evidence actually developed and structure "what if" reasoning to conform to facts at hand;
6. Display the logic flow and uncertainties of the accident mechanism in a way that all investigators can agree to its "truth" before the investigation is terminated.

Such a method, originally derived from NTSB's aircraft accident FDR/CVR analytical techniques dating back to 1960, exists and has been used very successfully in non-aviation accident investigations.[9,10]

The second type of report would be INTERPRETIVE reports based on the descriptive reports. My observations of disagreements suggest that disputes often arise with the interpretations placed on the accident data or mechanism after it has been reported. True, often the mechanism is uncertain or not fully developed. However, if the technical truth tests do not permit validation of the mechanism, the descriptive report would acknowledge the uncertainties. Then the interpretive report could acknowledge these gaps and could freely speculate about these uncertainties and gaps to the extent desired by their authors.

It will be alleged that reports which present "facts," "analysis" and "conclusions" today provide this descriptive and interpretive distinction. However, when these distinctions were tested in the classroom for technical truth with symbolic events modeling techniques now available, every report analyzed failed. We did not analyze any major catastrophic aviation accident reports. However, without exception, each report we did analyze contained one or more gaps or investigator's conclusions in the factual section, which affected the safety action taken. It isn't important whose reports we analyzed: every one had gaps in the description of the accident when rigorously tested, and fewer than 10% even mentioned any uncertainties.

This research sends me two loud, clear messages. As accident investigators, we all should strive for a generally acceptable INVESTIGATIVE methodological framework with technical truth tests that every participating investigator will use. Concurrently we should strive for the complete separation of descriptive and interpretive accident investigation reports. As Ben Franklin once said, we'd better hang together on these matters, or we'll all hang separately.

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Biography

Ludwig Benner, Jr. is Adjunct Professor at the University of Southern California's Institute of Safety and Systems, Eastern Region, where he developed the DIA-GRAMS accident investigation system for a core course, INVESTIGATION OF ACCIDENTS, in USC's Master of Science degree program. He received his BS degree in Chemical Engineering from Carnegie-Mellon University in 1950, and studied Interstate Commerce Law and Traffic and Transportation Management at the College of Advanced Traffic. He is a registered Professional Safety Engineer.

From 1950 to 1962 Mr. Benner served as transportation engineer with the Chemical Division of the Pittsburgh Plate Glass Co. in Ohio. He then joined Air Products & Chemicals, Inc. as Manager, Rail Transportation and Engineering Services, advancing to General Distribution Manager in 1965. In 1967, he joined EBS Management Consultants, Inc. as a Principal Consultant, providing client services in transportation, market development and safety. He joined the National Transportation Safety Board in 1970, and is presently Chief of the Hazardous Materials Division, Bureau of Technology, with responsibilities for accident investigations and evaluations of safeguards, procedures and performance of other Government agencies in hazardous materials transportation safety.

Mr. Benner also developed the 'D.E.C.I.D.E.' Decision Making Process approach for Fire Science instruction of emergency response personnel while an Adjunct Professor at Montgomery College. Author of over 30 publications in accident investigation, risk analysis and hazardous materials emergency management, he is also a frequent public speaker and has served in numerous community activities. He has testified on safety matters before the U.S. Congress on numerous occasions, served on two Virginia Legislative Study Commissions, a National Academy of Sciences panel, and on several Federal agency project and advisory groups, including UN and ICAO safety standards groups, and an NSF emergency response research project.

One Investigator's Attempts to Overcome Methodological Problems in Aircraft Accident Investigations

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The views expressed in this paper are solely those of the author and do not reflect the opinions of the National Transportation Safety Board.

Introduction

A well used phrase in our profession, "gather and report all the facts, conditions, and circumstances of the accident," describes our major investigative task. Yet, in view of the amount of effort expended to achieve this goal and in view of the concern for thoroughness and efficency, I have often asked myself, do I really need all the facts? If not, what facts do I need, and how do I know which ones I need?

An investigator must address these fundamental question in an attempt to improve his present fact-gathering and analytical methods. This must be accomplished to remain up-to-date with current technology in order to solve complex accident investigations with which he will likely be confronted in the future. In this regard, this paper will discuss these questions in an attempt to focus some attention on ways to improve accident investigations. It will include some pitfalls encountered from personal experiences and will examine how these pitfalls may be avoided by improving the investigative methodology.

Background

After having acquired some experience in military aircraft accident investigations and having attended the Safety Board's accident investigation school, I felt I was prepared to handle most aircraft accident investigations. I did not encounter any difficult documenting evidence gathered in an investigation, but it soon became clear to me that I needed to improve my ability to analyze and synthesize the data I was gathering to insure that I had all the relevant facts. How often have some investigators asked themselves, "have I thoroughly examined all the available evidence to permit me to conclude the on-scene investigation?" (For the purpose of this discussion, on-scene investigation does not mean solely the wreckage examination, but also includes other aspects of the investigation as well).

Synthesis of the accident data sometimes becomes the most difficult task to perform. We are probably better prepared to examine the bits and pieces of the accident story than we are equipped to effectively bring together these parts to explain the entire accident phenomenon. Subtle accident clues may be overlooked because of the dynamic circumstances in which they occur, in addition to our limitations in assimilating the sequence of events from the accident data. In major accident investigations, sometimes the data and the task can become complex to the point where an individual investigator cannot, through normal thought processes alone, identify all the accident-enabling factors without the use of some techniques. The investigator cannot expect to retain all the information and sort it out in his head. The techniques used have taken such forms as the organization of data into various formats, the use of illustrations for the purpose of animation, and the use of critical path and fault tree analyses. I think we are also aware of our limitations when we seek the use of an aircraft simulator to reconstruct the accident occurrence. The investigator must also consider the task of presenting the data in such a way that others can clearly understand the accident phenomenon. This usually takes the form of a narrative type report, but more use of graphic means to present the data, particularly during the on-scene investigation can be very valuable.

It is comforting to note that I was not the only one wrestling with similar ideas. Two articles which appeared in the Spring and Fall 1975 issues of the FORUM, and written by respected investigators within the Safety Board, addressed this subject of methodology in accident investigations. In the Spring issue article entitled, "The Role of Analysis in the Fact-Finding Process," by Gerard M. Bruggink, he raised two questions with respect to ICAO's definition of an accident investigation: (1) What constitutes an orderly fact-gathering process, and (2) How does one determine which information is related to the cause of an accident? He properly recognized that most investigation courses and textbooks relating to the analytical reasoning processes involved in an investigation were deficient and he highlighted those necessary skills. Of special interest to me was his comment concerning the possible view by some investigators that they should refrain from open discussions about what could have caused the accident. He stated, "Actually, nothing is more detrimental to the field phase of an investigation than the pretense that all pertinent facts can be discovered without a selective, analytical process." He further stated, "...fact finding and theorizing are so closely intertwined that any attempt to separate the two would negate the purpose of the investigation." It was his opinion that every specialist should be kept abreast of the overall development of the evidence and only when he understands the role of his contribution in the total context of the investigation, can he effectively recognize new evidence in his specialty area. I believe that the manner in which the participants are kept informed on the development of the investigation is of the utmost importance.

In the Fall 1975 issue of FORUM, the article entitled, "Accident Investigations: Multilinear Events Sequencing Methods," by Ludwig Benner, Jr., described an effective and useful method of handling accident data. He also made a presentation concerning "Accident Theory and Accident Investigation" at ISASI's 1975 annual seminar in Ottawa, Canada, which provided some of the background for the development of his suggested methodology. At that time, he challenged ISASI members in the development of an accident theory because, "assumptions, principles and rules of procedure are nowhere systematically organized, and that generally accepted rules of procedure for analyzing, predicting or explaining the accident phenomenon are not readily available to the accident investigator." As he appropriately stated, "Knowledge of these principles is assumed to be the province of the investigators."

A Suggested Solution

Experience has shown that we as investigators do not need all the facts. This, of course, is a misnomer. What we need are the relevant facts and how we manage to achieve this goal involves considerable expertise. We investigators must strive to improve that expertise. The following points are believed fundamentally important in our line of work:

(1) A proven and effective accident investigation methodology;

(2) Effective techniques to provide for the ability to visualize and assimilate accident data; and

(3) Effective techniques to provide for the ability to analyze, test, synthesize, and present accident data.

I believe most investigators who have participated in a major accident investigation will agree that one of the most difficult tasks in developing an accurate accident scenario from the wealth of accident data that develops is to determine the relevant evidence and place it in perspective. If an investigator will give some thought to how he normally accomplishes this task, he will immediately recognize how the three previously mentioned points play a vital role in explaining the accident phenomenon. If one waits to perform this function when he attempts to write the accident report, it will be too late to capture elusive evidence and he cannot be sure that he has all the available relevant facts. Without the use of a systematic approach to the accident:

(1) Objective reasoning becomes clouded with personal opinions;

(2) Participants begin to decide individually what is and what is not relevant evidence based on their judgments and interpretations;

(3) Participants jump to conclusions without supportable evidence; and

(4) The investigation is concluded without obtaining all the relevant facts.

A suggested solution to these pitfalls would, therefore, be to develop a methodology useful and recognizable by all participants so that all would be using the same yardstick, so to speak, to measure the "relevance" of the data.

The following is an example of how I applied, in a general way, Mr. Benner's events sequencing method in an accident investigation.

On February 10, 1978, Columbia Pacific Airlines, Flight 23, a Beech 99 commuter flight with 15 passengers and 2 pilots on board, crashed during takeoff from runway 36 at Richland, Washington. After liftoff, the airplane climbed steeply to 400 ft, stalled, then struck the ground 2,000 ft beyond the end of the runway. A severe fire erupted after impact. All on board were killed and the airplane was destroyed.

On-scene investigators initially hypothesized that the airplane pitched up steeply during the takeoff due to a stabilizer trim runaway malfunction. The reasons which influenced this initial thinking were based on the witnesses' description of the takeoff, the post-impact appearance of the stabilizer's position, and the previous history of potential runaway trim malfunctions in the Beech 99. However, it was learned that this initial assessment was in error once the stabilizer actuator jackscrew measurement was compared with Beech engineering data. This data showed that the stabilizer was in the prescribed range for takeoff at the time of ground impact. At this point it was clear that we had to reevaluate the evidence to ascertain what facts may have been overlooked.

It was then decided to first concentrate on determining the takeoff profile and the relevant events which lead up to the crash. Because of the unavailability of a cockpit voice or flight data recorder, we had to rely on witnesses, dispatching, and airplane performance data from which to construct a model of the takeoff profile (figure 1). Observations from several witnesses were recorded on a matrix chart (figure 2) to assist us in arriving at a consensus on the airplane's position and attitude during the takeoff. Once we completed the model profile, we began correlating this data with physical evidence being gathered from the wreckage examination. We used a time based sequencing method, of which an ex-

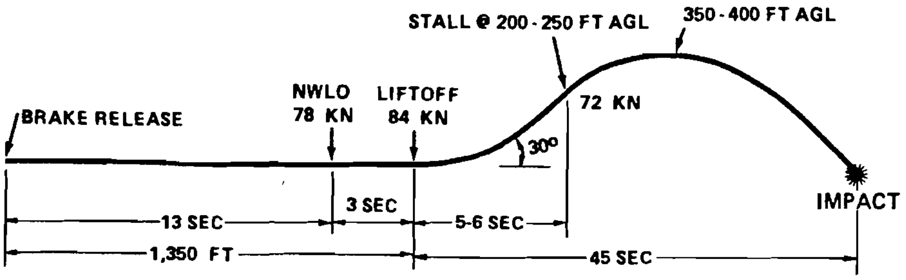

Figure 1.

WITNESS MATRIX CHART

	0 TIME → OBSERVED EVENTS IN SEGMENTS						
WITNESS AND LOCATION	POINT OF BRAKE RELEASE	POINT OF ROTATION	POINT OF LIFTOFF	ANGLE OF CLIMB	ATTITUDE IN CLIMB	ATTITUDE TOP OF CLIMB	ATTITUDE IN DESCENT
WITNESS (1)							
WITNESS (2)							
WITNESS (3)							
WITNESS (4)							

Figure 2.

SCENARIO MATRIX

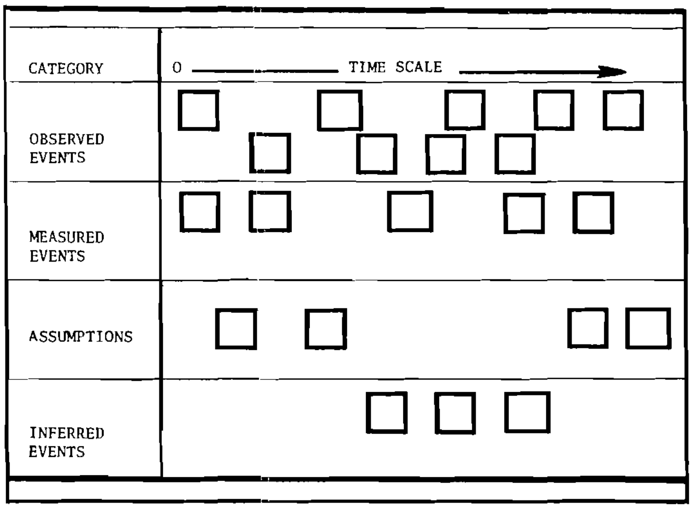

Figure 3.

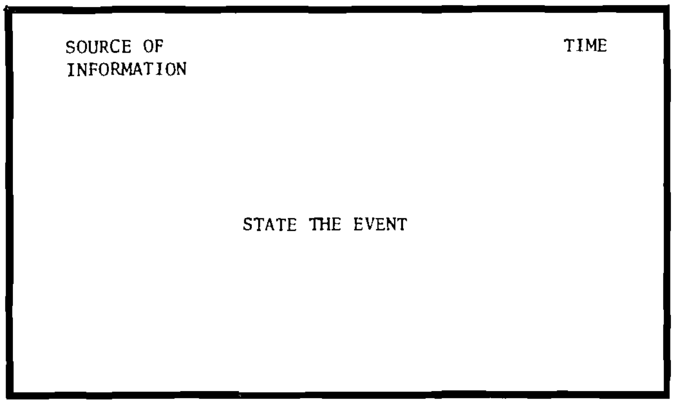

Figure 4.

ample of the basic format is shown (figure 3). We also used 3 x 5 index cards on which to record determined events (figure 4), which were arranged in the format shown in figure 3. *(An event is one action by an actor, linked to a change of state.)* Shortly after we began charting the data, we were able to see the direction in which it was leading the investigation. Additionally, we were able to agree and make an early but accurate hypothesis to explain how the accident probably occurred. It was determined that the airplane was mistrimmed for the takeoff. The following is a list of the accident enabling factors:

(1) Inoperative out-of-trim aural warning system;
(2) Malfunctioning clutch in the stabilizer trim actuator;
(3) Actuator trim rates;
(4) Type, location, and position of the stabilizer trim switches (Primary OFF, Standby ON);
(5) Type and condition of the trim position indicator;
(6) Location and condition of the flight bag;
(7) Airplane center of gravity and wing flap positions;
(8) Dispatching and flightcrew practices and procedures; and
(9) A hurried departure.

A flight test program conducted subsequently to the close-out of the on-scene investigation verified the conditions and events as developed. The Safety Board's determination of the probable cause was "...the failure or inability of the flightcrew to prevent a rapid pitchup and stall by exerting sufficient push force on the control wheel. The pitchup was induced by the combination of a mistrimmed horizontal stabilizer and a center of gravity near the aircraft's aft limit. The mistrimmed condition resulted from discrepancies in the aircraft's trim system and the flightcrew's probable preoccupation with making a timely departure. Additionally, a malfunctioning stabilizer trim actuator detracted from the flightcrew's efforts to prevent the stall."

Some advantages experienced in using such a systematic method of analyzing and synthesizing the accident data were:

(1) It provided an effective means of organizing and testing the data within the total context of the accident;
(2) It provided an effective means of insuring that all the relevant facts at the scene were recovered before termination of that phase of the investigation;
(3) It provided an effective means of stimulating and encouraging cooperation and active participation by members of the team; and
(4) It provided an effective means of informing the participants on the progress and direction of the investigation.

Conclusions

Not every accident investigation is alike. Many are not complex and an explanation can be arrived at rather easily. I do not mean to indicate that these would be conducted in a perfunctory manner, but the amount of time and effort expended may be comparatively small. On the other hand, there are those cases wherein the accident phenomenon cannot be readily identified. Probing for the actual accident scenario usually involves many manhours and other resources. It is necessary in such situations to approach the problem systematically to achieve effective and efficient use of the available resources. I believe that a method similar to the one mentioned should be used to meet this need and to obtain all the relevant evidence at any phase in the investigation. The major points are these:

(1) Strive to test the data before arriving at conclusions;
(2) Strive to develop the actual accident scenario before closing out the on-scene investigation; and
(3) Be able to present the accident data so that others can clearly understand and believe the accident scenario.

I believe that as the air transportation system becomes more complex, so will our investigations of accidents which occur within this system. It will, therefore, be incumbent on investigators to acquire the necessary knowledge, methods, and methodology in order to meet this demand. Perhaps there are other useful means which have served other investigators that go unmentioned. If so, it would be beneficial to bring these to the attention of other interested investigators. I look forward to seeing more similar discussions in future issues of the FORUM.

References

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Biography

Steve Corrie has been associated with incident and accident investigation since 1966. His experience began in the United States Marine Corps, serving as a pilot; safety, flight standardization, operations, and maintenance officer. He was qualified in both airplanes and helicopters, and flew nearly all of the aircraft in the Marine Corps inventory at the time he was discharged from active duty in 1969. He also gained some experience in Civil Aviation as a pilot and director of maintenance for a commuter airline.

Steve was employed by the National Transportation Safety Board in November 1970. He started his career as a field office investigator at the former Dulles International Airport Field Office before he transferred to the Seattle, Washington Field Office in August 1971. He transferred to the Washington, D.C. headquarters office in September 1977 where he currently serves in the Aviation Accident Division investigating primarily commuter airline and corporate aircraft accidents.

Steve holds an ATP with commercial privileges in single engine land and sea; multiengine land; and helicopter aircraft. He holds type ratings in the Cessna Citation, Gates Learjet, Boeing Vertol 107, and the Sikorsky S-58. So far he has accumulated 3,500 hrs of flight time.

Steve is the Secretary of the International Council of ISASI.

The Simultaneous Time & Events Process (STEP) Method of Accident Investigation

Richard W. Clarke, MO0891
and
J. Michael Jobanek, MO2259

I. Introduction

"We have met the enemy and he is us!" Many of us have heard this quotable quote from the Pogo comic strip, but there is no place it applies more aptly than in the science of aircraft accident investigation. The reasons for this are many, but the authors of this paper attribute it to the foibles of human nature which cause investigators to jump to conclusions relating to cause and circumstances of accidents and thus reach for simplistic solutions in increasingly complex accident scenarios. Professional accident investigators must avoid this pitfall while at the same time dealing within constraints of time, money, available personnel, workload, the media and our respective managements. Each of these constraints is very real and each diminishes the quality of investigations in varying magnitude; however, in our opinion, management must take the brunt of the criticism for poor investigative techniques. No more eloquent plea for management to educate themselves in the rudiments of scientific investigation technique exists than occurred during the field investigation of a recent transport aircraft accident. Within a few hours of the crash an investigator appeared in front of the news media, displayed the "smoking bolt" from the aircraft, and proceeded to suggest to all within earshot that this was the cause of the accident. This occurrence is not mentioned for the purpose of ridicule, but to emphasize the lack of sensitivity to the need for a more disciplined approach in the craft of accident investigation. Many investigating organizations have shown this deficiency in varying degrees.

If we are to make an intelligent decision about which way to direct our future endeavors in accident investigation, it is essential that we review the development of investigative methodology and tools. Accident investigation is no different from any other endeavor in that a sense of where one has been is essential if one is to have any idea of where one should go. Fortunately, the authors' experience has provided an opportunity to examine numerous accident reports dating back to the late 1940s. These reports give a needed benchmark or reference level of quality by which the reports of today may be judged. Needless to say, the tools, techniques and information available to the accident investigator have improved over the years just as the quality and reliability of aircraft hardware have improved; in many cases the accident reports have not. As commercial aviation entered the jet era, accident rates diminished because new technology eliminated numerous mechanical problems. As these mechanical failures were eliminated, the continuing occurrence of human factors failures, or what commonly is called "pilot error," became more visible. This brought about increased concern over the pilot error accidents and the installation of the Cockpit Voice Recorder (CVR) in 1967. Besides the CVR, the advent of the jet age brought about installation of other "human factors" equipment such as altitude alerters and Ground Proximity Warning Systems (GPWS). In addition to aircraft recorders, the ATC system, today, offers sophisticated recorded communication and radar coverage in the USA and many parts of Europe. This radar coverage and ATC voice tapes, which are continuously recorded, give the accident investigator a great deal of information that must be sifted and analyzed during the initial phases of the accident investigative process. This human factors information can be of great value in shaping the accident investigation, but only if it is organized, displayed and analyzed in a manner that lends itself to the scientific method of accident investigation.

In an effort to deal with the need for a system of considering both human factors and equipment-related problems, we propose a methodology called the Simultaneous Time and Events Process or STEP, for short. We offer it as a means of organizing the myriad of known and speculated events into a format that will give the accident investigator a more creative insight into what actually happened and what might have happened in an accident scenario. This will improve the overall quality of accident reports because it will allow the investigator to distinguish between what was known to have happened and what may have happened. Ideally, this will minimize the tendency toward unfounded speculation.

II. Defining the Problem

A review of past aircraft accident reports published by various governmental agencies, the military, and pilot groups indicates a dependence on the "chain of events" or "domino" theory in accident investigation. This theory, which evolved from the "single event" or "isolated cause" theory, has become the fundamental framework or methodology used in investigating aircraft accidents. The method has proven valuable over the years, but as more accident data has become available from Cockpit Voice Recorders (CVRs), Flight Data Recorders (FDRs), Air Route Traffic Control Center Radar Plots, Air Traffic Control Center Tapes and weather observations, it is becoming obsolete. Today there are multiple interrelated factors to organize, present and analyze in a meaningful format or flow diagram; therefore, conventional presentations, which visually depict the CVR and flight-path information during the final minutes of flight, do not facilitate an explanation of the interrelationship of the system and subsystem components that affect the accident. Thus, the need for a workable "real-world" methodology for analyzing the various elements of the man-machine-environment interface has resulted in the STEP method of accident analysis. It is especially applicable in the examination of crew coordination factors or procedures, but it can be adapted to examine a variety of problem areas in other transportation modes.

III. STEP Analysis

A. Accident Theory Evolution

Humans have probably always investigated accidents, purely out of a sense of curiosity. So long as the human race was unorganized and no significant store of community or personal property existed, curiosity served as an appropriate reason for an investigation; however, once property became an issue, compensation became a better motivation. Cause or blame needed to be established so that emotional or monetary compensation could be obtained. Today, we value lives and property and seek to preserve both while carrying out daily activities. For this reason, cause and blame begin to be replaced, as investigation motivators, by a desire to eliminate accidents and thus eliminate unplanned loss of life and property.

The word "unplanned" holds some importance for the safety profession and for society as a whole. Accidents are unplanned, but for the most part preventable. Prevention, until the last hundred years, has consisted of the legal system's seeking out culpable individuals who caused an accident and bringing these individuals to justice, either criminal or civil. The investigation profession, originally, was not distinguishable from the law enforcement profession. Insurance investigators were perhaps the first break from the strictly legal emphasis of accident investigation.

The safety profession began slightly more than one hundred years ago with legislation aimed at mine and railroad safety. This broadened to include general industrial safety and led to the rise of professional accident prevention specialists who sought to reduce the incidence of accidents. Their origin had been legal enforcement and they continued much of the tradition, albeit unconsciously.

Accident theory admitted to the dual possibilities of unsafe acts and unsafe conditions, one being favored by company owners and the other favored by company laborers. Either served as a prevention factor and both led to the post-accident search for the person who committed the act or who permitted the condition to exist. As time passed, a hybrid of this theory developed—the accident-prone individual. Accident proneness was convenient for safety experts in that location of such an individual would have represented a chance to eliminate both an unsafe action *and* an unsafe condition. The search for these unique individuals represented a sort of search for the mythical unicorn. Despite all of the literature devoted to the accident-prone individual, it seems surprising that so few, except for occasional criminals, were ever found by investigators.

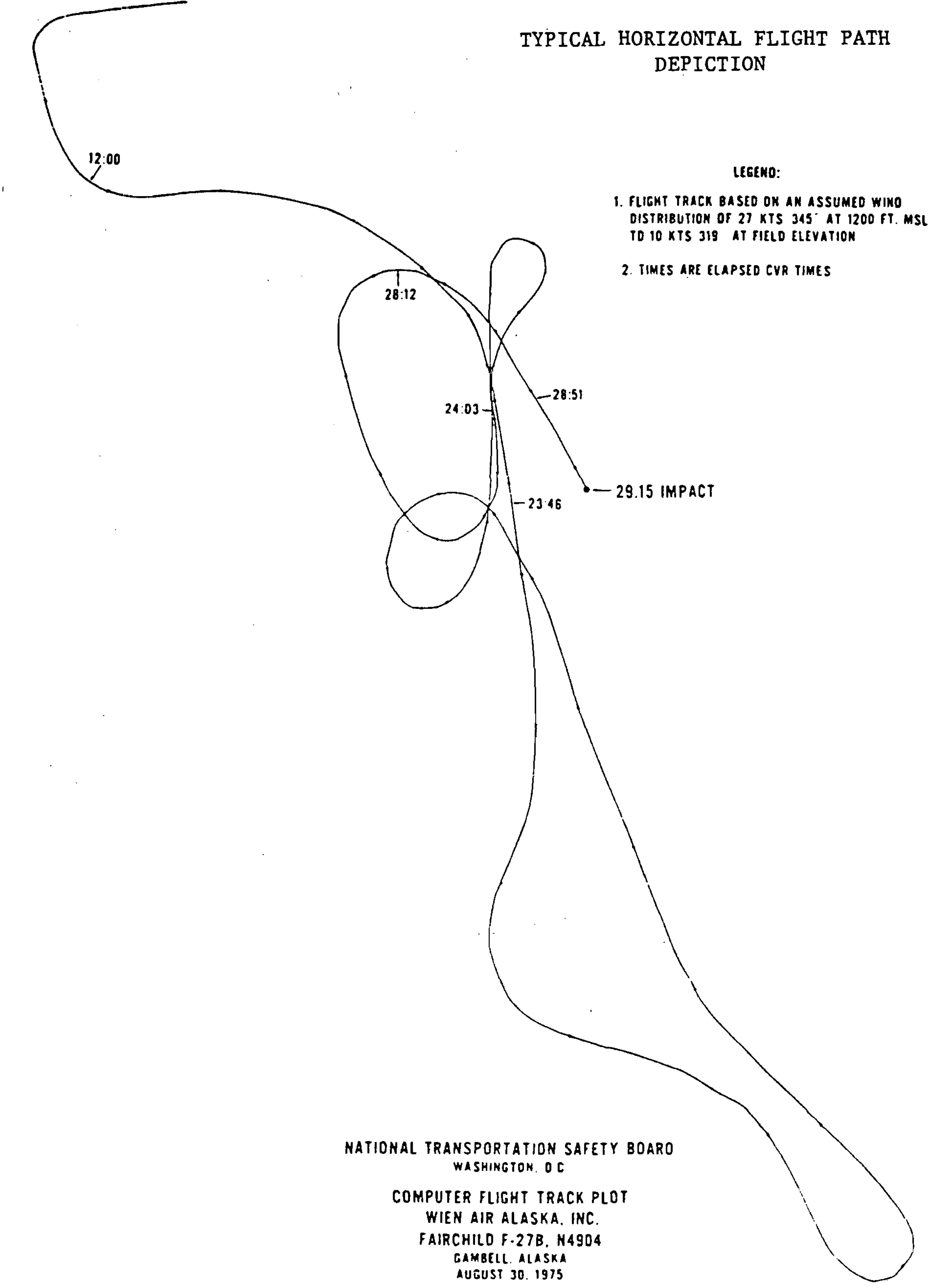
As time passed, the safety profession gained experience and sophistication. A reflection of this was the development of the chain-of-events theory of accidents. A new breed of unicorn arose and this permitted a new generation of investigators to go on new hunts for the "weak link," which could be any one thing from a bolt to a person. At this stage of development of the safety profession, the National Transportation Safety Board was chartered by the U.S. Congress. The Congress, representing a level of sophistication based on, but slightly ahead of, that of the general population, perceived the chain of events as the best in current safety thoughts and directed the Board to seek out the single cause of transportation accidents, as well as contributing factors. Without realizing it, the Congress tried to have its cake and eat it too. It sought out culpable individual causes, yet it wanted to find all other accident-enabling factors.

Aviation industry publications, for several years, have focused on the phenomenon of the "human factors" accident. The various articles usually laud the industry's success in eliminating technically caused accidents which result from equipment failures, and bemoan the industry's failure to eliminate accidents caused by human error. Typically, a statement appears to the effect that, "Today, most accidents are caused by human error." This almost implies that machines are getting better and humans are getting worse. Machines may be better, but humans are unchanged. Unfortunately, prevalent accident theory—fault technology—focuses upon the human being as if it were sufficient to say that the human failed and an accident occurred due to that person's failing. Such a judgment is not very helpful, nor is it very surprising; after all, we have become sophisticated enough to realize that the human is the most complex subsystem of the transportation system, viewed as a whole.

To say that a human failed is not to prevent an accident. In the extreme, this is shown, in some nations, by the arrest of aircraft crewmembers involved in accidents; despite the arrests, accidents continue. The human factors field needs a bridge to technical specialties, to integrate its knowledge with the other branches of aviation technology and develop a System Safety approach that may achieve a reduction in accidents below the residual level at which we operate now. For the accident investigator, STEP analysis may be the investigation tool that permits the integrated approach which is needed and which breaks the tradition of the single-cause, person-oriented accident.

Figure 1

TYPICAL HORIZONTAL FLIGHT PATH DEPICTION



LEGEND:

1. FLIGHT TRACK BASED ON AN ASSUMED WIND DISTRIBUTION OF 27 KTS 345° AT 1200 FT. MSL TO 10 KTS 319° AT FIELD ELEVATION
2. TIMES ARE ELAPSED CVR TIMES

NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D C

COMPUTER FLIGHT TRACK PLOT
WIEN AIR ALASKA, INC.
FAIRCHILD F-27B, N4904
GAMBELL, ALASKA
AUGUST 30, 1975

B. Derivation of STEP

STEP, as an investigation technique, is an adaptation of Mr. Ludwig Benner's multilinear events theory and is based upon aviation accident investigation experience and technology. In the field of transport aviation, and to some degree military aviation, we possess the technical advantage of flight data recorders (FDRs) and Cockpit Voice Recorders (CVRs) which are literal examples of Benner's theory without analysis being applied.

In doing work under Benner at the University of Southern California, the authors realized the advantages of his theory in the broadening of perspective which his work gave the investigation process. The ability to insert all known acts and conditions into a given moment of time, then to compare them to both the events which preceded and followed, as well as to the entire process, was invaluable. The theory seemed an excellent analytic tool for the investigator to use in reconstructing the accident process.

In the authors' work involving transport aircraft accidents, it seemed beneficial to adapt Benner's technique to existing analytic needs. Starting from the insight that the various voices and performance values available on CVRs, FDRs and ATC transcripts were actually parallel event streams, all of which made up the accident process, the authors began to fold them all together in a format based upon Benner's. It was found quickly that inconsistencies in events and in time frame in which they occurred stood out and that the parallelism of actors aided in picturing the playing out of the accident. In constructing the chart of parallel values, it was decided that both personnel and aircraft performance figures would be displayed together, thus providing the maximum of information in the display. This type of construction has proven very beneficial, as said before, in detecting inconsistencies of information or timing and has resulted in a very readable working document. The readability is a valuable asset, since a STEP analysis shown to someone familiar with aviation is the closest possible experience to observing or restaging the events. For pilots, particularly, STEP provides all the values used in a basic flight instrument scan; thus, aircraft performance and crew or ATC conversation can be compared for validity. As most of you realize, much equipment operation information can be gained from CVRs; thus, differing pieces of equipment such as landing gear, flaps and warning systems can be put into the STEP diagram.

STEP produces a real-world collection of data organized in a manner consistent with real-world behavior. It provides the investigator with a comprehensive analytic framework that goes as far as possible toward broadening the perception of accidents due to the amount of data portrayed. In this way, an investigator can reach conclusions based upon all available data and avoid non-sequitur conclusions forced upon him or her by lack of time and information.

IV. Utilization of STEP Analysis

Although the Simultaneous Time and Events Process is most adaptable to the air carrier accident, it can be applied to any type of accident scenario because it is really just a management tool for locating, sifting, organizing, displaying and analyzing information. As a basic management and organization tool, it can be applied in various parts of the accident investigation, starting with the field investigation and terminating with report writing.

- *Field Investigation*—The field or on-site investigation is often the most critical phase because of time constraints evolving from wreckage examination, body removal, runway openings, etc. The professionalism displayed during the field investigation sets the tone for the entire accident investigation; therefore, STEP should be incorporated from the earliest moment in an accident investigation for its management-organizational traits alone.
- *Laboratory Stage*—The laboratory stage of every accident would be served by a disciplined methodology for examining data collected during the field investigation. In this phase of the investigation, time constraints are alleviated and a well-disciplined inquiry that utilizes the scientific method will allow more facts to be uncovered and misinformation or gaps in information identified, thus giving impetus to further research.

The Simultaneous Time and Events Process involves utilization of a time baseline which starts at a predetermined point during the flight and usually terminates at impact. Individual parallel information "tracks" are drawn above the time line and are dedicated to each of the various "actors" in the accident scenario and include, but are not limited to, the following:

- *Voice transmissions* from ATC, captain, first officer, second officer or other cockpit occupants. ATC communications plus intercockpit communications are timed, written down verbatim and plotted in the most plausible position on the chart. ATC transmissions to and from other aircraft also should be included to indicate traffic flow, workload, distractions, etc.
- *Equipment* sounds such as bells, warnings associated with altitude alerters, ground proximity warning systems (GPWS), windshield wipers, etc. should be noted and their duration plotted.
- *Weather* information must be plotted to show forecast and real-time weather differences. This is valuable, especially when rapidly changing conditions exist.
- *Flight performance parameters* including headings, airspeed, vertical velocity, altitude and acceleration values must be plotted so that subtle changes can be evaluated with respect to the other so-called "actors." Additional factors can also be given a track of their own so that their action can be plotted with respect to all other activities.

Once all the "actors" and their actions have been plotted, an examination of their interrelationship is made with respect to time, speed, distance, workload, communications, crew coordination, etc. Also, lack of action can be examined; gaps in time and communications can be evaluated with respect to the hard-core guidelines of required procedures, checklist responses and known aircraft performance. The entire package of information breaks down the elements of the crew coordination factor, and gives the investigator a more complete data base for assessing the elusive enabling factors of the accident.

As an illustration of STEP utilization, during STEP analysis of a recent jet transport landing accident, it became apparent that the aircraft altitude information, though consistent in trend with other aircraft performance information, was not consistent with the actions of the crew or the planned descent path of the ILS approach. Comparison and

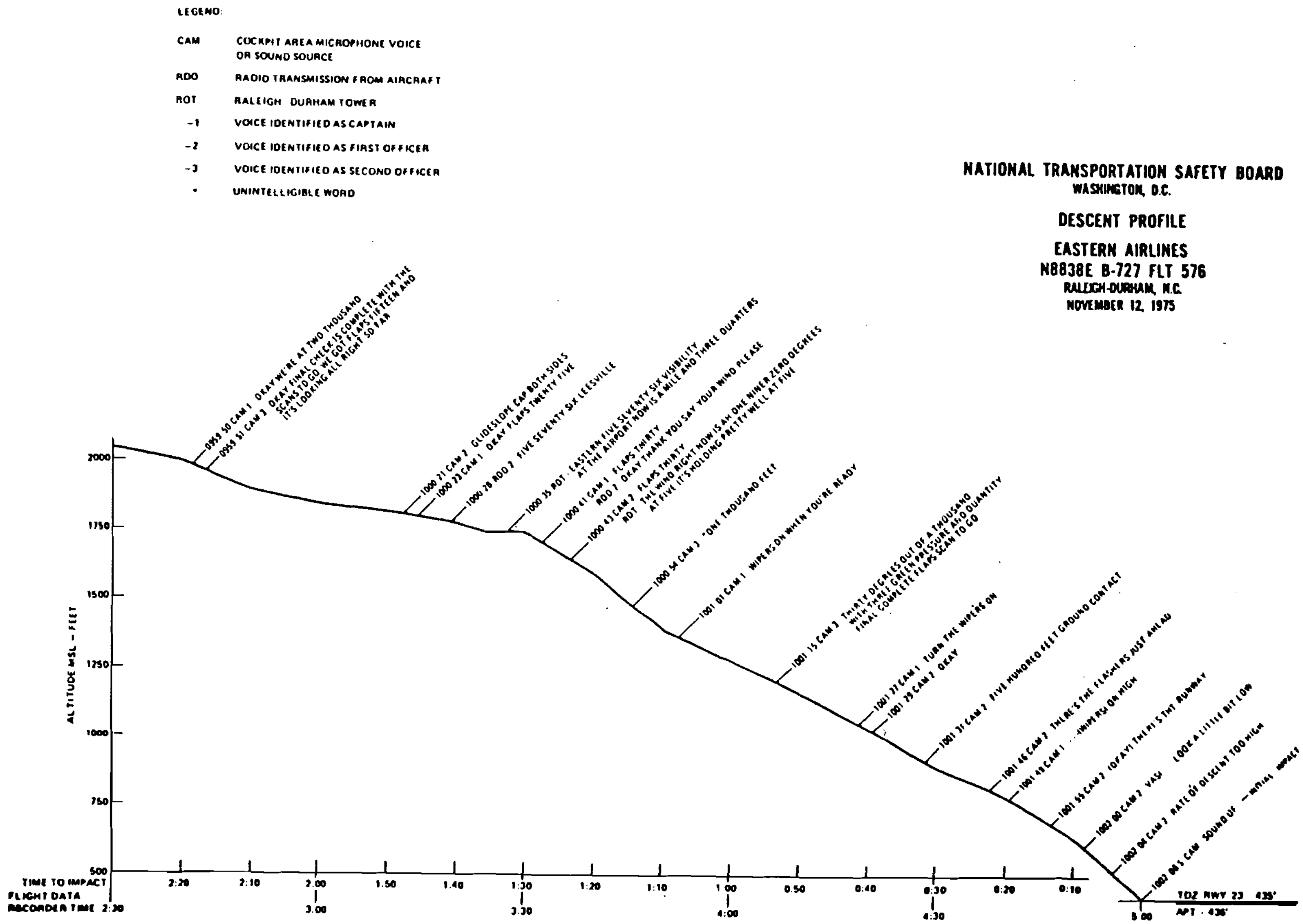


Figure 2
TYPICAL VERTICAL FLIGHT PATH DEPICTION

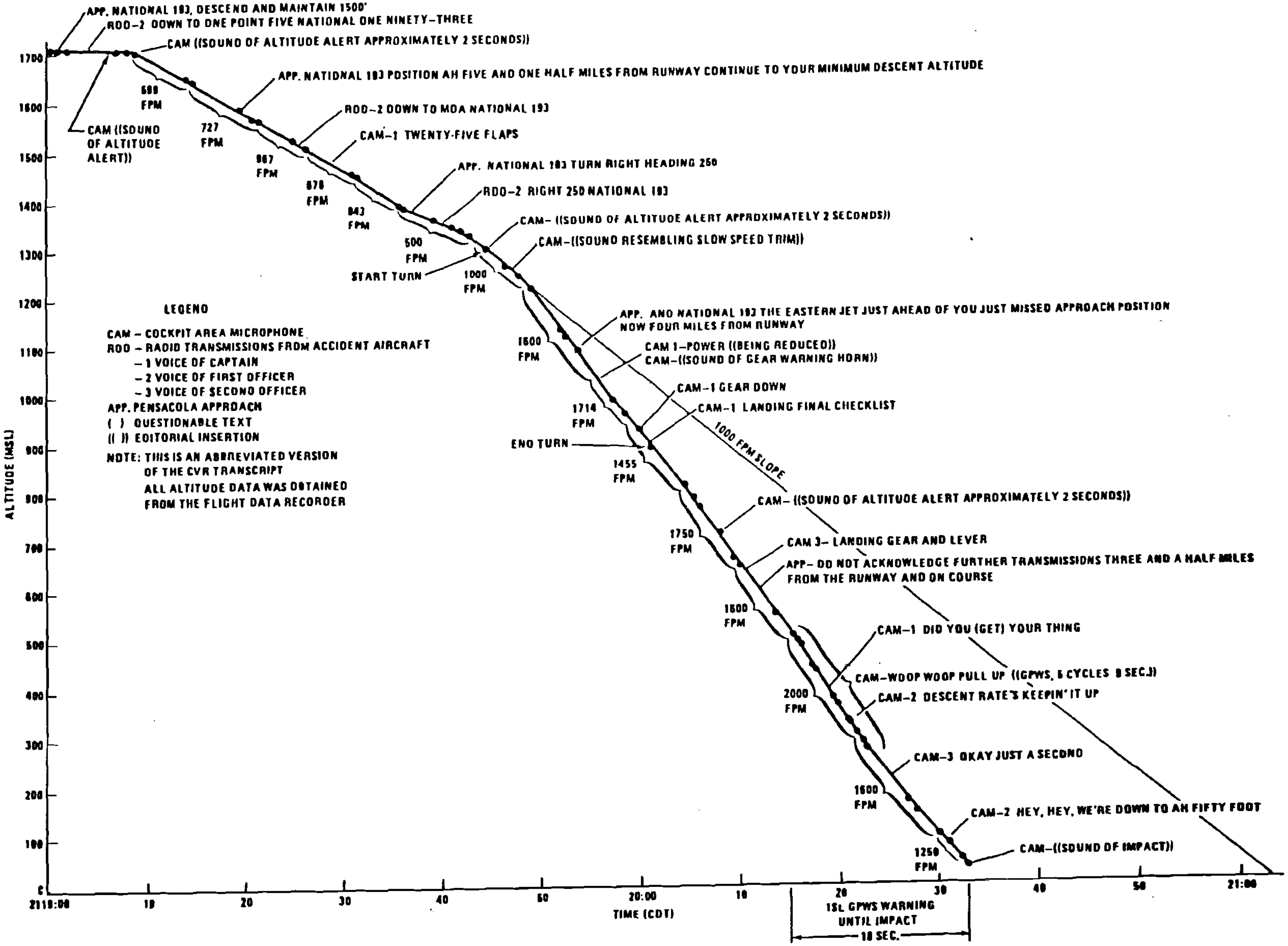


Figure 3
MODIFIED VERTICAL FLIGHT PATH
DEPICTION BASED UPON STEP
ANALYSIS

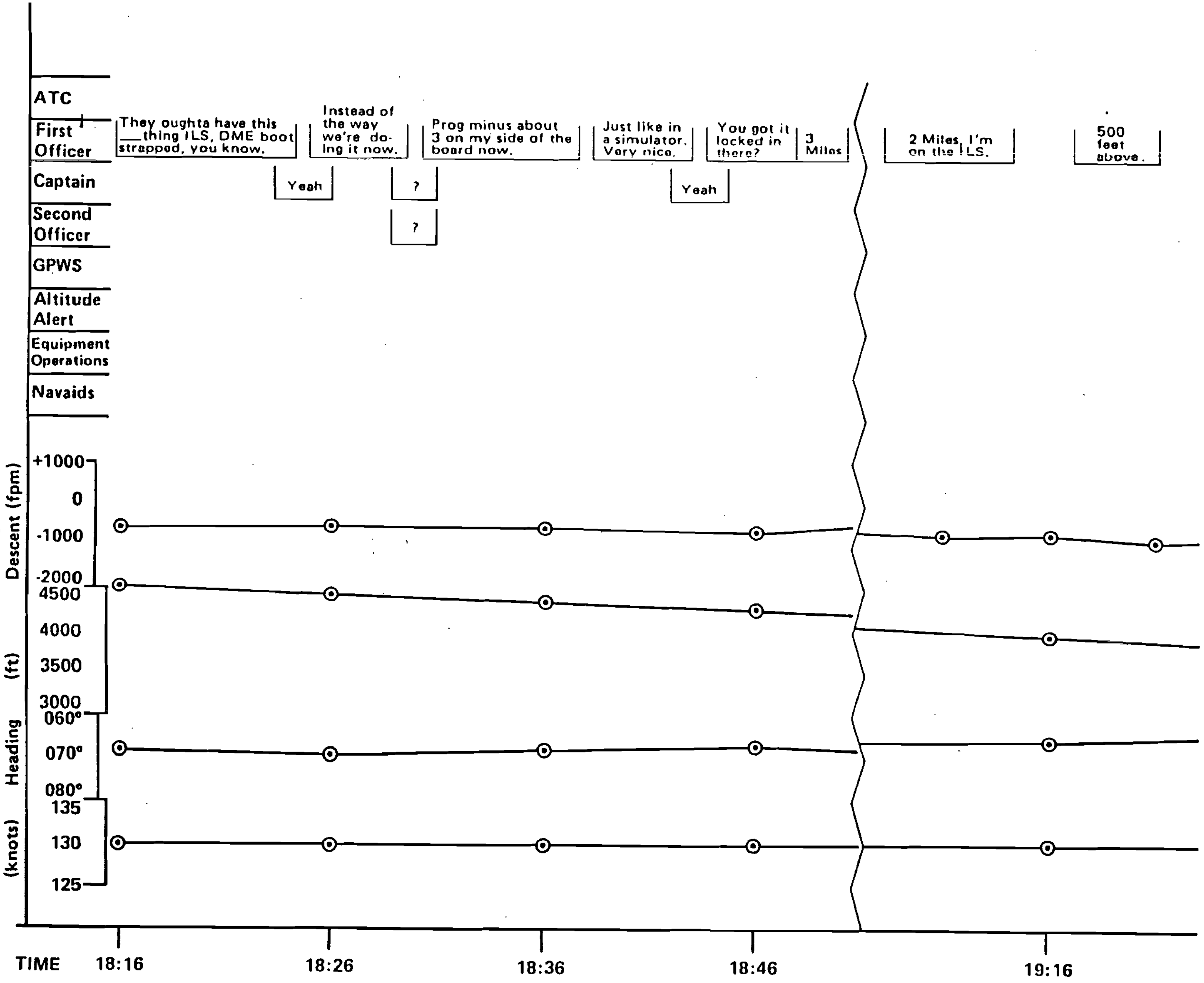


Figure 4a
SIMPLIFIED STEP ANALYSIS
ILLUSTRATING PARALLEL EVENT STREAMS

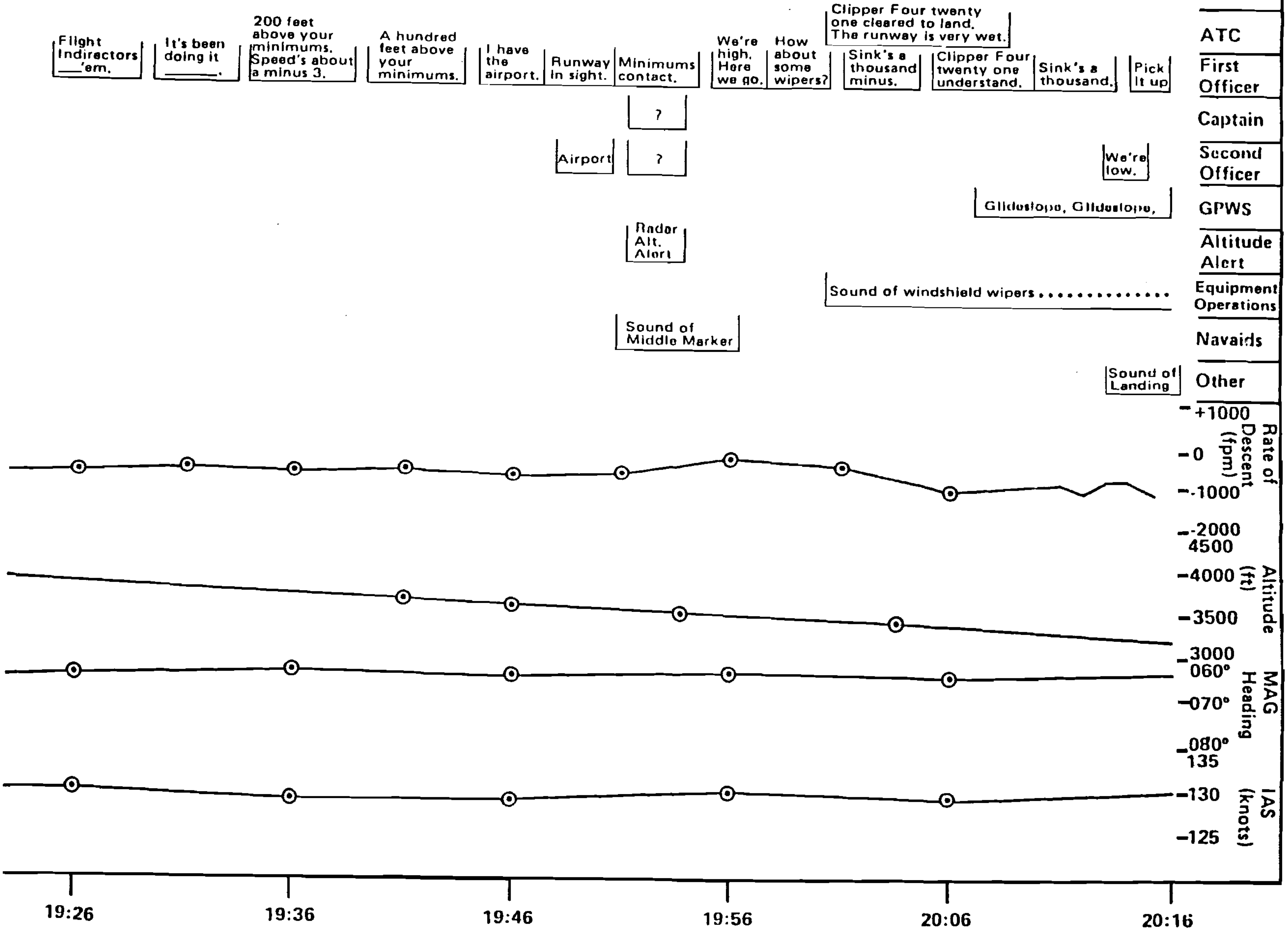


Figure 4b
STEP ANALYSIS CONTINUATION
TO ACCIDENT TERMINATION

correlation of STEP factors led to the hypothesis that the aircraft's FDR altitude trace was inaccurate. Conclusions regarding aircraft, crew, or navigation facility performance could not be drawn lacking resolution of the question raised by STEP; therefore, a specific analysis of the aircraft's glide path was undertaken and is described below.

ILS Profile

The ILS approach profile data was obtained and plotted with respect to the FDR altitude, speed, time and distance information. The approach plate depicted a 3.0-degree glide slope angle, but more exact information listed a 3.06-degree glide slope. This is within established tolerance levels. A large-scale, profile view of the glide slope, runway and glide slope intercept point was drawn and the "no-wind" data obtained from the FDR was plotted. The start point of the plot was the point of impact, 213 feet short of the runway threshold. Altitude data was plotted at one-second intervals for the 80 seconds prior to impact and at 10-second intervals preceding the glide slope intercept point. The resultant no-wind time, distance and altitude plot was computed and defined a glide slope of 2.52 degrees, which is well below the established 3.06-degree glide slope.

1. *CVR*—The F/O's CVR DME callouts were depicted and the time intervals calculated. This enabled calculation of an average ground speed and determination of a descent rate necessary for the aircraft to remain in close proximity to the published glide path.

   The ground speed averaged out to 277 ft/sec or 164 knots. Since the IAS was a constant 140 kts from the final approach fix inbound, the resultant tailwind was 24 kts.
2. *Post-Crash Interviews*—Crew statements made during the post-crash interview agreed with comments on the CVR and indicated that a precise flight path was flown.
3. *Hypothetical Flight Path*—In order to determine what magnitude wind would be required for the altitude trace to approximate the 3.06-degree glide slope more closely, the following assumptions were made. The FDR altitude points 80 seconds and 10 seconds prior to touchdown were projected on the 3.06 glide slope and the respective ground distance to the two points measured. With this known distance and the time interval of 70 seconds, a ground speed of 160 kts was computed. This closely corresponded to the ground speed computed from the first officer's DME callouts, and the matching vertical velocity necessary to fly the 3.06-degree glide slope.
4. *GPWS Glide Slope Warning*—The GPWS warning system, which marks a deviation from the ILS glide path, is armed to go off if the aircraft deviates 1.3 dots or more below the glide slope. In this specific case, the raw FDR altitude fell below the 1.3 dot low deviation; thus, the glide slope warning should have been activated by the GPWS. Since the warning did not activate prior to the aircraft's passing the middle marker, an assumption can be made that the actual altitude of the aircraft was *above* the 1.3 dot low deviation.

Although in this case much of the information that is normally available for flight path analysis is not available, the analysis which has been carried out validates the crew's statements that the aircraft was stabilized and on glide path until 10 seconds prior to impact. It was during this final 10 seconds of flight that serious flight-path deviations occurred. STEP pointed out the need for this detailed analysis and, once the altitude information was refined, it led to a more fruitful look at human performance factors.

V. Summary

STEP meets a need for developing a more comprehensive accident investigation technique. Current techniques and theory serve to address only single causation of accidents when, intuitively, the investigator knows that much more is involved. The limits of current theory are shown in the repeated frustration of reference to human error and the lack of progress in diminishing human error accidents. STEP provides the means for viewing human errors in context and analyzing their elements along with equipment factors. This, in turn, should provide useful information to both aircraft operators and designers.

The techniques used in STEP are largely those already used by many investigators. The difference, if any, lies in the format and combination of techniques. This analytic technique is useful both in the field and in the office, wherever pencil and paper are available; thus, an investigator can always begin a STEP analysis when needed.

For the future, STEP is adaptable to electronic processing with some innovative programming and integration with recorder readouts. As in the case of FDR readouts, an art, very likely, can be reduced to machine technology, thus allowing us all to spend more time on analysis and construction of quality reports and less on the details of arranging the data. Until that time, STEP is the best way to arrange the data.

Biography

Richard Clarke is a cofounder of Socal Safety Associates, a Reston, Virginia-based transportation safety consulting firm. Prior to the foundation of Socal, he served as Manager of Flight Operational Safety for the Flight Safety Foundation, Staff Engineer at the Air Line Pilots Association and as an Aviation Safety Officer in the U.S. Navy. He has an extensive flight background and holds an Airline Transport Pilot license. Mr. Clarke received a B.A. degree from the University of Florida in 1967 and a M.S. in Safety from the University of Southern California in 1979. He is the author of many safety related articles and is a member of the 1979-1981 FAA Safer Advisory Committee.

J. Michael Jobanek is a cofounder of Socal Safety Associates. He is also a Staff Engineer with the Air Line Pilots Association and flies the C-130 Hercules with the U.S. Air Force Reserves. He is dual-rated by the military as a pilot/navigator, accrued over 5,000 flying hours and has a commercial pilots license. Mr. Jobanek received a B.S. in Engineering from the U.S. Naval Academy in 1965; a M.S. in Civil Engineering from the University of Maryland in 1978; and a M.S. in Safety from the University of Southern California in 1981. He edits the Airport Operators Bulletin for the Flight Safety Foundation and lectures at the Glenn L. Martin School of Engineering at the University of Maryland.

Investigation in Small Countries

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When I a few years ago accepted the position as Chief Technical Investigator at the Swedish Board of Accident Investigation I had a faint hope that there would be a bit of spare time available to finish some safety research I was doing. I was wrong. After having criss-crossed Sweden for several years and worn out a number of shoes, but no trousers' seats, I have come to the conclusion that this is not the life for the restful.

The Scandinavian countries are small in population but large in size. Between the islands of Denmark, over the fjords and mountains of Norway and across the endless forests of Sweden, flying is the most practical method of transportation. The terrain varies from rolling lowland to ragged mountains, the weather from smiling summer sunshine to howling winter storms and the visibility from cloud-free view from horizon to horizon in 24 hours' sunshine to zero in noon-time winter darkness.

In Denmark, Norway and Sweden it was realized that with the expanding use of airplanes came a need for independent organizations to investigate accidents, and in the 1970s such organizations started their work in all three countries.

When the Swedish Board with Mr. Goran Steen as Director General started to work on July 1, 1978, the number of employees had been cut down to a bare minimum. However, the members were given high positions in the Government's Administration. We are two lawyers, with extensive courtroom experience as chief judges, acting as chairmen (this is required in Sweden), one operational investigator, one technical and two secretaries. Our responsibilities cover both civil and military aviation. We investigate approximately 30 serious accidents each year with full reports. People have wondered why the Sweden Commissions always are led by judges. The advantage of this is that the commission can take care of all aspects of an investigation, including the legal ones and work undisturbed by police investigations. This does not mean that the commission allocates blame. The main purpose of the investigation is still to improve flight safety. However, the reports cover the investigation in detail and can be used by other authorities, for instance the police, if they wish to pursue the matter further. We have had no such case yet.

Our military aircraft are Swedish designed and manufactured and the number of aircraft types is small. In case of accidents to these we have excellent support from the manufacturer and from the technical personnel and the laboratories of the Air Force.

On the civil aviation side the problem is more complex. We have no experts that can cover the field from a Piper Cub to a Boeing 747. Our solution to this problem is to make up a call-list of experts in various fields. This is done in cooperation with our CAA, SAS, Linjeflyg, the Swedish ALPA, the cabin crew organization and the aero clubs. We maintain an open attitude towards these organizations and towards the insurance company representatives that often contact us on the accident site. Furthermore, we regularly inform the manufacturers of the accident and invite them to send observers. Representatives of the people involved in the accidents are also invited as observers. The observers do not, of course, have any influence on the analyses, findings and recommendations.

In spite of our checklists it is not always easy to find the required help within the country. So, we must go abroad. When a Viscount dived into the ground on approach to Stockholm-Bromma Airport we received first class assistance from Rolls Royce, Dowty Rotol, British Aircraft Corporation and the Accident Investigation Branch of the Department of Trade, England. This made it possible for us to make a thorough investigation in reasonable time. Accident cause? Tail ice! Beyond the primary cause there was, however, an equally important contributing factor; a complete lack of information to the pilots regarding the risk of extending the flaps in icing conditions.

When you are stuck with a Russian TU-154 that has run off the end of the runway after an aborted take-off you feel a bit helpless, especially after having interviewed a crew that has seen and heard nothing. However, by delegating the technical investigation to Aeroflot, with Swedish observers present, and by having the flight recorder read in Moscow and getting a complete readout within 24 hours, the investigation boiled down to a fairly simple task. Accident cause? The crew forgot to switch on the hydraulic control system! Beyond this cause lay, however, a poorly de-

signed warning system that on taxiing for take-off flashed "Not ready for take-off" as long as the nosewheel steering was in the taxiing mode.

Another small country problem is the lack of overview of the problem area. When the wing of a light twin fails, the rotor mast of a helicopter fractures, the gyro of an air taxi and the ILS-receiver of another malfunction on approach the question arises if these are low frequency failures with no significance as far as overall safety is concerned. However, one realizes that what happens once in Sweden may happen hundreds of times throughout the world. In order to widen their view in this respect, the Scandinavian countries, including Finland and Iceland, pool their accidents in a computer system called Nordaid (organized by the CAA's in the countries). One of our first steps after an accident may therefore be to check for similar occurrences in Nordaid. But we do not stop there. As our friends at ICAO, NTSB, AIB and LBA (Luftfahrts Bundesamt in Germany) know we quite often draw on their experience. And what do we find? The single in-flight wing failure has happened at least 10 times before, and helicopter rotor masts have been fractured in at least 50 mast bumping cases. Our single occurrence suddenly takes dimensions. In Scandinavia the accident investigators of the various countries keep in very close contact. We all know each other, call each other, support each other and meet regularly to share experience. For instance, on September 15-16 this year we had a meeting in Oslo where Bill Tench was the main speaker. Last winter we had a review of our accident cases in Copenhagen and before that the Swedish Board arranged a two-day meeting for all Nordic investigators with David Holladay as main lecturer.

The advantage of being small, and with a very low frequency of major disasters, is that one may get more time to dig deep into the light aircraft accidents. Thoughts that bother us now are:

- Why is survivability not considered in soaring airplane cockpit design and why is this problem in general so poorly treated in light aircraft design? Is it not time to set up definite design requirements for survivability?
- Is "pilot error" really the primary cause in the majority of in-flight structural failures, or is it too easy to break the wing in combined pull-up and roll maneuvers? Why do wings fail when collision with the ground has been avoided and the aircraft is in a climb? Is it not about time that we make a thorough check of the control problems that lead to in-flight structural failures?
- Is it a single case of poor workmanship when the loose counterweight in a gyro looks as if it has been picked up in a junkyard, or should some of the equipment manufacturers take a second look at their production quality control?
- Why do some light twins roll on their backs when one engine stops at speeds well above V_{MC}?
- Is it true that wings cannot fail if you reduce your speed to the maneuvering speed in turbulence? Should we not give the pilots better warning regarding the high loads that can be obtained in vertical gusts when dynamic $C_{L_{Max}}$-effects, roll with opposing aileron deflections combine with a sharp vertical gust!!
- Is it really true that you can control the rotor rpm of a helicopter with a runaway engine with the twist grip, as stated in the emergency procedure, when one also can find a statement in the handbook that says: "Use of twist grip for rpm control is not authorized"? Is it not about time that we start writing better manuals?

Biography

Name: Aage Roed
Born: Sept. 2, 1922, Norway
Citizenship: Swedish

Education:

Basic, up to junior college, Norway. Mathematics, Uppsala University, Sweden. Aeronautical Engineering: University of Detroit, Michigan.

Employment:

- Head of Performance Group, Saab-Scania, Sweden
- Project Aerodynamicist responsible for the J 29 "Flying Barrel", the J 35 "Draken" and the AJ 37 "Viggen", Saab-Scania, Sweden
- Senior Aerodynamicist Lockheed, Burbank and Convair, San Diego
- Head, Flight Safety and System Analysis Section, The Aeronautical Research Institute, Sweden
- Chief Technical Investigator, Board of Accident Investigation
- Lecturer on safety to the Institute of Aviation Safety, Royal Institute of Technology, Stockholm, SAS, LIN, Norwegian and Swedish Air Forces, Swedish ATC-School, Austrian Air Force, Portuguese Air Force, TAP, Swedish Institute of Meteorology and Hydrology
- Author of: Flight Safety Aerodynamics, Flight Safety of Aircraft Structures and Systems, Flight Safety Aerodynamics for Helicopter Pilots, etc.

Human Performance Investigation

An Approach Towards the Assessment of Human Performance During Accident Investigations

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National Transportation Safety Board

Introduction

There is little disagreement that human error underlies the cause of a very large percentage of aviation accidents. Despite its incredible safety record, commercial aviation continues to be plagued with accidents where aircraft, in otherwise good condition, are literally flown into the ground or obstacles, in IFR and in VFR conditions, in daylight and in darkness, in good and in marginal visibility. In most of these accidents, the pilot has been cited for inadequacies in performance. The list is familiar: nonadherence to prescribed procedures; failure to monitor altitude; failure to recognize passage through decision height; inadequate supervision of flight; failure to exercise positive flight management. While these descriptive terms may be adequate explanations of what took place to cause the accident, they do not address the question of why the human failure occurred or how it was allowed to happen.

The dialogue on the subject of human performance has been ongoing for some 15 years, and it has swelled to a crescendo of criticism directed usually at the investigative authority for its lack of action or at the human factors investigator for his lack of understanding or his unwillingness to understand the basic mechanisms that cause a breakdown in expected crew performance.

In defense of the investigator, let me point out that 30 years ago the enormously high accident rate in the U.S. Air Force caused sufficient concern to begin research into the underlying "why" of pilot error; today that same organization is still attempting to come to grips with this problem. And let me point out also, in defense of that investigator, that we have yet to hear from our critics any suggestions for alternatives or improved methods of investigating the human performance aspects related to accident causation or suggestions on where in his procedures the investigator took the wrong approach.

The purpose of this paper is to give an overview of where the human factors effort of the Safety Board is going and to solicit constructive comments on our approach.

The Human Factors Group

For those of you who are only generally familiar with the task of the Human Factors Investigator and with the role of the Human Factors Division within the National Transportation Safety Board, let me give you a brief overview of the beginning of the Human Factors Group and its growing role since it came into existence in the mid 1950s.

The research conducted by Cornell University shortly after World War II on the crashworthiness of aircraft and the ability of the human body to withstand much greater forces than previously believed, showed the need to investigate the adequacy of occupant protection in aircraft accidents in as much detail as were the mechanical circumstances of the accident. Thus, the human factors specialty was established. The name "Human Factors", in the context of the investigator's task, of course was a misnomer in that it had little to do with the academic specialty embraced mostly by psychologists. We were merely interested in documenting the mechanics causing injury and death in accidents. Shortly thereafter, the Human Factors specialist's task expanded naturally to include the physical and physiological condition of the flightcrew as a causal factor in the accident as well as the cabin environment and its post-crash survival potential, including emergency egress and protection from fire and its toxic by-products. Over the years, the procedural aspects of cabin attendant effectiveness and training were added, as were the adequacies of firefighting and rescue capabilities of airports and the disaster preparedness of communities. We considered for a short period of time the concept of controlling and directing the mass casualty aspect of the investigation, including the recovery, pathology and identification of victims. In fact, many observers erroneously believe that this latter aspect is indeed controlled by the Safety Board. Considering the manpower and fiscal resources needed for that task, not to mention the legal aspects that would be involved, the Safety Board simply is not able to perform such a function and the law does not provide for that responsibility.

Finally, in the last 10 years, the Human Factors Group, as a natural outflow of its functional responsibilities, began to address the human performance question. This task was not taken on lightly. In contrast to the tasks of other specialists involved in accident investigation, such as powerplants, systems, operations, ATC, etc., the Human Factors specialist is asked to take on a number of specialties. We expect the Human Factors specialist to have expertise in such diverse disciplines as medicine, physiology, biology, sociology, engineering, chemistry and anthropology, to name only a few. To lighten the workload on the investigator, the future direction in the organization of the Human Factors effort, consistent with resources, is to split the traditional human factors specialty into three distinct areas, namely:

1. medical and crush injury factors,

2. survival and other post-crash factors, and
3. human performance factors.

Assessing Human Performance

The approach taken by the Human Factors Division in the investigation of human performance aspects of accidents was to design a simple investigative model patterned on the man-machine-environment concept. One of our ground rules, in the approach to this model, was that the procedure should be systemic, it should be a modest effort, it should be practical, and above all, the procedural steps should be understandable to all participants.

The model has six basic elements representing interrelated and overlapping areas affecting human performance. These are:

1. behavior aspects;
2. medical aspects;
3. equipment design considerations;
4. operational factors;
5. task or workload; and
6. environmental factors.

It is not the purpose of this paper to conceptualize this model; that is the purpose of a following paper in this session. However, let me attempt, with a few examples of past accident histories, to show the operational utility of our approach.

One of our early successful attempts to explain the underlying "why" of pilot error was during the investigation of the first wide-body transport aircraft accident that crashed in the Everglades near Miami in December 1972. The pilots were attempting to resolve an abnormal nose gear indication which interrupted the approach and landing routine. The aircraft's autopilot was engaged, but during the activities of all three crewmembers to resolve the nose gear problem, the autopilot somehow received a negative pitch input and the aircraft was allowed to descend into the ground. A detailed (although informal) human performance investigation revealed that equipment design, operational and behavioral factors combined to cause this accident. Equipment design, in that the hold function of the autopilot in the control wheel steering (CWS) mode of operation was not a positive function. Operational, in that company policy did not allow the use of the command function of the autopilot (which did have a positive altitude hold function). Consequently, pilot training did not emphasize the command feature of the autopilot. And behavioral, in that the captain did not assume or delegate positive aircraft control (one of the oldest adages in aviation) which again was traceable to inadequate training procedures.

Another example of a successful human performance investigation was during the investigation of an air taxi accident near Rockland, Maine, in May 1979. The crew flew the aircraft into trees while on a non-precision approach to the airport under adverse weather conditions. A thorough background investigation of the pilot revealed emotional problems of a personal nature as well as of a work-related nature. The work related problems were extreme management pressures on the pilot, who performed additional duties as the chief company pilot and as chief check pilot, but who was not allowed to make operational or management decisions. Further interviews with pilots who had flown for this company previously revealed an atmosphere of intimidation in the company, poor employee morale and the "cutting of corners" in standards and training to ensure profitability. The human performance investigation showed this combination of factors (behavioral, medical, and operational) to be strongly associated with the cause of this accident.

Conclusion

We believe that our approach to the investigation of the human performance aspects of accident causation will allow a rational analysis of the underlying "why's" of human performance failures. Only recently, the Safety Board established its first formal human performance group during the investigation of a Beech 99 commuter accident in Spokane, Washington. We are very much encouraged with this first formal and systematic attempt. The investigation showed that our model is viable and brings together all the human elements of the operational, systems, ATC and medical investigations into one document, which facilitates analysis and provides direction with respect to probable cause determination.

This first formal attempt also has shown that the composition of the human performance group is an important factor. The members of the group in this case were the FAA Regional Flight Surgeon, the Director of Operations of the company and an accident prevention specialist of the FAA. The group was headed by the Board's Engineering Psychologist, and aided by an Operations Specialist. The group members' qualifications were shown to be an important factor, as was the size of the group which should be kept small for maximum flexible response.

Finally, the interesting observation was made that only a few participants to the overall investigation really understood the reason for the formation of the Human Performance Group and its purpose in the overall scheme of the investigation. To eliminate misunderstandings and to assure efficient interfacing of information, we have found it necessary to mount an intense educational effort among all investigators concerning the purpose of this new investigative technique.

Our program is finally off the ground; we will welcome any suggestions you may have to refine our efforts to reduce the human error potential in aviation.

Biography

Mr. Walhout is Chief of the Human Factors Division with the Bureau of Technology of the National Transportation Safety Board in Washington, D.C. He directs the human factors aspects of accidents and, as such has been involved in aircraft crashworthiness and occupant survival for over 20 years.

Mr. Walhout previously was associated with the AvSER Division of the Flight Safety Foundation in Phoenix, Arizona where he participated in many of the research projects on crashworthiness performed by this organization for the Army, the FAA and industry.

He was educated in Europe and flew as a pilot in the Royal Netherlands Air Force for several years before coming to the U.S. He has remained active in aviation and presently maintains currency in the F-105 with the Air National Guard of the District of Columbia.

Human Performance Factors In Aviation Accidents: An Investigators Methodology

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The opinions herein are those of the author and do not represent official positions of the National Transportation Safety Board.

Introduction

An aircraft manned by a well trained and competent flightcrew descends prematurely below minimum descent altitude . . . there are no problems with the flight—nothing out of the ordinary is occurring . . . the flightcrew is behaving as if they know where they are and what they're doing . . . the aircraft flies right into a mountain. What is the "real why" of that accident? The National Transportation Safety Board has determined that approximately 85% of general aviation accidents cannot be explained in the usual causative categories such as mechanical, structural, engine failures, etc., but fall into an amorphous category called "human error." But what constitutes human error? And what is there in the way an aircraft, or a company training policy or flight procedures or the human cognitive structure is designed that would "help" a pilot into an error? The human cannot be expected to perform at his/ her maximum level of performance all the time. The "gestalt" of the aviation environment must be designed with the human in mind. It must take account of his/her cognitive, sensory, perceptual, physiological, memory and physical limitations. The ultimate test of any aviation environment is that the human can use it and operate in it effectively, efficiently and safely. Simply stating that there was a "human error" is not enough, and saying a pilot descended below minimum descent altitude because he/she simply made a mistake or was not paying attention is an unfair and even erroneous statement. It is important to go further and determine why an error occurred. In this regard, the National Transportation Safety Board (NTSB) is now attempting to formally investigate the underlying causes of a pilot's error or his/her failure to perform adequately which may have contributed to an accident.

The Human Performance Protocol

The Board is currently involved in developing a formal human performance protocol to be used in accident investigation, and in setting up procedures for such an investigation on a regular basis. The first attempt to implement this new concept occurred during the NTSB investigation of the Cascade Airways, Inc., Beech 99 accident in Spokane, WA. on January 20, 1981. This accident involved a commuter aircraft operating as Flight 201 and carrying two flightcrew and seven passengers. It occurred around 1127 p.s.t. in instrument meteorological conditions during a localizer approach to runway 3 at Spokane International Airport (Figure 1). The aircraft hit a hill (2,646 feet) approximately 4.5 miles from the runway threshold, near the final approach fix and about 1,800 feet southeast of the Spokane VORTAC. This approach procedure required that an altitude of 3,500 feet be maintained until the final approach fix was passed, and that the minimum descent altitude for this approach was 2,760 feet. The flightcrew and five passengers were killed and two passengers were seriously injured.

Since the multiplicity of factors that affect and interact with human or pilot performance are very complex, for the purposes of establishing an aircraft accident investigation protocol, this author has enumerated six fundamental factor categories that affect or interact with pilot performance. These include the behavioral/psychological, medical, operational, task, equipment design, and environmental variables. Figure 2 illustrates the basic model. The behavioral profile illustrates the ways in which a pilot interacts with

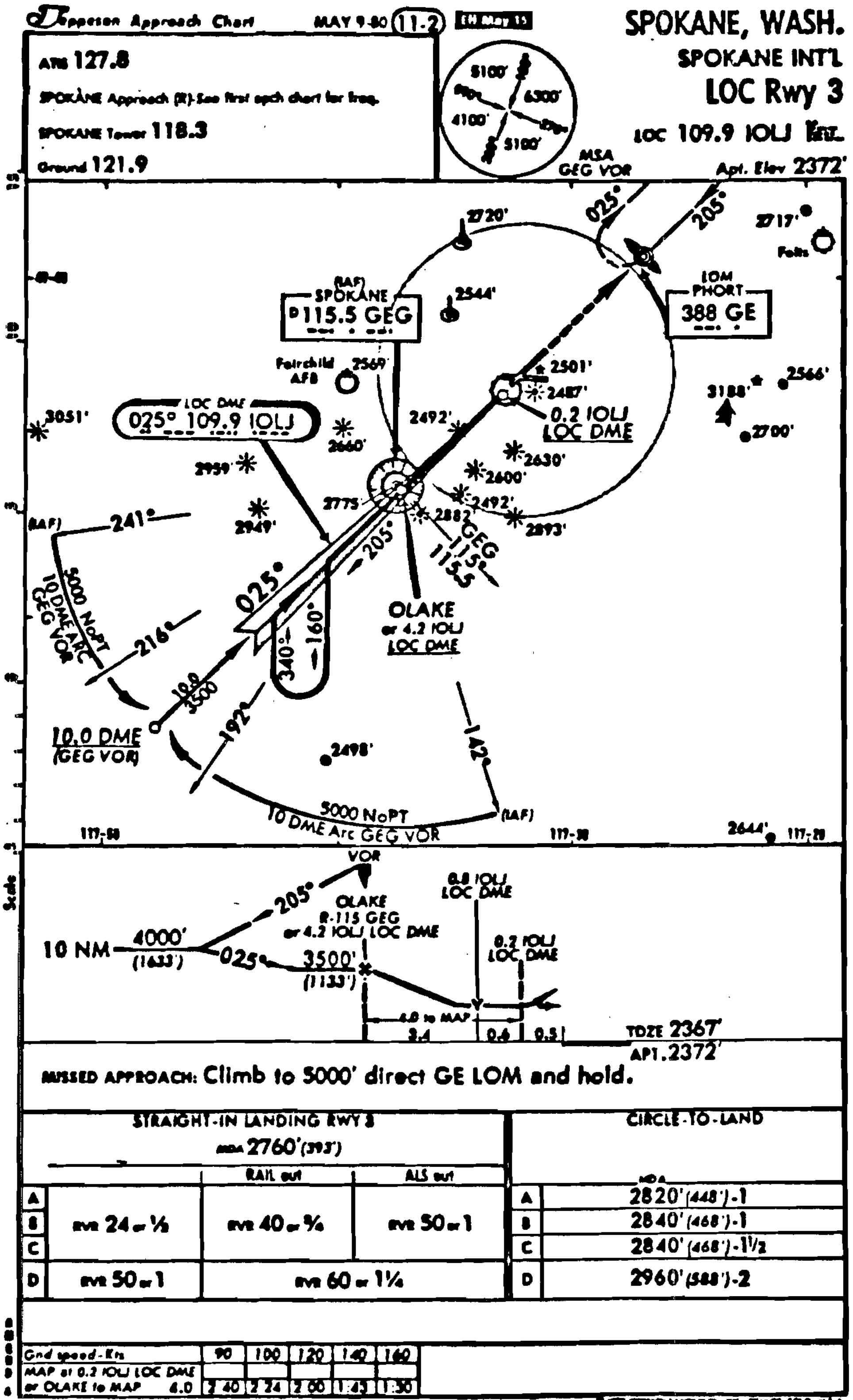

Figure 1

(Not to be used for navigational purposes.)

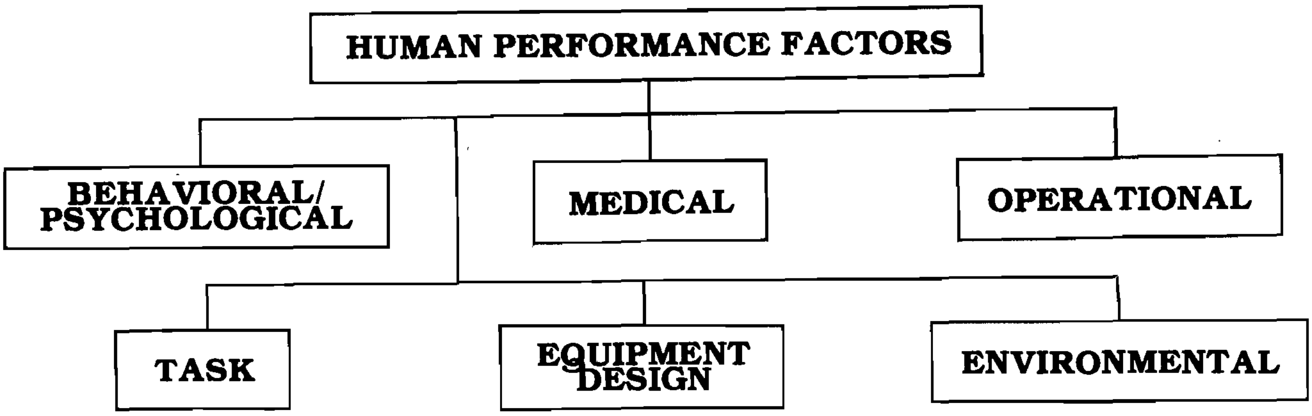

Figure 2

his/her environment and the factors he/she brings to a situation. This would include such information as previous activities, cockpit personality, interpersonal relations, attention and expectation potential, and attitude (Figure 3).

The medical profile involves the predisposing physiological and sensory variables which could affect performance. These would include such aspects as general health, sensory acuity, fatigue symptoms, drug use and circadian desynchronosis (Figure 4).

The operational profile contains the procedural factors which could affect pilot performance. This profile involves documenting the flight performance of the crew and assessing the relation of such issues as training, management influence and personnel monitoring practices to pilot behavior (Figure 5). As an example, in the Cascade Beech 99 accident, the Board investigated the approach procedure into Spokane International Airport which the flightcrew would have been using (Figure 1). This localizer approach to Runway 3 contains two separate navigational aids which both offer distance information: the Spokane VORTAC and the localizer DME. Several pilots who came forward during the accident investigation indicated that they had surveyed

**BEHAVIORAL/
PSYCHOLOGICAL**

FOR EXAMPLE:

1. PREVIOUS 24 HOURS
2. PREVIOUS 72 HOURS
3. FUTURE PLANS
4. PERSONALITY/INTERESTS/HOBBIES
5. PERSONAL PROBLEMS
6. INTERPERSONAL RELATIONS
   - — FAMILY/FRIENDS
   - — CREW
7. COCKPIT PERSONALITY/CREW COORDINATION
8. ATTENTION/PREOCCUPATION
   - — EXPERIENCE
9. ATTITUDE
10. "ACCIDENT PRONENESS"
11. MENTAL SEQUENCING OF TASKS

Figure 3

MEDICAL

FOR EXAMPLE:

1. PHYSICAL/CHEMICAL
   - — GENERAL HEALTH
     - HEART, DIABETES, ETC.
   - — SENSES
     - VISION
     - HEARING
     - VESTIBULAR
     - REACTION TIME
   - — DRUGS/ALCOHOL
   - — AGE
   - — CIRCADIAN/DISYNCHRONOSIS
   - — FATIGUE
     - ACUTE
     - CHRONIC
2. LAST PHYSICAL CHECKUP
3. TOXICOLOGY/AUTOPSY ANALYSIS

Figure 4

OPERATIONAL

FOR EXAMPLE:

1. TRAINING
   - PREVIOUS
   - ON-GOING
2. PERSONNEL SELECTION
3. OPERATING PROCEDURES
4. MANAGEMENT
5. PERSONNEL MONITORING PRACTICES

Figure 5

the approach procedure chart and then selected and navigated from the incorrect DME (the Spokane VORTAC, rather than the localizer DME).

The task profile involves the work-specific variables which could affect human performance. This would include such aspects as workload, familiarity, task sequence and task components (Figure 6).

The equipment design profile involves the pilot-equipment interaction dynamics which could affect his performance (Figure 7). In an area where new technology is constantly developing such as in navigation and communication aids and in automated displays, this is a most important factor, and it includes investigating such issues as cockpit configuration, display and control design, and man-machine dynamics. For example, in the Cascade accident, the human performance aspects of the Collins TCR-451 distance measuring equipment mode selector was investigated (Figure 8). In this model, the push button mode selector allows a pilot to select mileage readings from two different navaids by selecting the DME NAV selector 1 or 2. Also, this Collins DME has a push button HOLD function capability which allows a pilot to continue reading distance mileage from one selected NAV station frequency while tuning in another NAV station frequency; when the "HOLD" function is selected, an amber light will illuminate above the depressed hold button. Considering, in the Spokane localizer 3 approach, if the number 2 navigation receiver were tuned to the Spokane VORTAC with the number 2 DME selector in use, DME mileage would be displayed from the Spokane VORTAC. If the pilot then selected the DME HOLD button, distance information would still come from the Spokane VORTAC even if the pilot had returned the number 2 navigation receiver to the localizer frequency. The pilot would have to reselect the DME NAV 2 button in order to receive distance information from the retuned navigation station. There was no readout of the "HOLD" frequency displayed in the cockpit of the Cascade Beech 99. Therefore, memory was required on the part of the pilot when using this DME HOLD feature. The pilot had to remember a previously tuned-in frequency while he was performing his other cockpit duties. Thus, while this feature allows a pilot to control his/her own workload by tuning in navigation stations when it is most convenient for

TASK

FOR EXAMPLE:

1. DIFFICULTY/EASE OF TASK
2. FAMILIARITY
3. TASK SEQUENCE
4. TASK COMPONENTS
5. INSTRUCTION MANUALS

Figure 6

EQUIPMENT DESIGN

FOR EXAMPLE:

1. COCKPIT CONFIGURATION ANTHROPOMETRY
   - SPEECH COMMUNICATION
2. DISPLAY DESIGN/CONFIGURATION
   - SENSORY PRESENTATION OF INFORMATION
   - LIGHTING
3. CONTROL DESIGN/CONFIGURATION
   - CODING
   - SWITCHING
4. SEAT DESIGN/CONFIGURATION
5. MAN-MACHINE DYNAMICS

Figure 7

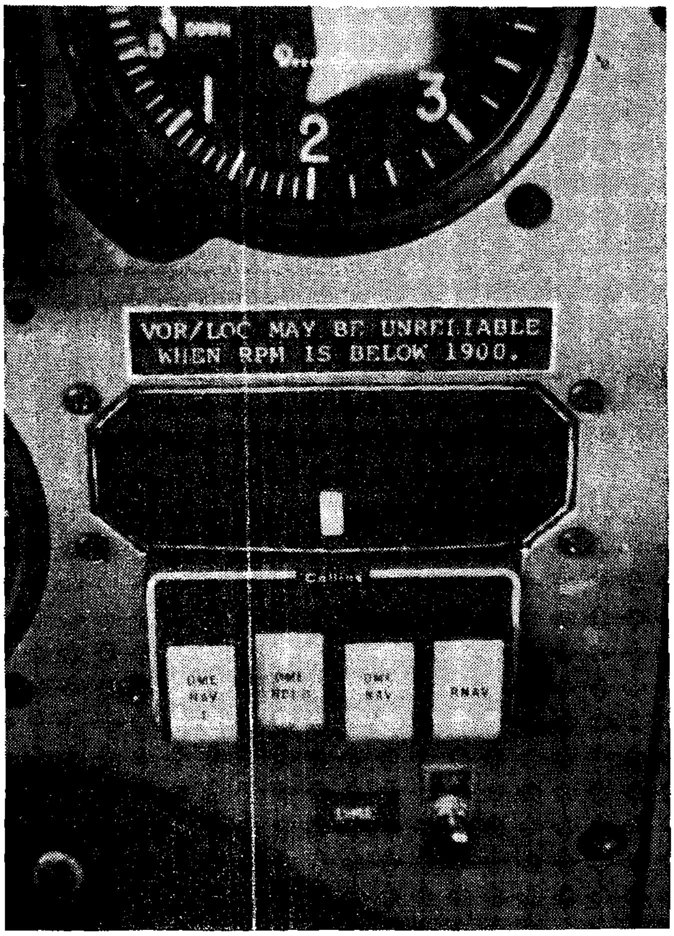

Figure 8

him/her, it may be that the added memory load may be less desirable at another greater workload time which is not in the pilot's control.

The environmental profile contains those internal and external factors which could have affected flightcrew performance. This would include weather, glare, sun orientation, cockpit noise, temperature and contaminants (Figure 9). For example, in Cascade the flightcrew were not using an interphone system for intracockpit communications; therefore the cockpit noise levels and the effect on flightcrew verbal communications were analyzed. During the investigation, the Safety Board recorded noise measurements in the cockpit of a Cascade Beech 99 during flight, and also received similar measurements from Beech Aircraft Corporation. These data indicated a particular noise environment where face-to-face verbal communication is difficult and requires a vocal effort of shouting or greater. Although, during normal operations, flightcrews can develop and use hand or body signals as alternate means of communications so that verbal communication is not necessary, this practice could become unreliable at best, particularly when a crisis or emergency situation demands unambiguous and efficient transfer of information between the pilots. In this accident the cockpit noise level could have precluded effective verbal communication between flightcrew. In the Air New England DeHavilland DHC-6 accident in Hyannis, MA. on June 17, 1979, the first officer stated that because of the cockpit noise, he experienced difficulty with intracockpit communication without the use of headsets and interphone. In the National Airlines Boeing 727 accident in Pensacola, Fla. on May 8, 1978, the loudness of the ground proximity warning system impeded verbal intra-cockpit communication. The evidence on cockpit noise levels and flightcrew communication has led NTSB to recommend the use of crew interphone systems in aircraft where cockpit noise levels preclude effective face-to-face verbal communication between the flightcrew.

ENVIRONMENTAL

FOR EXAMPLE:

1. OUTSIDE ENVIRONMENT
   - WEATHER
   - VISIBILITY
   - GLARE
   - POTENTIAL VISUAL ILLUSIONS
2. INSIDE ENVIRONMENT
   - NOISE
   - TEMPERATURE/HUMIDITY
   - AIR/PRESSURE
   - CONTAMINANTS
   - ORIENTATION

Figure 9

Summary

In summary, this paper provides an overview of the variety and complexity of information and variables that must be explored in order to determine the human performance factors which may have impacted a flightcrew at the time of an accident. During the course of the investigation both subjective and objective measurements will be taken. The subjective data will be gathered from interviews with the flightcrew, family, company employees, peers, etc. In interviewing the flightcrew, an "accident-recall" scenario will be used in which techniques conducive to memory facilitation will be employed. Also in some interviews, both abbreviated questionnaires and subjective rating scales will be used to assess the impact of the various human performance factors and the multifaceted variables of workload and fatigue. There will also be objective measurements taken of both medical and physical variables. These may include medical examinations and toxicological and autopsy analyses. It will further include measurement of physical variables such as cockpit anthropometry, cockpit noise and lighting, the angle of the sun, the length of time to perform components of a particular flight task, and so forth.

As stated earlier, these protocols and procedures are in the process of being developed. Ultimately, this author envisions an eventual comprehensive checklist that would encompass the information which is contained in the human performance factors and would serve at least as a guideline for this kind of investigation.

This author believes that the concept of a human performance investigation for aviation accidents has finally come of age. We have the technical information and the capability to make assessments of this kind; and, perhaps most important, we now have the support. No one wants 85% of aviation accidents unexplained. To determine an accident cause as "human error" will not help prevent future accidents. As Air Safety Investigators, we have a mandate to determine the "why" of an accident. Looking into the human performance aspects of an accident will not only solve the immediate puzzling accident but will lead to a safer environment for the pilot. "Human error" is not simply that; the ultimate test of the design of the total aviation environment is the pilot's ability to function in it effectively, efficiently and safely.

Biography

Dr. Janis H. Stoklosa joined the National Transportation Safety Board in 1980 as an Air Safety Investigator with a speciality in human performance. She was previously employed at Transportation Systems Center, Cambridge, Mass., as an Engineering Psychologist and worked in man/system interface issues; and at the Massachusetts Institute of Technology, Cambridge, Mass., as an Assistant Director of a Teleconference on Mental Workload: its definition, assessment and applications.

Dr. Stoklosa received a Doctorate in Human Engineering and Psychology from Harvard University, Cambridge, Mass. in 1976; and studied the areas of human engineering, sensation, perception, physiological psychology, human physiology, statistics and measurement.

Dr. Stoklosa taught in the Department of Psychology and Social Relations at Harvard University in the areas of human engineering, physiological psychology and the introduction to psychology and social relations. She also did research at the Guggenheim Center for Aerospace Health and Safety, Harvard School of Public Health, with Dr. Ross A. McFarland and studied pilot and operator performance under various space environments. She has publications in the areas of noise, alcohol, carbon monoxide, marijuana, deceleration and teleconferencing.

Dr. Stoklosa also holds professional membership in the American Psychological Association, the Human Factors Society, the New England Chapter of the Human Factors Society, and was elected President of the New England Chapter of the Human Factors Society for 1980-81. She also is licensed as a Psychologist in Massachusetts.

Human Performance Investigation—The Investigator-In-Charge and Report Writer Roles

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Introduction

The scope of this paper is limited to the roles of the Investigator-in-Charge (IIC) and report writer as they pertain to the human performance aspect of a major aircraft accident investigation. The National Transportation Safety Board's recently expanded effort to examine indepth the "underlying why" behind human error in aircraft accidents was formalized with the addition to the Board's staff of an investigator with a PhD in Human Engineering and Psychology. Although the Board, for years, has delved into the human performance aspects of accident causation as part of the investigative process, this year a formalized Human Performance Group was introduced as part of a major aircraft accident investigation. The experience as a result of that effort has illustrated several problems which must be confronted by the IIC. This paper discusses these problems and presents considerations which the IIC must be prepared to take into account during a human performance investigation.

Once the fact-gathering investigation is complete and all relevant data have been collected, the information has to be integrated into the final report of the accident. The intangible nature of most human performance information and the sensitivity of selected information require special considerations and effort in proper reporting and analyzing. The traditional cause-effect manner of presenting facts, analyses and conclusions must be modified to discuss adequately the human performance influence in the overall accident scenario. This paper discusses difficulties and considerations which the report writer must handle.

Background

In a paper presented at the ISASI Seminar in September 1979 at Montreal,[1] I discussed a suggested methodology and case histories on how a decision-making model could be applied to the investigation of human error in aircraft accident investigations. The use of the decision-making model was offered in an attempt to structure or to formalize the collection and analysis of facts regarding the subtle influences which underlie pilot information processing and subsequent erroneous decisions. The erroneous decisions were those evidenced by some particular incorrect behavior which were documented to have led to an accident.

In order to support the rationale behind the need for the decision-making model methodology, I offered two hypotheses which postulated reasons for the failure of previous human factors accident investigation efforts. The first hypothesis suggested that the very expertise of the present investigators and the methods employed by them may be at the root of the problem of not solving the human error aspects. It was stated that we had been quite successful in investigating, reporting and solving the hardware, environmental and measurable human factors aspects. The fact that we have routinely attempted to apply the same expertise and methods, employed to investigate those aspects, to the investigation of the intangible human factors was offered as a reason for our previous failures. It was suggested that we should re-examine our existing methods with a view toward a revised approach to investigating human performance.

The second hypothesis involved the fact that the solution to the human performance problems requires a different reasoning process than that used to solve the hardware, environmental and measurable human factors. It was suggested that we investigators were reluctant to deviate from our traditional reasoning processes, thereby precluding viable solutions to human error accidents. The difference between a deductive argument, which produces "conclusive evidence of the truth of its conclusion", and an inductive argument, which provides "some evidence" of the truth of its conclusion, was explained. Since we investigators essentially use deductive reasoning during our investigations and analysis report writing, we feel secure because the validity of our conclusion is self-evident and cannot be challenged by our peers or superiors. However, when the validity of our conclusions cannot be tested conclusively, and we have to deal with speculation based on probabilities and likelihoods, we become cautious and reluctant. Caution is commendable, but reluctance to attack the problem or ignoring the problem cannot be tolerated.

It has been extremely interesting to me that the previously presented hypotheses have proven quite true as a result of my recent experience during a major investigation involving a thorough human performance effort. Many of the problems encountered as IIC during that investigation, regarding the human performance aspects, were the result of the specialists and group members attempting to use their tried and true expertise and previously developed methdologies when examining human performance aspects. Their personal biases and reluctance to deviate from deductive reasoning methods required special efforts to maintain objectivity during the investigation of the human performance matters. These problems were equally evident during the report writing phase. Reviewing and approving officials required thorough and convincing arguments to include some human performance aspects in the report.

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1. "Application of a Decision-Making Model to the Investigation of Human Error in Aircraft Accidents," presented at the International Society of Air Safety Investigators' Seminar, Montreal, Quebec, Canada, September 1979.

Considerations for the IIC

The following considerations for the IIC were illustrated during the Safety Board's recent human performance effort:

1. Who does the human performance investigation?
2. Who heads up the human performance group, if one is to be formed as a separate entity?
3. Who are members of the human performance group?
4. What information to collect?
5. How to control release of sensitive information?
6. Who assesses relevancy of the information?

The above list is by no means totally inclusive; however, it contains the major topics brought to light during my exposure to this matter. The following discussion illustrates why these particular subjects must be considered. All of the considerations are interrelated and, therefore, are discussed in this context.

It became immediately apparent that the traditional specialty group approach to major investigations must be modified for a human performance investigation. The interface of all specialty groups' data collection and investigative activities with the human performance aspects requires more than normal coordination on the part of the IIC and Specialty Group Leaders. As in the past, many specialty groups collect human performance facts as part of their groups' activities. For example, operations collects considerable pilot data related to human performance, as does the cockpit voice recorder group, the air traffic group, and the traditional human factors group. If a formal human performance group is formed, considerable coordination is required to insure no unnecessary overlap and to insure thorough and complete coverage of relevant information. In certain cases, virtually every specialty group will provide data for the eventual human performance analysis.

If a human performance group is formed, two major considerations are: who heads up the group and what type persons make up the group. A multidisciplinary specialist qualified in behavioral sciences, aviation knowledge and most importantly investigative talents is extremely difficult to find or even develop. Therefore, a group effort using all the required talents and skills possessed by several individuals becomes a requirement. One difficulty encountered in the recent investigation involved this aspect. The human performance specialist was not familiar with aviation terminology and the aviation investigators were not familiar with the human behavioral aspects. Control of personal biases was difficult, yet can be overcome with a well managed group. Again, the IIC has to monitor and direct to preclude the loss of objectivity. It must be remembered that the pilot-oriented investigator must document and investigate pilot related information. In the same context, the behavioral scientist must restrict his or her investigative efforts to human factors data. Interrelated relevancy cannot be assessed until a thorough record is complete. The IIC must maintain control during the factfinding phase to insure that goal.

Some behavioral information can be collected solely by a human performance group without aviation oriented persons present. For example, widow or family member interviews or medical personnel interviews might be conducted without aviation expertise available. However, a pilot's peers, live crewmembers, company management/training personnel, etc., require both aviation and human performance expertise to thoroughly complete such interviews. This may require combined efforts of the operations (or air traffic control, etc.) and human performance groups. This raises another practical consideration. That is, the size of the group obviously must be controlled for certain interviews. All of the above matters must be considered and managed by the IIC.

A real world situation regarding staffing and workload obviously precludes assigning a human performance specialist as Group Chairman in each major case. Nevertheless, human performance must be investigated in every case. Therefore, the responsibility of the IIC is greatly increased in that he must insure investigation of all relevant human performance aspects by the various assigned groups without the assistance of a specific group leader. One possible alternative to the problem of not having a human performance Group Chairman involves the IIC having a checklist of sorts to insure collection of required data by the various groups. Such data would be collected or at least examined in all cases. Then, as the focus of the investigation becomes apparent from other group findings, the direction of the human performance effort could be modified, expanded, etc. If the circumstances begin to illustrate the need for expanded effort in a particular area, a human performance group could be formed, similar to the present method used in the aircract performance group.

Another matter which is rather unique to the human performance investigation involves control and release of information. The traditional daily progress meeting (en masse) report of the on-scene investigative team must be modified slightly. The purpose of the progress meeting is generally to report daily findings, exchange information and plan additional efforts. The progress meeting permits all involved investigators to learn of the various groups' findings to date. The IIC maintains the scope of the investigation and encourages party participation at such meetings to insure a complete record. Some human performance information is straightforward need-to-know type which can be discussed openly at such meetings. For example, the crew work/rest/duty times, age, training, etc., can be reported openly and noted in written field factual notes. Other information, however, must be controlled-release because of its sensitivity. For example, selected medical information, peer interviews, behavioral profile information and previous personal activities, etc., should not be indiscriminately briefed or discussed before the entire investigative team, nor released to the public or media out of context. This type of information must be collected as part of the human performance investigation, but it must be controlled. The IIC obviously must be aware of all information regarding the investigation, but he must be sensitive to preclude inappropriate release or discussion of private/personal data. The coordinators of the parties to the investigation should be briefed by the IIC to insure an open and cooperative spirit, since access to some human performance information will require party assistance. Again, the IIC must be aware of these considerations and must be prepared to cope with them as they arise.

Considerations for the Report Writer

The final accident report writer faces several problems which must be considered when presenting and analyzing human performance information. Among those considerations are:

1. How to assess relevancy of certain behavior or actions deemed "abnormal" or "nonstandard";
2. Sensitivity and privacy invasion possibilities versus accident cause/prevention significance;

3. Avoidance of speculation versus logical and reasonable explanations.

The traditional format for the final accident report writer involves presenting relevant facts, conditions and circumstances and analyzing those aspects following the rules of logic to reach pertinent and viable conclusions. The resultant conclusions should lead to pertinent findings and cause(s) determination. These subsequently lead to prevention measures, the ultimate goal of accident investigation. Deductive methods are relatively easy to present and lead to convincing conclusions. For example, a measured or calculated windshear produced a calculated aircraft performance loss which was weighed against the aircraft capability and a conclusion was reached that the wind shear exceeded the aircraft performance capability. Or, the engine failed because the turbine blade failed, because of fatigue which originated from a manufacturing defect, which was not detected during inspection, because the inspection procedure was inadequate, etc. These environmental or hardware causes are easy to follow when presented logically by the report writer. A straight-line cause/effect can be drawn. This is not necessarily true for certain human performance aspects such as complacency, fatigue, distraction or judgment. For purposes of this discussion, those aspects are referred to as the intangible human performance factors versus the measurable human factors such as heart attach, drug/alcohol impairment, hearing, eyesight, etc.

The straight-line cause/effect relationship does not work for the intangible aspects unless, for instance, a pilot states (or leaves a note) that he was complacent and did not pay attention, or he was distracted and failed to perform a vital function. Short of such fortuitous circumstances, inductive logic must be employed to present the most likely reason for some abnormal behavior. In the case where "abnormal" behavior is documented, but not proven likely to be relevant, the report writer's dilemma is whether or not to present it in the report. Some persons believe such information should be reported for statistical base reasons and for educational reasons. However, when inductive reasoning establishes a *reasonable* or *likely* cause/effect relationship to explain the abnormal behavior which led to the cause it *must* be included in the final report. Of course, such cause/effect relationships are not conclusive or universally self-evident and, therefore, can be challenged. The report writer must be prepared to handle this problem.

For example, behavioral scientists have proven quite convincingly that certain environmental conditions and behavioral actions can produce fatigue, both chronic and acute. They also have proven that human operators (pilots) make errors when fatigued. Similarly, behavioral scientists have demonstrated that humans are subject to distraction which in turn can cause critical errors to be made. However, the same behavioral scientists can prove that *all* humans *will not* make the same critical errors when fatigued, distracted or complacent. The variable response or reaction by humans to the same conditions cannot be conclusively measured; therefore, they are intangible and extremely difficult to present in the final report.

In addition, if an investigation revealed that a pilot made an error leading to an accident and fatiguing conditions or distracting conversation or elements existed, or evidence of complacency was present, it does not necessarily follow that he made the error because of these reasons. Deductive methods are not possible and one can only speculate as to the cause/effect relationship. The viability of these speculative conclusions is only as good as the reasonableness or likelihood of the relationship established by the report writer.

Just because a pilot did not sleep well, did not eat breakfast, appeared complacent, engaged in distracting conversation on final approach, etc., does not necessarily account for his failure to flare properly in a low visibility approach accident. Therein lies the dilemma of the report writer when analyzing the human performance aspects. It is relatively easy to prove the existence of distracting or fatiguing phenomena or complacent behavior (as defined by behavioral scientists); however, it is virtually impossible to establish a direct cause/effect relationship between the phenomena and pilot performance, short of the pilot so stating.

Regarding sensitive human performance matters, the report writer faces the problem of what information to include in the final report. Of course, in the interest of determining the cause and especially the "underlying whys," plus prevention measures, the report writer is obligated to present all relevant information in the final report. Because of the sensitive and intangible nature of certain human performance aspects, critical factors may be deleted from the report if traditional cause/effect deductive reasoning is required. For example, previous medical problems not necessarily connected to flying restrictions or previous psychological test results or even other behavioral abnormalities (as assessed by behavioral scientists) may or may not be readily tied to the reasons (why) for the errors which resulted in an accident. Even though a psychiatrist or other scientist can demonstrate that such abnormalities have accounted for such errors in a laboratory situation, the existence of such factors in a pilot's history may or may not explain the error(s) in questions. Again, the report writer's dilemma is whether to present and analyze such data and also *how* to present the information.

Regarding the question of whether to present the data, the answer is "yes," if a reasonable relationship can be established using inductive reasoning. Pure speculative discussions are not acceptable because the conclusions reached in this manner involve conjecture or guesswork. The only time speculative-type discussions should be included in the report is when a fixed number of possible explanations for a behavior are known and no particular one is more reasonable to account for the behavior. The report writer should merely state that a reason could not be determined and then list the possible reasons. Regarding how to present the inductive argument, the report writer must present all pertinent facts from the accident regarding the human error and associated "abnormal" behavior. A "reasonable" or "likely" conclusion should be drawn following a discussion of the human behavioral traits and tendencies "proven" by psychologists (behavioral scientists) to account for the reason(s) for the documented error(s). The reviewing and approving officials, as well as the reader, of the final report should be aware of, and should accept, the "softness" of such conclusions, as compared to those reached by deductive means.

Summary

This paper contains few solutions for the numerous problems presented. If the solutions were readily apparent, we would be much further along in our lengthy quest to solve the human performance aspects of aircraft accidents. The purpose of this paper is to give other accident investigators the benefit of the problems encountered and considerations which became apparent during the Safety Board's recent major investigation in which human performance aspects were examined indepth. Hopefully, other IICs and report writers will be able to benefit from our limited exposure and more solutions will be forthcoming. We welcome any suggestions or criticisms which could assist in reaching our mutual goal of solving the human error aspects of aircraft accidents and ultimately reducing the human error causes.

Video Investigations: A Complementary Source

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What is a video investigation?

In plain terms, it is an investigation using a video camera, attached to a portable V.C.R. (Video Cassette Recorder), to record and preserve the facts of an investigation on video tape. Its purpose is to document for later review the scene of the accident, the vehicle involved and investigation notes. The final objective is a better investigation thru visual and audio recording, preserved for later scrutiny and report preparation by the investigation team.

What kind of video equipment is available for use by investigators?

To illustrate let me brief you on the various types of video equipment and its evolution, so you will have a judgmental perspective and background. The first video tape recorder was introduced in 1956. It was black-and-white, and as you might suspect it had direct applicability to network television. It was cumbersome, and obviously not portable. Neither was it easy to work with, but it did offer instantaneous playback, as opposed to film, and it was the beginning of the network two inch video tape.

Technology moved on, and in 1967 the first ½-inch black-and-white portable (by 1967 standards) was on the market. It was a reel-to-reel type, but was quite an advancement for the time.

A year later, 1968, the first standardized 2-inch format, color V.T.R. (Video Tape Recorder) went into use at the network level. This is also known as quad format. The format, for reference purposes, refers to the size of the tape used.

In 1970 the first standardized ½-inch V.T.R. was produced, and later in 1970 a full-function portable editor machine was available. In 1972 frequent use of ½-inch color V.T.R.'s was made by C.A.T.V. (Cable Television). Also in 1972, the first use of ½-inch video tape by broadcast T.V. was done at the Republican Convention. Still in 1972, commercial production of ¾-inch video cassettes were accomplished. 1972 was a very progressive year for the video cassette and video tape recorder industry.

1973 brought the first low cost color T.V. camera (less than $15,000) to the commercial market. In 1974 E.N.G. (Electronic News Gathering) with video cameras and recorders, went full swing, and is still going strong. Also in 1974, Sony introduced a second generation video cassette recorder, smaller and better and easier to use.

In 1976 a full line of ½-inch (small format) video equipment was introduced. 1978 saw the first practical home V.C.R. and small, lightweight color camera.

So here we stand, on the threshold of the future, in 1981, looking into video communications which have become inexpensive, reliable and easy to use.

Now that you know a little about the history, I'm going to explain more about the formats and what they mean. We will speak of four formats: 2-inch, 1-inch, ¾-inch and ½-inch. There is ¼-inch tape, and a compatible V.C.R., but it is very new to the market and offers only 30 minutes of field capability.

There are primarily four formats for video tape, and correspondingly four formats of V.T.R.s. They are:

1. Two-inch; also known as quad format. Used in Network T.V.
2. One-inch; used in some C.A.T.V. (Cable T.V. Stations) and sometimes for location shots by C.A.T.V. Stations.
3. Three-quarter-inch; used by C.A.T.V., industrial users and large organizations, for training and field communications.
4. Half-inch; used by the home viewers. All of the home V.C.R.s are half-inch format video tape. However, there are two different types of half-inch format: V.H.S. and BETA. They are not compatible with one another and, simply stated, one will not play on a machine designed for the other, despite the fact they are both half-inch.

5. The quarter-inch format is new, has promise, but as yet is limited to a thirty minute tape, and approximately forty-five minutes on a charge of batteries.

Most of the equipment is marketed under well known names, such as:

J.V.C. (Japanese Victor Corporation)
R.C.A. (Radio Corporation of America)
AKAI
Quasar
Motorola
Panasonic
Sony
Technicolor (Quarter-inch format)

All manufacturers produce portable units suitable for field use. The units are small enough to fit in a flite bag or chart case. They all record anywhere from two to six hours, with the exception of the quarter-inch format, which is only good for thirty minutes. Choice and price range vary considerably.

Cameras

As you might expect, all of the V.C.R. manufacturers make cameras, or have compatible equipment that will work with other manufacturers' cameras. However, you have to make sure that the camera you select will give you good performance with the V.C.R. you select. Try it before you buy it. The dealer should be more than happy to show you how it works, and what you can do with the camera and V.C.R.

The beauty of the new-generation color video cameras is that, in handling characteristics and appearance, they are very much like a sound movie camera. Video cameras weigh 4 to 10 pounds. The only difference is that you put nothing into them. No film, no tape, just electronics. They usually have at least ten feet of cable attached, which allows moving and positioning the camera. The cable attaches to the V.C.R., and via this cable the electrons move to the magnetic oxide on the video tape to record both picture and sound.

The camera cable can be extended up to 80 feet without picture degradation or audio loss. All you do is attach a cable extension which screws onto the existing cable. If you are operating from an alternate power source such as car battery or A.C., you can move around easily in an 80 foot range.

These video cameras are rugged and have fast lenses, some of which are interchangeable. Power zooms are available up to 6:1. The cameras are fully automatic, or have manual override. Many have back-light compensators that help when working in strong sunshine or setting sunlight. The camera will do its best to compensate for the strong back-light automatically.

White balance is a term you may not be familiar with, and on a color camera it adjusts the camera for white, and compensates the color tones. It is easily set; you just point the camera at a bright white object and adjust a dial.

The microphone is built into the camera and is automatic. When the camera trigger is pulled, you get both audio and video. You can plug an earphone into most cameras and monitor your sound, or you can plug an earphone into the V.C.R. and monitor the sound. If you elect to use an external microphone, you can place the camera on a tripod, or have someone else hold it, while you walk out in front of it and illustrate a part or explain a piece of wreckage.

What makes a video package?

Usually you will find the following:

1. Video Camera, and some sort of protective case
2. V.C.R., with case or shoulder strap
3. Battery package, either self contained or belt type
4. Electronic viewfinder (miniature T.V., usually built into video camera, or attached to the side of the camera)
5. T.V. or monitor, for later review; electronic viewfinder is used in the field
6. Recording tape
7. Camera extension cables.

The camera puts the electronic impulses into the V.C.R., which records them on tape and operates both the camera and the recorder from the self-contained battery pack for up to one-and-one-half hours. The field investigation can be reviewed thru the electronic view finder, using the ear plug for monitoring the sound.

The monitor (T.V.) can be operated from a cigar lighter in an auto, or other vehicle, as long as it is 12 volts. An adapter is necessary, but it is inexpensive and lasts a long time.

You can also purchase a Tuner Timer for your portable V.C.R. which will let you record from a T.V. set. This is often helpful, as you can incorporate news broadcasts dealing with your investigation into the tape. In many cases there will be witnesses' names and statements that may be of aid. Anything that can be a source of information may, at some point in the investigation, be of help.

How does video differ from film?

Most of you by this time have seen the difference between video and film, but just so the understanding is complete, let me point out some of the dramatic differences:

1. The V.C.R. and Color Camera are all electronic and have no film in them. They use video tape, which is a magnetic oxide coated medium, that imprints video and audio, and also allows erasing and reuse.
2. The tape is in the recorder.
3. The tape is reuseable; film is not.
4. The results with a video camera are instantaneous. You know what you have got when you get it. Conversely, if you're not getting it, you know that right away too.
5. With video, if you don't like what you have shot, you can continue to shoot till you get it right, or you can erase and start over.
6. Time of tape ranges from 2 to 6 hours.
7. Black-and-white or color depends on the camera; the tape will record either.

Weight and dependability

1. Under 20 pounds for camera and recorder, tape and battery.

2. All units are now solid state chip technology; durability and dependability are excellent.

Flexibility

In my experience it is excellent. Most portable units have at least three power sources: A.C., D.C. battery pack and auto cigar lighters. They also have rechargeable batteries, which give up to one-and-one-half hours of operation in the field before replacement is necessary. The battery operates both the camera and the recorder.

Portability

The camera, recorder, extra batteries and tape can easily be fit into a flight bag or chart case. Weight should be no more than 20 to 25 pounds. One person operation is easy, and on record discussions can be held and taped. The camera can be mounted on a tripod and operated remotely while you and others have a caucus in front of the camera.

Utility

The beauty of the portable V.C.R. and camera is that anyone with a little "hands on" experience can easily operate both the camera and the recorder. If you can operate a normal cassette tape recorder, you can operate a V.C.R. It's that simple.

I want to emphasize that no special training is necessary, and no special technical skill is required. The "hands on" learning can be accomplished in 15 minutes, and the show can go on right away. Practice will improve your skill and technique and will remove any mystique surrounding the equipment.

Applicability

You will be amazed, after your first usage, how much information and how many facts you are able to put into a few minutes of audio and visual communication on video tape. Just reviewing the scene of the investigation, in a leisurely atmosphere like your hotel room or office will give you more perspective than you thought possible. You can look for clues that you may have missed and make notes and comments for follow-up investigation. If you have a piece of evidence you can take it back to the hotel or office and use the macro-focus capability of the camera to preserve it on tape. Then, if a destructive test is necessary, you have the part on tape with your comments, and that can be compared to the lab results.

You can copy additional tapes, at a modest cost (less than twenty-five dollars), and send them to other experts or associates for review and comment. This will reduce the cost of their personal visit and transmit much of the information to them in visual format.

You can dub (take off) only the sound track of the video cassette for transcription. All you do is plug a tape recorder into the monitor plug, and play the V.C.R., allowing you to have a written transcription of your work prepared.

You can also play the video tape back in slow motion, or you can pause it to study a scene. In some units, you can advance frame by frame, and you can also take 35mm photos from the screen. You can edit the tape, changing the narrative, and still retain the master without deletion. Witnesses can be recorded at the scene, showing via body language and illustration what they saw, and at the same time telling you what they heard. You can do all of this and more, with a portable V.C.R. and camera.

As you learn more about your equipment and the practical learning that comes with use, you will find more and more applicability.

Limitations

Virtually none, that cannot be overcome with ingenuity.

Summary

I've tried to give you a feel for the practical application of on scene investigations using a V.C.R. and camera. I hope I've been successful in whetting your imaginations. The cost is modest, under twenty-five hundred dollars for a complete V.C.R. package. The benefit is immense. I told you in the beginning that the video investigation was a complementary source. I hope this brief presentation has illustrated that point. Used in conjunction with the other tools available to the investigator, it becomes a warehouse of data, to be reviewed and recounted as often as necessary, to lead, eventually, to a more accurate determination of cause.

It is my belief that video investigations have the potential to add unparalleled perspective to our investigations, and it's my hope that you will take an earnest look at the state of the art.

Investigation of Aircraft Fires

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Introduction

In an aircraft accident investigation, you, the investigator, are frequently confronted with the problem of determining whether or not the aircraft was on fire prior to impact. The problem is compounded by the fact that the evidence may be masked or destroyed by the post-impact fire. (If there was not post-impact fire, there was probably no inflight fire, either. If there was, it won't be very difficult to investigate.) The problem, then, is one of differentiating between the pre- and post-impact fire evidence.

Unless the wreckage was completely consumed by fire, an inflight fire will usually leave positive evidence. You must realize, though, that many strange things can occur during the dynamics of an impact and any accident involving fire may exhibit evidence that can be interpreted either way. Individual clues must be analyzed in context with the surrounding evidence.

The best way to start an inflight fire investigation is to consider the indirect *indications* of inflight fire first, and then look for hard evidence that the inflight fire actually existed.

Indirect Evidence

Witnesses. Did anyone see inflight fire? Unforuntately, it is not uncommon for eye witnesses close to the impact point to state emphatically that there was an inflight fire. This is due to the difference in time between the appearance of the impact fire ball and the sound of the impact—sometimes several seconds.

The human mind has trouble with this and it tends to assume that whatever is perceived first must have happened first. Even understanding the phenomenon, this feeling is difficult to disregard. Thus the witness is seldom lying; he (she) is merely rationalizing the order in which things were actually seen or heard. Other normal phenomena such as strobe lights, rotating beacons, landing lights, wing illumination lights, sunlight reflections, exhaust, fuel dumping and so on can be mistaken for fire or smoke; or at least can confirm the illusion in the witness' mind that there was fire before impact.

The most reliable witness is probably one who was not near the impact and could not have been influenced by the impact sound and fireball. In questioning witnesses about inflight fire, it is important to pin them down on what their perceptions were and in which order they were perceived. Also, it is helpful to know what their viewing angle and direction was and what the attitude of the aircraft was when they saw it.

Circumstances of the Accident. Some accidents, just by their very nature, make inflight fire unlikely. Before you start a difficult and time-consuming inflight fire investigation, you ought to have an accident where that is at least a reasonable possibility.

Indirect Evidence in the Wreckage. Suppose there were an inflight fire or smoke in the cabin or cockpit. Would there by any indication on warning lights or temperature gauges? What would the pilot have done? Did he dump cabin pressure? Open a window? Actuate a ram air ventilation system? Turn off all electrical circuits? Discharge a fire extinguishing system? Go on oxygen? Reach for a smoke mask? Set an emergency transponder code? Make a radio distress call? All of these are indirect clues that a fire (or smoke) existed and they are usually easy to check before starting an exhaustive examination of the wreckage for direct evidence.

Direct Evidence

Now that you've done the easy things, you must have found some reason to continue the investigation and search for confirming evidence of inflight fire in the wreckage itself. This examination is going to take some time, but it is fairly logical and requires only an understanding of the effects of a fire inflight and the dynamics of impact. This analysis will be discussed under three major headings: Inflight Fire Effects, Crash Dynamics and Impact Effects.

Inflight Fire Effects

The principle difference between an inflight fire and a ground fire is that the inflight fire is influenced by the airflow within or around the aircraft. If a fire starts in and is confined to a compartment with no airflow, it will be indistinguishable from a ground fire. Normally, though, a fire will burn through to an area which does have airflow before significant damage to the aircraft occurs. Most commonly, it will encounter the slipstream of the aircraft which will have two effects on it:

1. It will increase the intensity of the fire and raise its temperature; and
2. It will develop a fire pattern which follows the flow of the slipstream.

These provide positive clues to the existence of an inflight fire. A fuel fire on the ground (for example) will burn in the neighborhood of 1600° or 2000°F unless there is some localized forced draft or chimney effect which increases the temperature. Inflight, the same fuel can produce

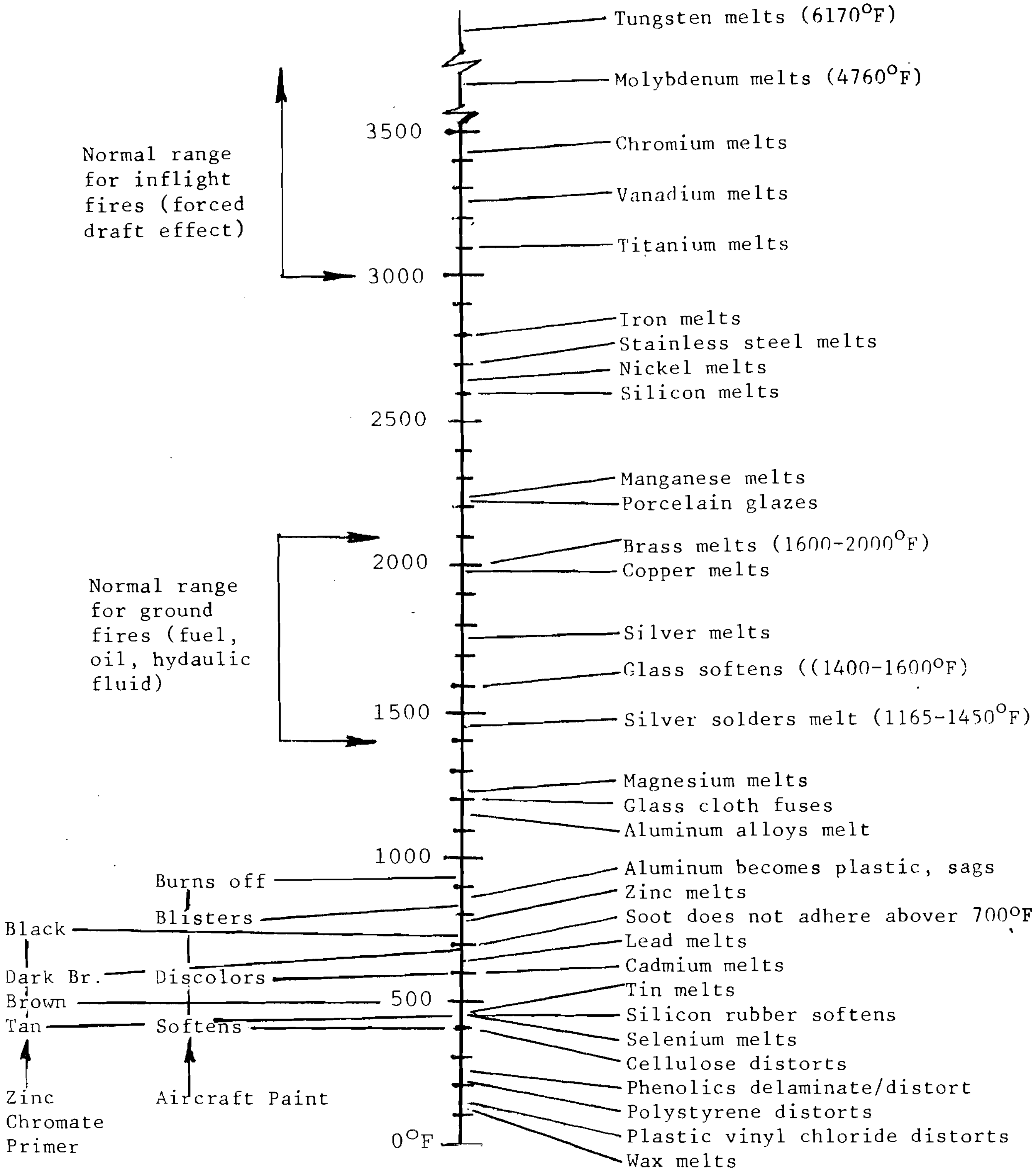

TABLE NO. 1. TEMPERATURE COMPARISIONS FOR AIRCRAFT FIRE INVESTIGATION. Ref. Aircraft Fire Investigator's Manual - National Fire Protection Association temperatures in excess of 3000°F due to the blowtorch effect of the slipstream. Obviously, if components are melted which have a melting point substantially above 2000°F, inflight fire must be suspected. See Table No. 1. This table is constructed to give the investigator an idea of relative temperatures in a format useful during a field investigation. Consult the *Aircraft Fire Investigators Manual*, National Fire Protection Association, for specific temperatures.

The soot pattern from a ground fire generally flows upward as modified by the wind on the ground. The soot pattern inflight is going to follow the slipstream or the dominant airflow. (In a closed area, the airflow may not necessarily be front to rear.) Since the deposit of soot is very rapid in a fire fueled by a hydrocarbon, the direction of the pattern is a helpful clue as to when the fire occurred.

Furthermore, an inflight fire tends to originate from a single source and expand outward in a cone-shaped pattern. This cone-shaped pattern is sometimes visible in a ground fire, depending on how the wreckage lies with respect to the fire, but generally it is not.

Sometimes, the destruction of the aircraft on impact is such that no positive determination of soot pattern can be made. In this case, local clues as to the flow of soot can be used.

If the soot flowed across (or along) a panel with rivet heads or other obstructions to the airflow, you would reasonably expect to find a build-up of soot on the upstream side of the rivet head and clear, soot-free area behind it. This "shadowing" effect suggests an inflight fire if the shadow follows the slipstream. [CAUTION: A ground fire can leave the same indication if (after impact) the part is oriented aft end up.]

Finally, if the inflight fire was hot enough to melt metal, you might reasonably expect to find some indication of that in the slipstream. Aluminum or steel tubing, for example, will exhibit a characteristic sharpening or "pencil point" appearance if it melted in the presence of a slipstream. In a ground fire, the tubing simply "drips" and the molten flow is downward. Furthermore, the molten metal must go somewhere. In a slipstream, it tends to disperse into small particles of metal. If you find it coating or adhering to a "relatively" unburned surface downstream of the source, that would be an indication of inflight fire. On the ground, of course, the molten metal melts and drips in large blobs and collects under the melting part. Aluminum can also exhibit a "broomstraw" appearance if it has been heated close to its melting point and then exposed to the shock of impact. [CAUTION: This same phenomena can sometimes be seen in an aluminum part that is under stress and exposed to fire after impact.]

Crash Dynamics

The distribution of the wreckage is a function primarily of the angle and velocity of impact and (to a lesser extent) the nature of the terrain where the impact occurred. As a rule, the wreckage will be within a fan-shaped pattern surrounding the impact crater. The fan will be spread out from the crater in the direction of flight prior to impact. While some light weight material may be wind-blown outside this area, even this would have some consistency to it. A fairly heavy part outside the distribution pattern would be inconsistent, particularly if it had been exposed to fire. Likewise, melted or burned parts of the aircraft found back along the flight path well outside the distribution pattern would also indicate inflight fire.

When the aircraft disintegrates on impact, some parts of it will burn and some won't. Those that burn usually contain ruptured fuel tanks which burn both the wreckage and portions of the surrounding terrain. Thus any part landing within that burn area should also have some evidence of fire. This would be normal. Suppose, though, a part shows evidence of fire and it is outside any burn area? Superficially, this could be interpreted as evidence of inflight fire. Perhaps, but there is risk here. Consider an impact where the aircraft hit, exploded, bounced, hit again, exploded again, and finally slid to a stop with various sections of it still burning. The part we are interested in was exposed to fire during the first impact, but wasn't ripped loose until the second impact. It landed outside the burn area. What you have here is a clue that inflight fire may have existed, but you can't build your whole case on it without confirming evidence.

In general, everything within the burn areas should be burned and everything outside of them should not. Recognizing that there may be plausible reasons for exceptions, you should still treat the exceptions as significant. Obviously, this aspect of the investigation depends on an accurate diagram on the wreckage distribution. If you don't know where the burn areas were or where various parts were found, you have lost about one-third of your ability to substantiate inflight fire.

Impact Effects

Here, we will consider the appearance of the parts instead of where they were found. The problem is to determine which happened first; the fire damage or the impact damage. Realizing that no one single clue provides absolute certainty, the problem is fairly straight forward in terms of its logic.

Crumpled Parts. Do you have a burned part that is also crumpled? If so, look inside the folds. If the inside is fairly clean, it is almost certain to be the result of ground fire. On the other hand, if the insides of the folds are also burned or sooted, that would suggest that the fire occurred before the crumpling. [CAUTION: Exposure to severe ground fire may burn everything, crumpled or not. It depends on the degree of crumpling and the intensity of the fire.]

Fracture Edges. If you have a burned part that is also fractured, examine the fracture edges. If they are also burned (sooted), that indicates ground fire. If not, perhaps the sooting occurred before the fracture. [CAUTION: Handling or moving the wreckage will create "fresh" fractures and fool you. Fracture evidence should be consistent with other fracture surfaces in the area.]

Scratches. Is the scratch on top of the soot or filled with it? [Same CAUTION as above. There is no way of telling when the scratch was made unless you can relate it to something that happened during the impact dynamics. It is a clue, but not a positive clue either way.]

Protected Parts. Suppose two mating components, both burned, are ripped apart during impact. The space between them (or under them) is unburned. It was clearly protected from fire damage during the time they were together; therefore, the fire occurred first. [CAUTION: One side of the part may have been protected from fire damage due to its orientation to the fire or because something else protected it after impact. You need to find consistent evidence here.

Don't confuse the natural difference in painted surfaces that are exposed to fire. The epoxy-painted skin of an airplane, for example, may appear different from the zinc chromate-painted structure beneath it when both are exposed to fire.]

Rivet Holes. Was a riveted section both burned and pulled apart? Check the rivet holes and the areas beneath the rivet heads. Sooted? Ground fire. Clean? Inflight fire. [CAUTION: This assumes no additional damage during investigation or wreckage removal. Also, a crash involving multiple impacts can create this type of evidence, because sooting is almost instantaneous. A part can become sooted during its initial exposure to fire and subsequently ripped loose leaving the rivet holes clean.]

Mud and Dirt. Is the mud on the soot or under it. If it is under it, it is almost certainly ground fire. If it is on top of it, it may be inflight fire, but this is a very weak clue. The sooting occurs almost instantaneously while the mudding and dirting doesn't occur until the part has come to rest or (at least) until the dirt has been blown into the air and fallen back down on the part.

Molten Metal. If you see molten metal, its flow ought to follow gravity in a ground fire. [CAUTION: If it appears to follow the slipstream, consider the possible orientation of the part with respect to the ground fire before reaching a final conclusion.]

Adjacent Parts. Logically, an inflight fire is going to leave evidence throughout its path. It is pretty hard to sell the idea of an inflight fire if there is a clean and unburned part right in the middle of where the fire is supposed to have been. Evidence of inflight fire should be consistent with the location of the parts before impact. Ground fire should be consistent with where they were located after impact.

Fire Pattern. When you bring two fractured pieces together, the fire pattern should be continuous across them —if it was an inflight fire. This is strong (but not absolutely conclusive) evidence, particularly if the pieces were found some distance apart.

Investigative Procedure

Before you launch into an extensive inflight fire investigation, you should have gone through the "indirect" clues that an inflight fire existed. Perhaps the mechanics of the accident suggest it as a reasonable possibility, or perhaps the witness statements are persuasive. If so, you should consider some or all of the following steps:

1. Know what is "normal" for that aircraft. Some metals, particularly titanium or stainless steel, pick up heat discoloration as a function of time and temperature. It is not uncommon for painted surfaces in the vicinity of engine exhausts to exhibit sooting and heat discoloration. This would be normal.

2. Construct an accurate wreckage diagram to include final flight path, location of major components, and location of ground fire areas. Use this diagram to plot smaller components significant to your investigation.

3. Take photographs of significant parts and components as they were originally found. This may help solve the question of when a particular fracture or scratch occurred.

4. Talk to the fire or rescue crew first on the scene. Find out what, if anything, they did to the wreckage.

5. Talk to the witnesses, if any. Plot their location and statements on your diagram.

6. Search back along the flight path of the aircraft. You are particularly looking for molten metal or burned aircraft parts.

7. Reconstruct the wreckage (or at least that area where you suspect inflight fire). Here, you are looking for the overall fire and soot pattern, the continuity of the pattern across fractured surfaces, and the origin of the fire.

8. Re-assemble all parts and components in the area where you think the fire originated. Here, you are looking for consistency of fire damage.

9. Think. Sit down and look at what you've got. Apply some logic. Ask yourself, "How could this evidence have been produced? What other evidence should be here?"

Summary

If you have taken all or most of those steps, you have given yourself your best chance of examining all three areas: Inflight Fire Effects, Crash Dynamics and Impact Effects. Remember that much of what you see will be evidence of ground fire. That's normal. The clues to inflight fire will be subtle and a single clue is rarely conclusive. Don't build your case on it, because there will probably be isolated clues in any accident (assuming the wreckage burns) which could be interpreted as inflight fire. Remember that you are looking for consistency of evidence that will show that the fire behaved as you would expect an inflight fire to behave and certainly occurred before breakup of the aircraft at impact.

Bibligraphy

The material for this paper was drawn from personal experience and the collective wisdom of other experienced investigators. Additional information is available from many sources. Since much of the material is duplicative (we all borrow freely from each other in the investigation business), the author hesitates to use specific references for fear of ignorning the original source.

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Biography

Richard H. Wood is a Professional Safety Engineer and has been certified by the Board of Certified Safety Professionals. He is a pilot with over 6000 hours of flying time and has investigated over 50 aircraft accidents, in the military and as a private consultant.

He currently teaches safety program management, Aircraft Accident Investigation, and Accident Photography for the Institute of Safety and Systems Management at the University of Southern California.

Basic Principles of Crashworthiness

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I consider it a real privilege to be here today, to kick off a session that I believe is of critical importance to ISASI. We have, as an association, been concerned since our founding, with the quality of aircraft accident investigation as it is performed around the world. I believe we have contributed to this effort with our seminars and with ***forum*** magazine. Today we are addressing an area that has not received enough attention by field investigators or by government managers, and the proof is in the files, like the holes are in the Swiss cheese. We, who are daily concerned with the area of crash survivability, are regularly confronted with an unnecessary shortage of data in the area of crash survival. The speakers for this session are here for one primary reason. We want each of you, personally and for your organization, to take from this session the basic principles of crash data collection and a motivation to collect that data at every accident site that you are responsible for, to store and use that data to make aircraft more crashworthy.

The goals of any crashworthiness investigation are as follows:

1. Determine the cause of each injury to each occupant.
2. Determine the relationship, if any, of each injury to the subject of mishap causation.
3. Determine the performance of each item in the crash protection chain, to establish whether it worked as it should.
4. Determine the magnitude of the crash forces present.
5. Identify those items which made injury and death more, or less, likely.

Background

The field of crashworthiness is a mature one, and in aviation can be traced back to within a few years of the Wright Brothers' first flight. Well known names like Hugh DeHaven, John Stapp and others have pioneered in aviation, automotive design in recent years has mandated numerous safety features, and while some may be of arguable benefit, the fact is that in auto accidents there is only one fatality for each 38 serious injuries. In general aviation, there are two fatalities for each serious injury.[1] Without belaboring the point, it is apparent that the aircraft occupant is not provided with a degree of protection comparable to the auto occupant, and in fact some of the aircraft environment is extremely lethal compared to automotive interiors.

The principles of occupant protection were clearly stated by DeHaven in 1952 so we are not preaching some new thing here today. We simply want to get our profession to do a better job in this area.

Figure 1 shows the role of accident investigation in the aviation system. We have for years concentrated on the prevention feedback loop. Today we want to concentrate on the injury reduction feedback loop.

Basic Principles

The basic elements in the crash protection chain are identified, for ease in reference, by the letters CREEP. These stand for:

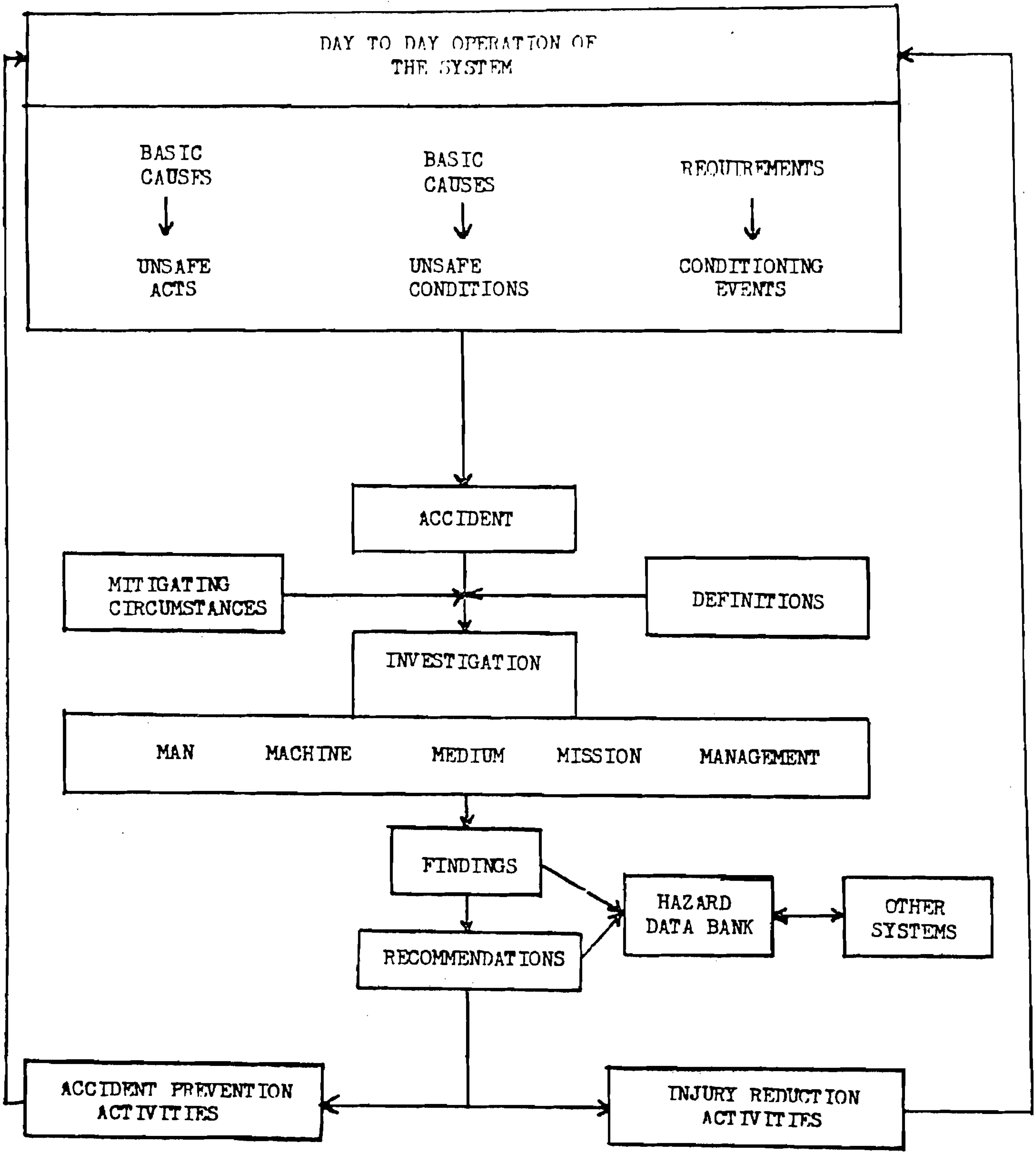
CONTAINER
RESTRAINT
ENVIRONMENT
ENERGY ABSORPTION
POST CRASH FACTORS

I will take these in order with examples.

Container: In order for the contents to survive the impact, the container must remain sufficiently intact for the contents to have a livable space. Contents include crew, passengers and cargo. It is important to examine the container very carefully at the accident site. Major changes can take place when the wreckage is moved. It is also important to remember that what you see may not be what it was like during the impact sequence. One of the most graphic results of the NASA series of crash tests at Langley was the photo sequence of the Navajo 45-degree nose down impact. The contained volume was reduced to nearly zero in the crew area during ground contact, but the roof popped back up again and looked very "normal" and habitable to the post-impact investigator.

Restraint: It is necessary for each item inside the container to be properly restrained. The key issue here is what constitutes proper restraint. Due to the extensive research of the past, documents such as the Army's "Crash Survival Design Guide"[2] exist to bring together the best current knowledge on human tolerance to crash forces. These body limits are far above the minimal "minor crash loads" that restraint systems must meet. There would be far fewer deaths and injuries if restraint systems more closely approached human tolerance limits.

The restraint systems must distribute the loads to the body in the proper places; for example, across the pelvic area and not into soft or weak areas. The restraint system must have a positive lock (metal to metal) and not have free ends which could flex under crash loads and release the latch. The non-metallic crimp type belt has had a very poor history in this regard.



ACCIDENT INVESTIGATION FEEDBACK LOOP

The chest restraint system is much more effective if a double harness is used, as it is possible to twist free of a single diagonal belt.

The loads of the belt system must be taken by structures strong enough to carry the loads and pass them into primary aircraft structure. Other items in the aircraft must be similarly restrained, such as carry-on baggage, galley units, etc.

Environment: It is very important to insure that the well restrained occupant in the intact container is not struck by, or forced into an object in the cabin area. Items such as gear struts, transmissions, cabin fixtures and miscellaneous equipment must not be free to penetrate or fly free in the cabin. The flexing of the body should not allow the striking of lethal objects such as controls, panels and knobs, window latches, etc. The body extremities should not be trapped by collapsing secondary structures or displacement. Instructions for emergency use should be clearly understood by all occupants under less than normal conditions.

Rarely do we find in the record of an investigation a listing of the loose objects in the cabin and what they did, or good photos of the parts of the cockpit that were struck by the occupants.

Energy Absorption: The energy of the moving vehicle must be brought to zero during the crash sequence. The velocity energy of the occupant must also be brought to zero in this time. Major problems occur, oft times called "the second collision," when the aircraft or car decelerates at impact but the people continue at constant velocity until they reach the now nearly stationary vehicle component and experience much higher forces than the vehicle. The restraint systems must hold the occupant to the primary structure and decelerate him at a rate at least as slow as the primary structure. Energy absorption devices and structure allow for progressive collapse of the vehicle ahead of and below the occupant, providing a longer distance and thus longer time for body deceleration. These principles will be reviewed in Bill Reed's paper.

The aircraft structures contribute greatly to the rate of deceleration. For example, if sharp edged bulkheads or firewalls dig into the ground, the rate of deceleration will be much greater than if the structure is allowed to slide across the ground for a longer distance.

NASA Langley is experimenting with energy absorbing floor structure designs which appear to be lighter than existing sub-floor structures. More and better data from the field is needed.

Post Crash Factors: Following the impact, the occupants need to be able to exit the aircraft under any combinations of attitude and damage, prior to injury from post crash fire or other causes.

The NTSB has recently pointed out[3] what has been known for many years, that many aircraft have only one door and no other exits. If that one door is damaged, jammed, on the bottom or against a tree, the occupants are forced to cut their way out of the metal and plastic container. Even in cases where secondary exits are provided, styling often dictates that they be hidden as well as possible from any rescuer. Often the design of safety devices and handles on doors are such that non-pilot personnel do not readily understand their use. Also, some of these mechanisms are easily made inoperable in very minor accidents. The NTSB pointed out the problem of doors which require two separate actions to open. Most often these are on the passenger side of the aircraft.

The most severe of the post crash hazards is fire. When fire occurs, the probability of fatality increases from 13% to 59%.[4] Unless the occupants can exit promptly, a much increased risk occurs from fire. The NTSB Report estimates 300 fire deaths each year.

Methods of crash fire prevention are now well known. The Army UH-1 has incorporated a crashworthy fuel system since the early '70s and their rate of thermal fatalities in Hueys is almost zero. The technology from this design, which was pioneered by Harry Robertson, one of our speakers this afternoon, was transferred by Dr. Robertson to the Indy race cars, and any of you who have seen some of the spectacular crashes in recent years, know how effective that has been.

The crash investigator must document the condition of each system containing flammable fluids, where the breaks and leaks occurred, sources of ignition, etc. This should be done when fire does not occur, as well as when it does. (It's lots easier in the former situation.)

Conclusion

I believe that a major reason for our lack of effort in collecting crashworthiness data has been our preoccupation with determining cause, both because of government desires for statistics and the entire litigation environment.

I submit that we do not need one more accident investigation for purposes of prevention; we could work hard for years with what we already know. There are no new accidents, just old causes in new locations.

But we could reduce the rate of trauma in the accidents we do have, with little cost or penalty in performance, if we would focus our efforts on crash survival investigations and collect the necessary data to show what is really happening in crashes of a relatively minor nature. This session today is designed to prepare you to begin that effort.

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About the Author

David S. Hall is a former Naval Aviator, and he has served as a Senior Product Safety Specialist for a general aviation engine manufacturer, taught Aviation Safety and Accident Prevention at USC for four years, and now is affiliated with the Crash Research Institute. He also teaches at Arizona State University and is involved in private consulting work in mishap prevention and mishap investigation. He is a PE (Safety) in California, and a member of the International Society of Air Safety Investigators, SAFE, AIAA, System Safety Society, and Society of Flight Test Engineers. He holds an Airline Transport Pilot Rating and is an active general aviation pilot.

Collection of Data on Impact Dynamics

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The task of improving crash survivability continues. Since the 1950s we've seen a profound improvement in aviation safety, and the survivability of those accidents that happen has, somewhat grudgingly, yielded to continual improvement.

The improvement in survivability owes much to the pioneers of the crash survival, or "crashworthiness" movement. Those pioneers, A. Howard Hasbrook and his dedicated team at the Cornell Crash Injury Research Institute, John Stapp, Jack Carroll, Gerry Bruggink, Hal Roegner, Jim Turnbow, Gerrit Walhout, Harry Robertson, Chuck Miller, and, of course, many others, developed the first hand data describing crash impact conditions and then went on to correlate that data with the known ability of humans to withstand crash forces. They found ways to improve the chances of occupant survival, and more importantly, they convinced many of the skeptics in aviation that improving crashworthiness is a reasonable, viable way to improve aviation safety.

The pioneers of crashworthiness have convinced us that crashworthiness can be improved, and they've shown us how to approach the solutions of the difficult crashworthiness problems.

We continue to learn more about ways to improve survivability, but injuries still happen, and people still die, in accidents that should be survivable. The most powerful weapon we have to prevent injuries and deaths when aviation accidents happen is—knowledge. One of the important ways to gain that knowledge is to collect facts about crash impact dynamics from investigation of accidents.

More information is needed to tell us how and why injuries happen, and sometimes, why they don't happen, so ways can be found to prevent injuries and reduce the severity of injuries.

The on-site investigator needs to know what data to collect, and how to record it so that it is as definitive as it can be, simply because much information about crash dynamics is lost forever once the airplane is moved away from where it crashed. When you collect crash impact data, keep in mind that the analysis of the data often takes place months after the data were recorded, and quite often, the analyst is not the investigator who collected the facts. Recorded, understandable information is what counts.

Certainly, the analyst is concerned with the overall kinematics of the crash. He needs to know as much as can be known about the gyrations the airplane went through. What happened to the whole airplane during the whole crash? It is becoming standard, now, to collect data relating to the flight path angle just prior to impact, impact angle, airplane attitude at initial impact, width, length, and depth of gouge marks, structural collapse, impact speed, and so forth, and also to sketch impact marks with dimensions. These data are critically important, but more information is needed.

The first rule to follow is to collect data for all of the crash, and not just for the initial impact or the most severe impact. Separate the crash into identifiable segments and collect data to describe each segment, individually. In this way the accident dynamics can be reduced to small enough parts to be understandable, and the facts collected by investigation can be more useable. The analyst needs to know initial conditions for each segment, and also the conditions at the end of each separate part of the crash. Using that information, crash forces, and just as importantly, the direction of crash forces applied to the airplane and its occupants may be estimated, for each part of the crash.

While collecting the data relating to crash dynamics, it is important to know how the information is likely to be used. In most cases, the analyst will use the data to determine crash forces and accelerations which will then be used to describe the impact conditions. Thus, the immediate objective of the crash dynamics investigation is to collect facts which can be used in determining crash forces and the direction of those forces.

Crash forces arise from a number of identifiable sources. The nature of these sources, and their interactions, determine the magnitude of the applied forces. The direction and duration of the applied forces determine the velocity change that occurs in any segment of the crash, and the amount of kinetic energy that is dissipated during each part of the crash. Ultimately, the kinetic energy dissipated in the individual parts of the crash should add up to the kinetic energy the airplane possessed just prior to initial impact.

Structural collapse, plowing of earth or other impact surface material, impulsive acceleration of the impact surface material, and friction between the aircraft and the impact surface produce and limit crash forces. These conditions can be investigated separately and then the data can be correlated. It is helpful to look at the type of information that needs to be collected for each of these types of force producers.

Structural Collapse:

Structural collapse is difficult to describe verbally in enough detail to allow an analyst who has not seen the wreckage to use the information. Therefore, it is very helpful to provide photographs of damage along with measurements describing the damage quantitatively. The information provided should tell not only how far the structure collapsed, but also the direction of the collapse. In addition, measurements of the extent of structural collapse should give the width and height of the collapsed portion of structure, as well as the depth of collapse. If it is possible to do so, describe the collapsed structural components.

Include measuring devices, such as rulers or tape measurers in photographs to help in scaling the damage during analysis, and whenever possible provide photographs taken from more than one position to help define the extent of damage.

Plowing or Impulsive Acceleration of Impact Surface Material:

Plowing and impulsive acceleration, or earth scooping, both develop forces based on the amount of earth, or other impact surface material involved, and on the characteristics of the surface material.

Measure gouges and impact craters, giving enough information to allow determination of the volume of material involved. Use a sketch to record the data, and show not only the maximum length, width and depth of the marks, but also give measurements at other locations so the size and shape of the depression is clearly defined.

Obtain a sample of the material which makes up the impact surface from a location near the point of impact, but taken from an undisturbed spot. Try to collect the sample without crushing it and try to preserve it so that its moisture content will not change before it can be analyzed. Remember that the soil may vary greatly from point to point along the path of the aircraft as it crashed, so it is important to obtain samples near each location of earth plowing or scooping and to mark the samples carefully to identify their source.

These earth samples should be analyzed in an engineering laboratory to determine the characteristics of the soil. These characteristics can then be used to estimate plowing and earth scooping forces. Suitable engineering laboratories serve the building and construction industry and are available in most metropolitan areas and in the civil engineering departments of many colleges and universities. The report of soil characteristics should be included with the accident report.

Friction:

Friction forces occur when any object slides along another. The magnitude of the force produced depends upon the kind of materials that come into contact with each other, the condition of the contact surfaces, and the force which presses the surfaces together. These factors vary so much that friction forces should be measured in every case when the airplane slides along the impact surface.

To measure the friction forces, obtain a sample of material that is the same as the part of the airplane that slid along the impact surface, place a known weight on the sample, and then measure the force required to pull the weighted sample along the impact surface. Be careful to pull the sample in the same direction as you want it to move, not at an angle and not upward. Record the weight of the sample and its weight and the force required to pull the sample along at a steady speed. The sample does not need to be large, and a small spring scale can be used to measure the force with sufficient accuracy.

These ideas have been presented to help make the collection of data on crash dynamics a little less obscure and to help to identify more clearly the type of information that is needed for crash dynamics analysis. Please understand that it is still necessary to collect data about initial impact conditions and principal impact conditions. It is still necessary to determine crash impact angle and flight path direction, and to investigate all the other factors that are usually part of a thorough investigation. Those things haven't changed, and won't change. If crash survivability is to continue to improve, though, then more information is needed to define the conditions that are encountered in severe but survivable crashes. Keep in mind, too, that as more success is realized in the effort to improve survivability, the survivable crash becomes a more severe crash. The need for data continues to grow. It just won't go away.

An important point, here, is that for crash dynamics analysis there is never too much information available—and seldom enough—to do the job the way we want to. And it is a very important job.

Biography

William H. Reed is Chairman of the Department of Aeronautical Technology at Arizona State University, having been a member of the faculty since 1966. From 1962 until 1966, he was a project engineer for the Aviation Safety Engineering and Research Division of Flight Safety Foundation (AVSER), engaged in research concerning crash impact conditions and survivability. Since 1966, while at Arizona State University, he has continued experimental work directed toward improving crash impact survival, and also worked as a consultant in accident reconstruction.

Crash Data on Structures

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Introduction

The theme for this series of papers is crashworthiness analysis. When Dave Hall approached us to contribute to this session, he indicated that since Transport Canada's standard form for Reporting on Investigation of an Aircraft Accident includes substantial data collection requirements on wreckage and impact information, and also on survival and fire data, Transport Canada could probably contribute some information in the form of case history examples which would be pertinent to the theme for this session.

Once I had started to collect case histories which showed potential as crashworthiness examples some persistent, and rather discouraging, areas of concern became apparent.

Crashworthiness can be considered to apply to the period from the "point of inevitability" where the pilot can no longer avoid the accident to the termination of the crash cycle. Crashworthiness of the affected aircraft will determine the chances of survival of the occupants during this phase of the accident flight. The areas of crashworthiness which I repeatedly found to appear wanting concerned the seat and restraint systems.

In preparing this paper I found nothing particularly new or revolutionary. I found, however, that though the

FAR Emergency Landing Conditions v Crash Survival Design Guide Data

Direction	FAR 23.561		FAR 25.561	CSDG
	Norm.	Acro.		
Forward	9.0g	9.0g	9.0g	40.0g
Down	3.0g	4.5g	4.5g	25.0g
Side	1.5g	1.5g	1.5g	20.0g
Up	3.0g	4.5g	2.0g	15.0g

NOTE:– CSDG Values Quoted Refer To Human Body Tolerance To Acceleration

FIGURE 1

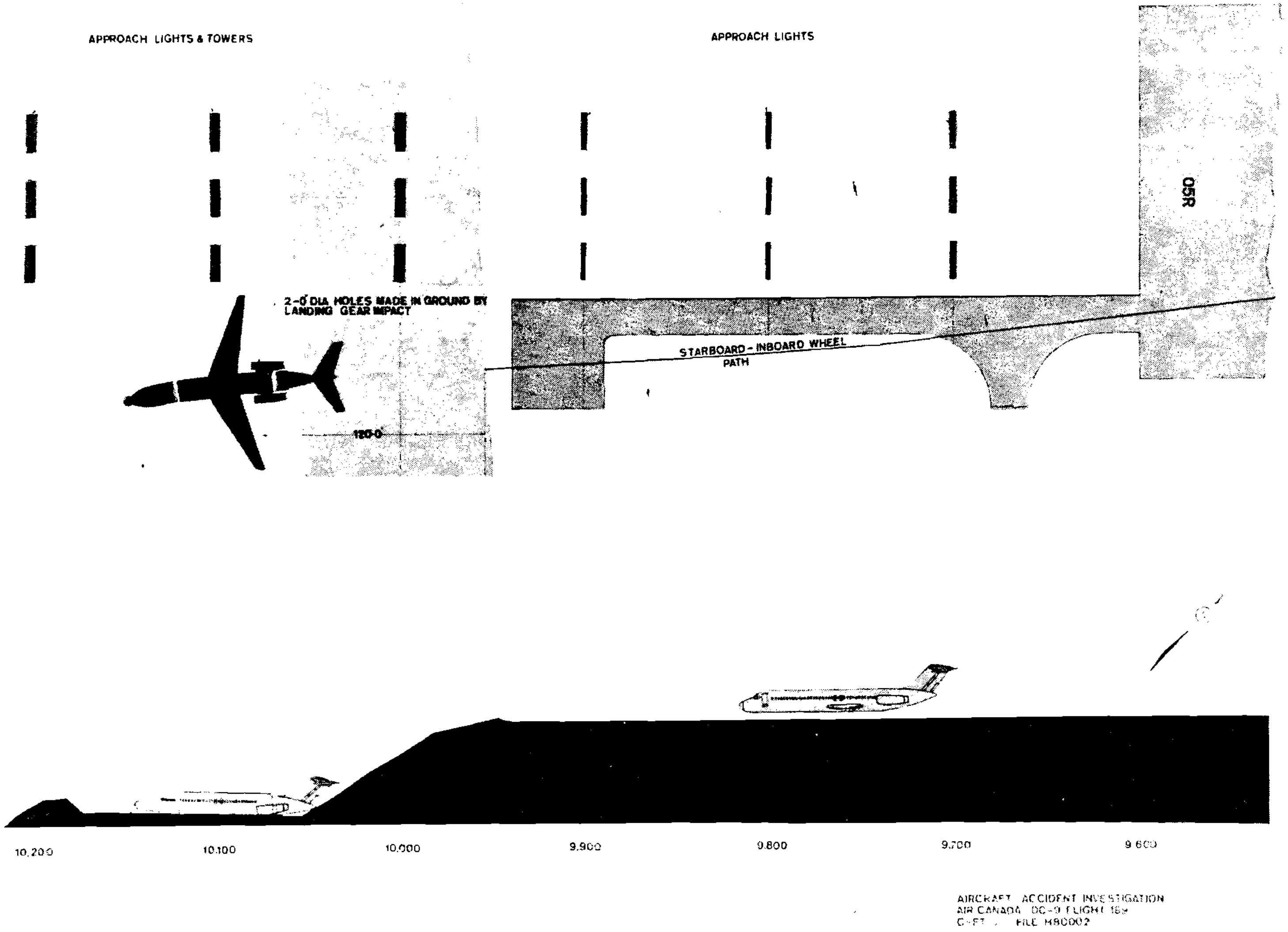

APPROACH LIGHTS & TOWERS
APPROACH LIGHTS
05R
2-0 DIA HOLES MADE IN GROUND BY LANDING GEAR IMPACT
STARBOARD - INBOARD WHEEL PATH
120-0
10,200
10,100
10,000
9,900
9,800
9,700
9,600
AIRCRAFT ACCIDENT INVESTIGATION
AIR CANADA DC-9 FLIGHT 189
C-FT FILE H80002

Photo 1

individually revealed information would probably not surprise any experienced ISASI member, the *collective* pattern was sufficient to cause me and my colleagues concern, and I would like to share this concern with you all.

Figure 1 shows the vast differences that exist between FAR 23 and FAR 25 requirements for crew and passenger restraint systems and the U.S. Army's widely accepted Crash Survival Design Guide values for human body tolerances. Professor Jerry Snyder has correctly and succinctly noted that we currently put 40G occupants in 20G aircraft protected by 9G or less seat and restraint systems (and ones which are mostly devoid of any upper body restraint at that).

The major case histories that I would like to review are some selected large commercial aircraft crashes. Each has been selected because it is an example of apparently preventable injuries and deaths despite being a severe crash, since in each case a major part of the airframe survived the crash sequence relatively intact.

Case History Number 1

This is a DC-9 which ran off the end of the runway during an aborted take-off, and plunged over a 51 feet high cliff at about 42 knots (Photo 1). The calculated initial crash impulse forces for this accident were about 16G forward for .18 second, and about 19G downward for about .13 second.

Major fuselage fracture occurred at fuselage stations 437 and 996, corresponding to rows 6 and 7 seats and the rear pressure bulkhead (Photo 2). Undercarriage rearward collapse and rupture of the wing tanks led to a massive fuel spill, but by great good fortune there was no fire. Photo 3 shows the aircraft had just sufficient forward speed to fly free and not slide nose first down the embankment. Photo 4 shows the massive destruction of the cabin underfloor structure revealed when wreckage removal was initiated.

There were 2 fatalities; in seat 6A the occupant's heart was speared by metal shard and in seat 7A the occupant suffocated when trapped under a folded seat. There were 47 serious injuries, mostly fractured extremities and spinal injuries, while 58 others survived mostly with bruises and lacerations, but all with mobility.

The galley exit was completely blocked by the displaced commissary. Three exit windows were jammed by fuselage distortion while the rear exit door was jammed up against the cliff. Most occupants evacuated through the forward fuselage break (Photo 5). This was also over the major fuel spill areas. Views of the fuselage interior before any major clean-up show that collapsed seats and overhead racks made exit very difficult even for the walking wounded (Photo 6). A total of 50 minutes passed before the last of the injured was removed by emergency service personnel. It is readily apparent that the fatalities would have been very high if fire had broken out.

The typical collapse pattern observed for seat structures under the relatively high vertical loading resulting from this crash showed that some energy absorption occurred during this collapse. However the high vertical G component was undoubtedly responsible for the large number of spinal injuries.

The overall pattern was one of seat failure and separation from the floor tracks under the influence of loads far in excess of FAR requirements, but basically within human body tolerances. Most occupants remained strapped in their seats; actual seat belt failures were rare.

Photo 2

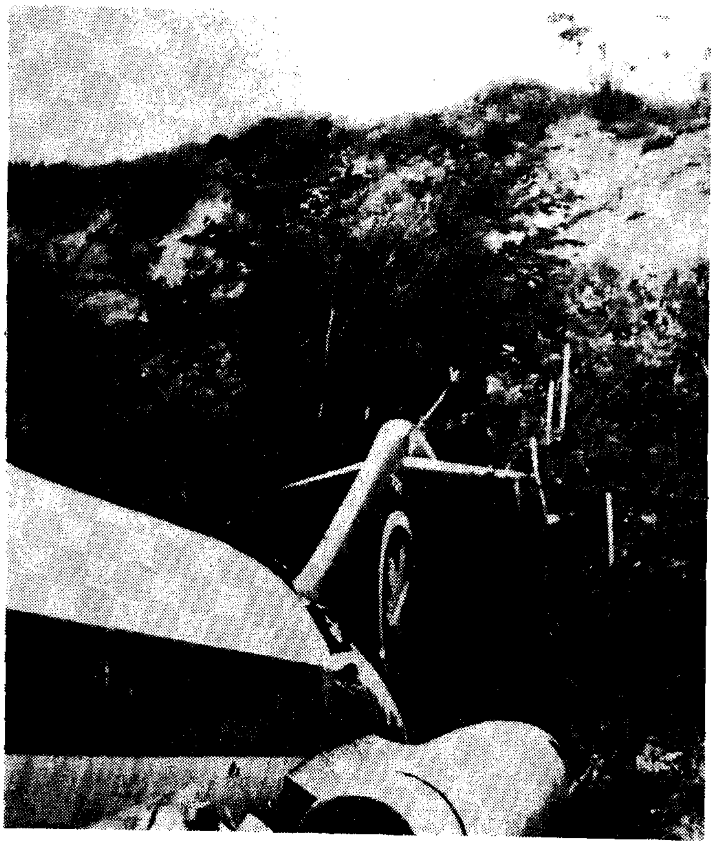


Photo 3

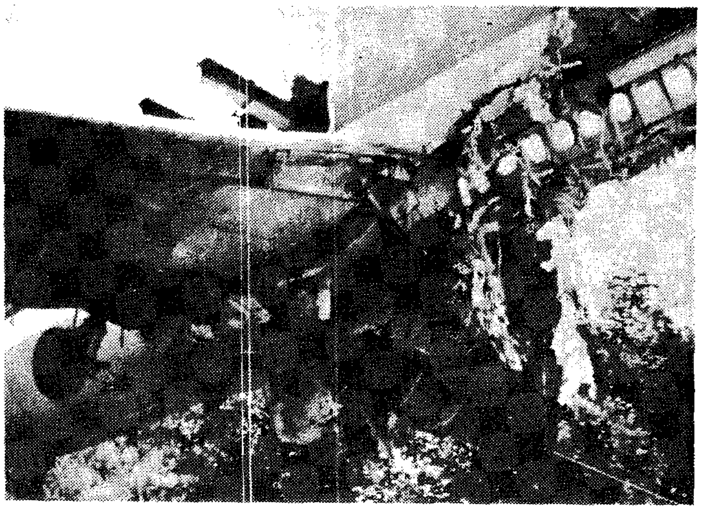


Photo 4

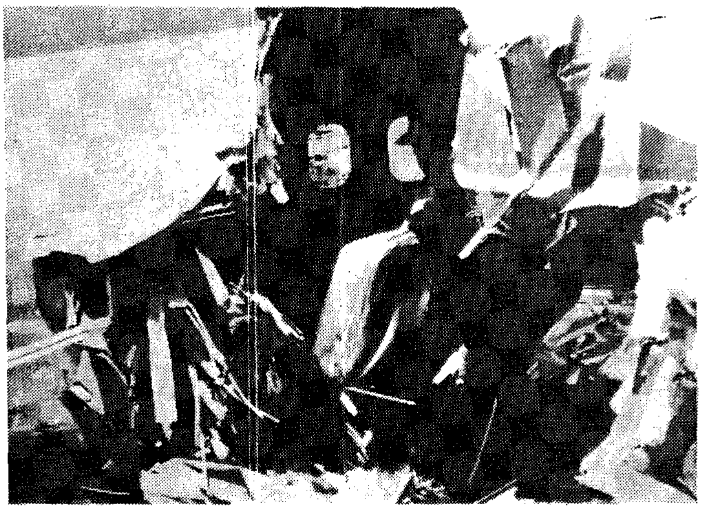


Photo 5

Photo 6

Case History Number 2

This is a Lockheed Electra (half cargo and half passenger configuration) which crashed onto fresh sea ice over 100 feet depth of Arctic Ocean about 2-3 miles short of the intended runway threshold, shown diagramatically in Photo 7.

Photo 8 shows the initial impact conditions, Photo 9 shows the early cockpit separation at the Stn. 200 production joint. Photo 10 shows the cockpit and cargo tobogganing about 750 feet along the ice, only to sink when finally stopped. The main cabin underfloor forward end cut into the ice, causing the main fuselage structure to decelerate at about 20-22G maximum for about .22 second as the right wing exploded.

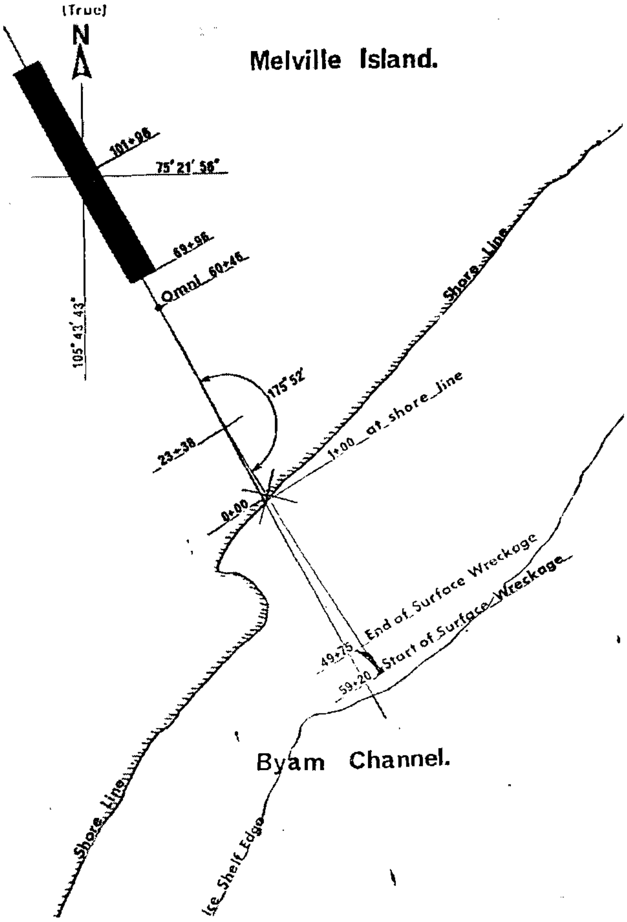
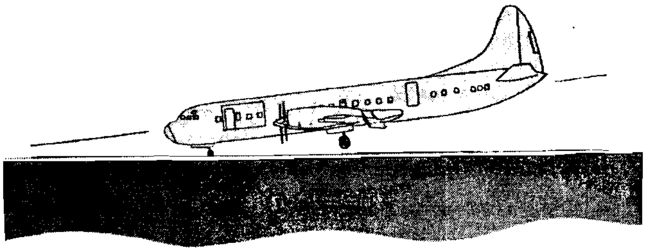


Photo 7



INITIAL IMPACT CONDITIONS:-
200 ft/sec Ground Speed, 321 Degrees True
1,400 ft/min Descent Rate, Left Wing Low
Impact Nose Wheel First on to 8" Thick Ice
Photo 8

Photo 11 shows the major wreckage distribution. The item flagged 15 was an Arctic survival kit weighing about 650 lb which had been installed in the place of the left rear toilet. This cabinet was not well restrained, and broke loose under crash deceleration. The remains of the kit were found 500 feet down the ice, showing the kit had broken free and swept all of the seats out of the fuselage ahead of it. There were 31 fatalities and 2 survivors, but autopsy evidence showed there were 16 potential survivors, who survived the crash cycle with servicable injuries only to die subsequently in the winter arctic environment of exposure (10) or drowning (6). The first officer and engineer survived. The captain did not have his shoulder harness fastened, and was knocked unconscious and subsequently drowned when the cockpit slowly sank. A general surface wreckage view is shown in Photo 12.

Divers carried out a thorough underwater inspection of the aft fuselage section. Fire damage shows that this portion rested forward end down for a long time before finally sinking through the fire weakened ice (Photo 13). Interior views clearly show how the survival kit tore through the rear bulkhead, and swept away all the seats and occupants (Photo 14). However, it was evident that the floor tracks

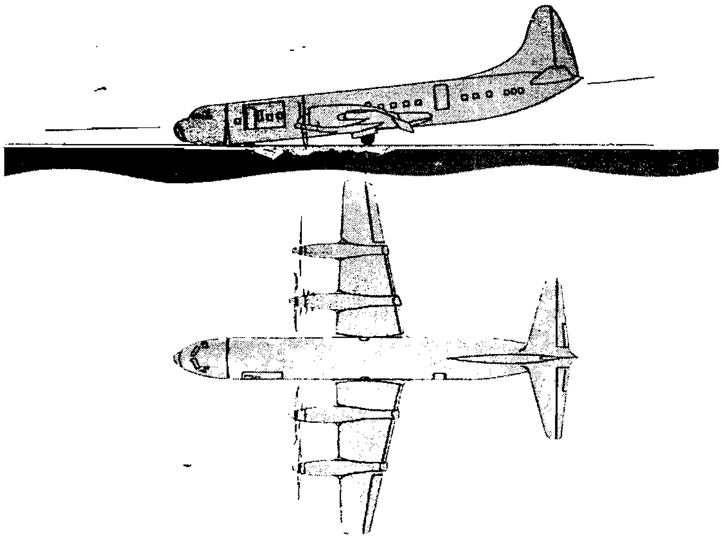


Photo 9

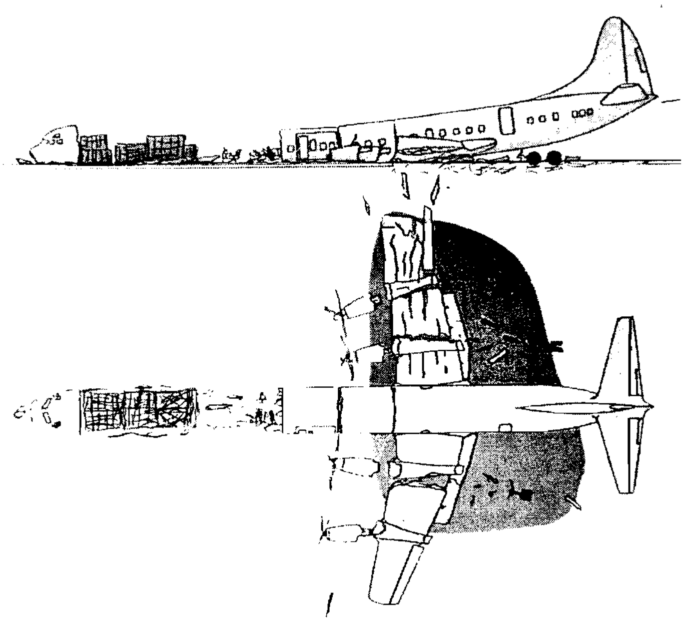


Photo 10

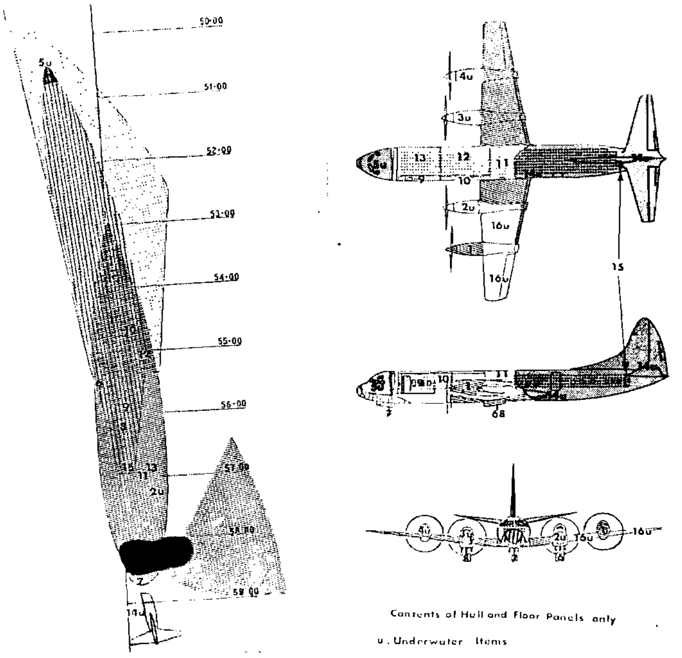


Photo 11

Photo 12

Photo 13

Photo 14

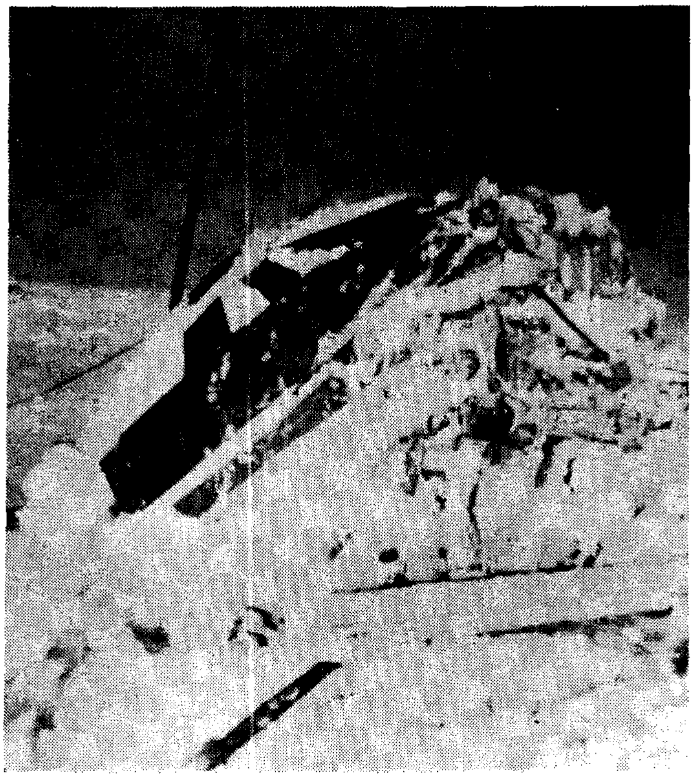


Photo 15

were relatively undistorted. Most occupants did not suffer seat belt failure. Photo 15 shows the limited damage incurred by the cockpit section. Again, the common pattern was for the seats to fail by separating from the floor tracks. The long survival times for many occupants resulted from lack of a major "second collision" when shot out onto smooth ice or into the water.

Case History Number 3

This is a Fairchild F-27 (an example of which is shown in Photo 16) which had its right hand engine low pressure compressor disc burst just after lift-off, severing the forward engine and gearbox and propeller assembly, which was recovered from just off the runway (Photo 17). The crew elected to execute a short emergency go-around, but were not able to maintain flying speed and crashed just short of final for an emergency landing (Photo 18). There were 17 fatalities and 7 survivors. Impact was nose down and right wing low at about 145 ft/sec. The aft fuselage and tail cartwheeled away from the main impact site and was not burnt. The tail assembly separately at final impact at the aft pressure bulkhead (Photo 19).

At the crash scene the inverted aft fuselage section showed relatively intact structure, but all seats except for the left rear had separated during the final impact sequence (Photo 20). The final crash pulse was estimated at only 9-10 G forward for about .2-.25 sec. (initial crash pulse effects on the rear fuselage were undetermined, but must have been less severe, as no seat separation occurred until final impact).

It again appeared that the seats generally left the floor tracks when the latter distorted. Each seat assembly generally remained intact, but all showed signs of collapse forward and downward, giving some energy absorption. Again occupants generally did not suffer seat belt failures.

Photo 16

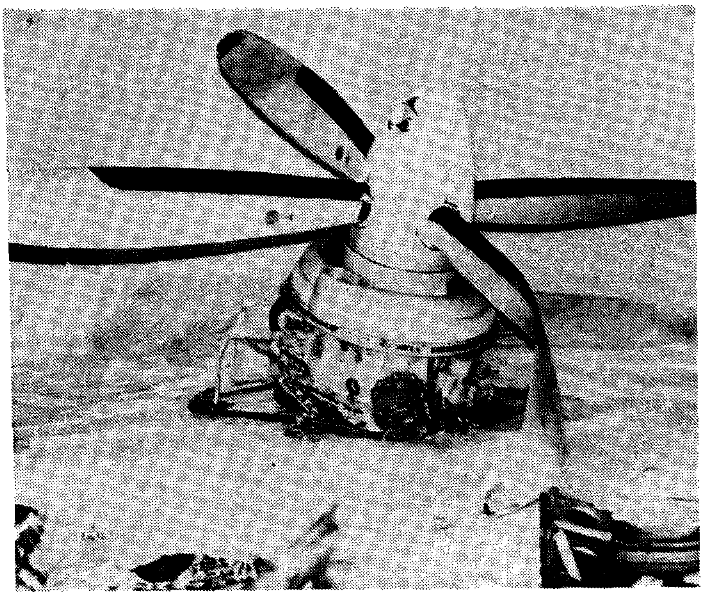


Photo 17

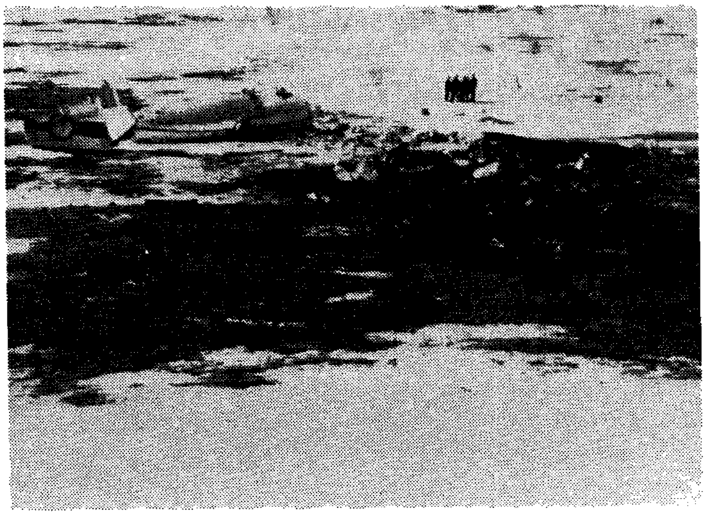


Photo 18

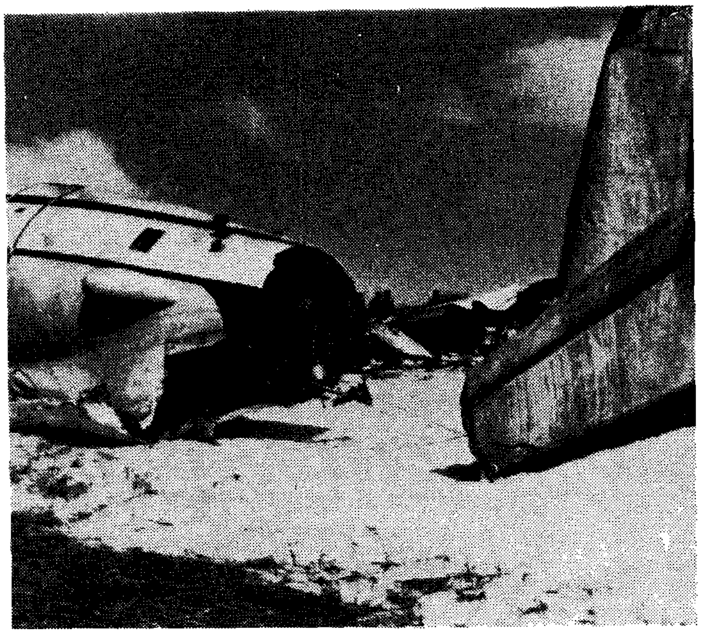


Photo 19

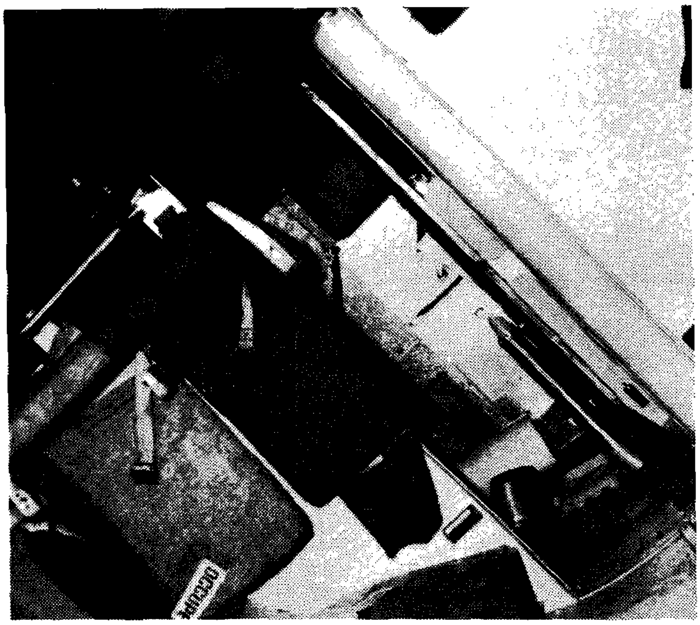


Photo 20

U.S. Army (Arizona State U)
Crash Survival Design Guide

Design Factor	Hazard Potential	Optimum Number
1 Crew Retention System	17.9%	130
2 Passenger Rentention	17.2%	125
3 Postcrash Fire Potential	35.2%	255
4 Airframe Crashworthiness	17.2%	125
5 Evacuation Potential	8.3%	60
6 Injurious Environment	4.2%	30
TOTALS	100.0%	725

NOTE:- Retention Systems Total 35.1%

FIGURE 2

Summary of Case History Findings

All three major carrier crash examples show some common characteristics. These were seat and restraint collapse and separation from the floor tracks under the influence of loads well within human body tolerances.

The FAR 25 9G limit means most seat/restraint systems installed in current carrier aircraft will most probably allow passengers to suffer "second collision" and severe injury potential, even when at least a major part of the surrounding structure provides a tolerable survivable environment throughout most crash impulse cycles.

Review of General Aviation Seat/Restraint Systems

FAR 23 provides no better constraints than does FAR 25 (Figure 1), and is usually accompanied by a more hostile environment. Since the majority of FAR 23 aircraft are not fitted with upper body restraints, crippling impact with the cabin interior fittings, even during relatively modest crash cycles, is highly probable. (Though FAR 23 aircraft certified since July 1978 are required to have shoulder harness installed for front seat occupants, this only protects a small minority of general aviation users.)

Recent studies indicate general aviation has roughly 12 times more fatalities per 100,000,000 passenger miles than do automobiles. On average 2 of every 3 occupants die in serious aircraft accidents, while on average only 1 in 25 occupants die in comparably serious automobile accidents. Current model automobiles have a cheap, effective 6,000 lb breaking strength rated lap and shoulder harnesses on front seats, and 6,000 lb lap belts for all other occupants. All seat and restraint systems are rated for 20G loading, and the surrounding environment typically uses padding and energy absorbing materials throughout.

General aviation, by contrast, commonly uses relatively expensive 1,500 lb lap belts (and only the occasional shoulder harness) installed on a nominal 9G seat surrounded by a hostile, unprotected environment. All this in aircraft that current studies indicate have a 50-70% chance of crashing in their typical 20 year life.

The U.S. Army's widely accepted Crash Survival Design (CSD) Guide, with which A.S.U. graduates have become familiar (Figure 2), indicates seat/restraint systems represent more than one-third of the overall hazard potential factors to be considered when evaluating aircraft. Aviation Safety Engineering (ASE) has studied and evaluated several FAR 23 Aircraft using the CSD Guide rating system, and a remarkably consistent and discouraging pattern has become apparent.

The following exemplary aircraft have been selected from ASE's study: BD-4, Cessna 150, Piper PA-30, Beech Queen Air, and deHavilland Twin Otter.

The CSDG evaluation is summarized in Figure 3 and shows all aircraft are fairly good to excellent in all factors EXCEPT seat/restraint systems. However, essentially ALL

Data Collection on Seats and Restraint Systems

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Introduction

There are significant efforts underway at the present time to improve the crash safety of all types of aircraft. The military, primarily the U.S. Army, has led the way with its crashworthiness-oriented research and development programs. Perhaps of even more importance, they have established stringent specifications requiring the inclusion of crashworthy features in their new aircraft and have conducted retrofit programs to improve the crashworthiness of existing aircraft. The civil sector is following suit primarily through programs sponsored by the FAA. Although there has not been as direct an approach for requiring incorporation of crashworthy features into civil aircraft as in military aircraft, there nevertheless are significant current efforts being made to develop the technology and analytical tools needed to enable improved crashworthiness to be included in civilian aircraft.

In establishing what modifications should be made to an aircraft to improve its crashworthiness, it is vital that primary causation factors are determined. Efforts can then be directed towards solving the most critical problems and providing improvements in those areas which will produce the most immediate and needed effects. Because the seat and restraint system interface directly with the occupants of an aircraft, it is extremely important that these items do not constitute the weak link in the overall structural restraint chain. It is, therefore, important that the restraint system and seat receive an extremely high priority in any selection of items to be improved, and that the investigator obtain all possible data from wreckage. This information should be most helpful in understanding the overall crash kinematics and in assessing weaknesses in the seat and restraint systems, thus highlighting those areas most deserving immediate attention to improve the crash safety of the system.

This paper deals with specific data concerning the performance of seats and restraint systems which should be collected by the aircraft crash investigator.

Sources of Injuries

Although the subject of occupant injury is dealt with specifically in other papers presented at this seminar, it is important to mention here how these injuries relate to the performance of the occupied volume created by the surrounding aircraft structure and to the performance of the seat and restraint system. The specific details on injuries should be available from other sources such as autopsy reports. However, during the postcrash investigation of the seat and restraint systems, it would be useful to observe the occupied volume and to record details of any apparent points of occupant contact. These data would be helpful in reconstructing the kinematics of the seat and occupant and in understanding what caused the injuries experienced by the occupant during the crash.

Causes of injuries can be grouped under several major headings, all of which can be influenced, and some completely controlled, by the performance of the seat and restraint systems. These headings are:

- Intrusion
- Entrapment
- Excessive loads
- Secondary impacts
- Ejection

Intrusion injuries are those experienced by the occupant when a livable volume is not maintained within the structure of the aircraft. These injuries can be caused by complete or partial crushing of the fuselage or by intrusion of an aircraft structural member or other item in the crash area. Injuries range from crushing to impalement. There is little that can be done with the seat and restraint system alone to eliminate this occurrence; however, a system which holds the occupant very close to the center of the volume, or close to his original position, can minimize

Selected CSDG Crashworthiness Ratings

CSDG Factor	Opt. No.	BD-4	Cessna 150	Piper PA-30	Queen Air	Twin Otter
1 Crew	130	32*	34*	30*	49#	43*
2 Pass	125	32*	34*	33*	32*	38*
3 Fire	255	207	216	190	204	170
4 Airf	125	78#	93	108	104	95
5 Evac	60	50	50	37#	45	45
6 Envr	30	21	21	20	22	21
TOTAL	725	420#	448#	418#	456#	412#
%AGE	100	58#	62#	58#	63#	57#

*=Less Than 33% of Optimum Number
#=33% to 66% of Optimum Number

FIGURE 3

aircraft rate below one-third of the optimum in the seat/restraint hazard potential area. (Note, Transport Canada's Queen Air is unusual in providing upper body restraint for the crew, which boosted its rating.)

Summary

The represented case histories and design evaluations illustrate an obvious severe weakness of current aircraft seat/restraint requirements and design and manufacture.

The automobile industry has long since introduced seat/restraint regulations, design and manufacturing standards which have demonstrably provided the automobile driver and passengers with far superior protection than is currently available in almost any aircraft. This has also been accomplished at what, by aircraft standards, is a relatively negligible cost.

The resistance of the aviation community to the introduction of comparable safety standards and systems is inexplicable and inexcusable. I doubt that there are very many of us in ISASI that have not seen an example of needless loss of life or serious injury comparable to some of the preceding examples. I also expect that most of us have suffered the frustations of seeing the System refuse to make the obvious and necessary improvements. How much more blood must be spilled before those long overdue, obvious and necessary improvements in seat/restraint systems are finally introduced? Let us all try yet again to get the message across. Remember the life you save may your own.

About the Authors

All of the authors are on the staff of Transport Canada's Aviation Safety Engineering Facility (ASE), and as such are full-time career aviation safety investigators.

Robin McLeod is Superintendent, Engineering Analysis at ASE, and as such supervises all engineering failure analyses undertaken by ASE. He entered aviation as a student apprentice with Rolls Royce in England, has a BSc in Mechanical Engineering from Bristol University, U.K. and is a specialist in materials engineering and failure analysis.

Jim Hutchinson and Jack Melson are members of ASE staff working under Robin. Jim is Supervisor, Materials Failure Analysis and was Chairman of the Structures Group in the DC-9 and F-27 investigations. Jack is ASE's Aeronautical Engineering and Stress Analysis Specialist, and has done extensive crashworthiness evaluations over the past decade.

Terry Heaslip is the Chief of ASE and is responsible for the management and operation of the new ASE Facility at Ottawa, Canada, in support of Transport Canada's national transportation safety programs. The Facility is a multi-million dollar engineering and laboratory complex which is primarily responsible for support of aviation safety investigations and defect analysis, but also provides technical assistance to Transport Canada's highway, rail and marine safety programs.

Figure 1. Severe impact of this agricultural aircraft caused extensive damage, but cockpit integrity was maintained (from Reference 1).

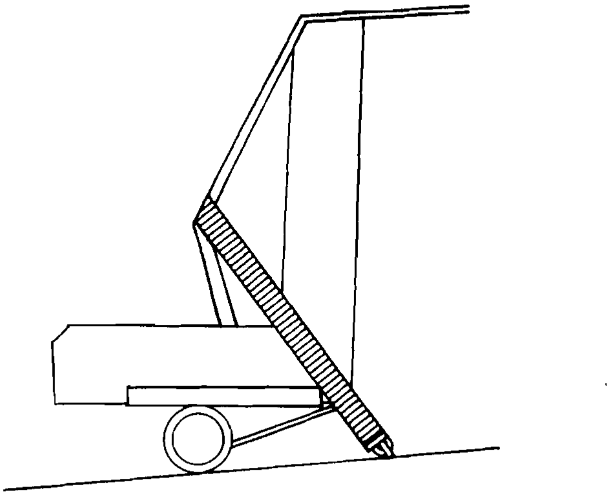
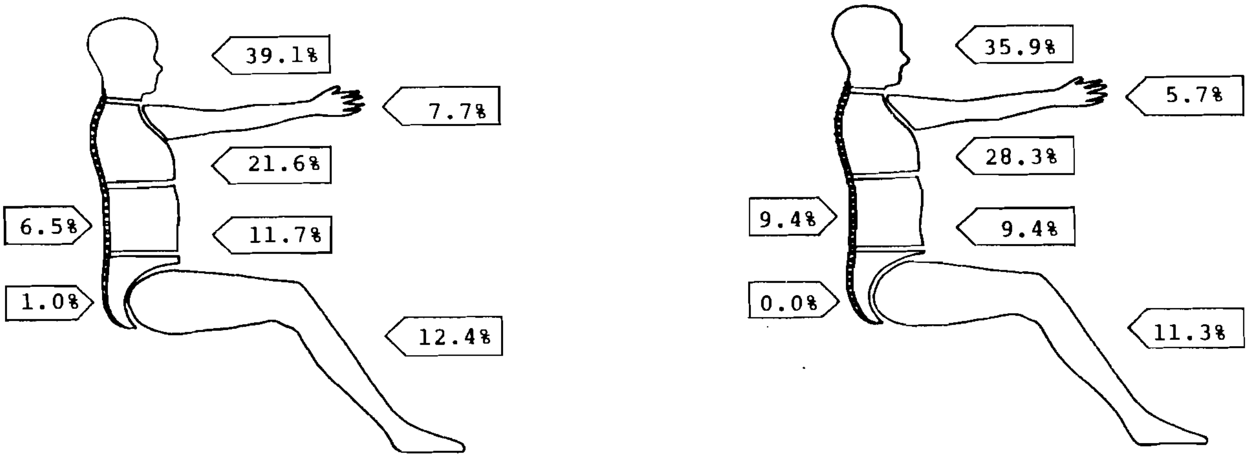
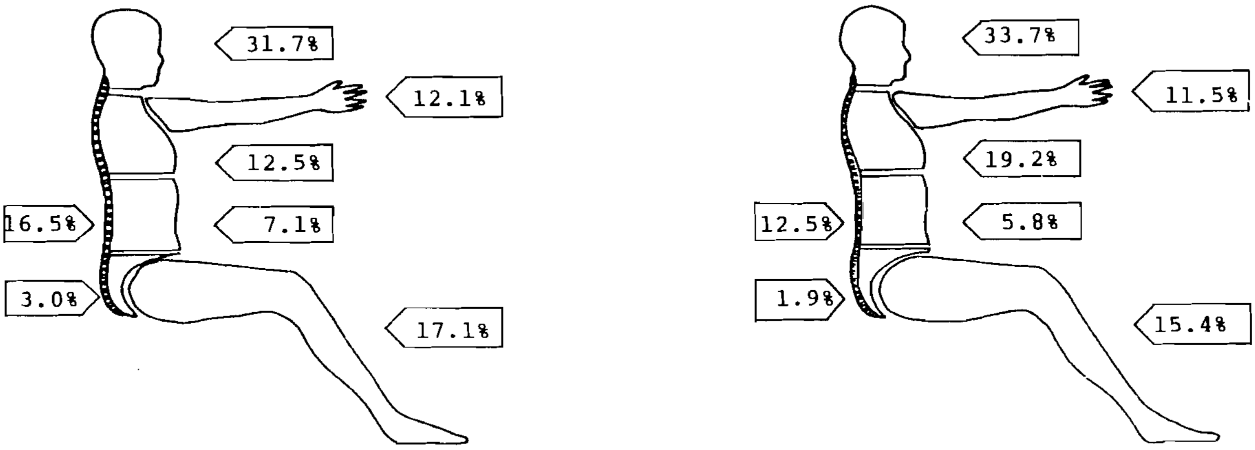


Figure 2. Schematic of aircraft seat showing mounting directly over large tubular main spar with little space or structure to attentuate vertical impact forces (from Reference 2).



a. Frequency of fatal injuries, helicopters.

c. Frequency of fatal injuries, light fixed-wing.



b. Frequency of major and fatal injuries, helicopters.

d. Frequency of major and fatal injuries, light fixed-wing.

Figure 3. Frequency of injuries to body parts in U.S. Army aircraft accidents, 1971-76 (from Reference 2).

injuries due to intruding members or crushing structure. As demonstrated by investigations of accidents involving aerial application aircraft conducted by the FAA Civil Aeromedical Institute[1] the occupied volume of some aircraft can remain intact even when the remainder of the structure is destroyed, as shown in Figure 1. However, despite maintenance of such an acceptable volume, the occupant can be injured or killed due to failures of the seat and/or restraint system, as was the case in this example.

Entrapment injuries can be minimized by a seat and restraint system design which does not collapse in any way that will trap the occupant. Entrapment can be caused by deformation of the aircraft structure such as floors, bulkheads, or pedals, as well as deformation of the seat; and injuries can result from collapsing structure crushing and/or trapping limbs or other parts of the body within the crushed volume or under collapsed items. However, a secondary effect, which can be more hazardous, is that the occupant may be unable to exit the aircraft and therefore be subjected to postcrash hazards such as fire or water.

Excessive loads are defined as loads applied to the occupant that exceed levels tolerable to the human body. These loads can result from too stiff a structure throughout or in specific places in the aircraft, including the seat. As an example, seats may be placed on the top of a wing spar, as shown in Figure 2. If crash impact loads are not attenuated sufficiently by deforming material, impacted terrain as well as aircraft structure, then they are passed on to the occupant and may produce loading injuries. Excessive loads may also be experienced if the seat collapses, resulting in a secondary impact of the occupant with the floor or other surrounding structure. The loads associated with secondary impact are generally applied to localized regions of the body and may exceed tolerable levels to an even greater extent than the loads resulting from the principal impact.

Secondary impacts can cause extremely serious injuries or rather minor effects. For example, if a seat catastrophically fails and the occupant impacts the floor, loads in excess of organ suspension and spinal strengths can easily be experienced. On the other hand, secondary impact of an extremity, such as a hand or a foot, may simply produce bruises, abrasions or broken limbs. Probably the most dangerous secondary impacts are experienced by an occupant's head, face, neck, and upper torso. Statistics, as shown in Figure 3, reflect a high rate of severe injuries to these areas in crashes of light fixed-wing and rotary wing aircraft. These types of injuries can be caused by lap-belt-only restraint used in many of the aircraft coupled with the close proximity of seat backs, food trays, instrument panels, glare shields, control yokes, consoles and other protrusions in close proximity with the occupant. Figures 4 and 5 illustrate the strike envelopes for a 95th-percentile occupant restrained by a military five-point restraint system and subjected to a 30-G spineward and sideward acceleration, respectively. Figures 6 and 7 illustrate the strike envelopes for a 95th-percentile occupant exposed to 4 G and restrained by a lap belt only. It can easily be seen that, even with upper body restraint, secondary impacts of upper body and head are likely; with only a lap belt, they are to be expected.

After providing the primary function of supporting the occupant of an aircraft in a comfortable manner, the seat's responsibility is to support and restrain the occupant under the loading conditions resulting from a crash. If accomplished adequately, this will minimize the hazards associated with the sources of injury presented above and will decelerate the occupant together with the airframe in a tolerable environment.[3]

The postcrash information which should be collected is relevant to the performance of the various components within the system. These components may have either failed to perform their assigned functions, performed them in an inadequate manner or functioned as intended. The collection of quantitative data concerning the performance of these components provides information that is useful to those attempting to understand the injury patterns experienced by the occupants and to develop new hardware that will minimize the chances of continued occurrence of these injuries.

Desired Data

As mentioned previously, data concerning the specific injuries to the occupant must be available together with occupant data such as height and weight. In addition, points of occupant impact with the seat or surrounding aircraft structure should be noted. These points of contact would be apparent in the form of dents in sheet metal or other evidence of impact that can be correlated with injury noted on body members. All data related to the structural performance of the seat and restraint system should be observed, measured, and recorded.

Specific information desired for restraints and seat systems is as follows:

- Aircraft and impact data
- Occupant physical and injury data
- Secondary impact data
- Floor structure and tracks
- Fittings that attach the seat to the tracks
- Seat structure
- Attachments of restraint systems to seats or other aircraft structure
- Restraint system components.

Modes of failure and desired data for each of these areas are presented below.

Aircraft and Impact Data

The aircraft type and model number should be recorded. In addition, all information, whether measured or estimated, concerning the aircraft impact attitude and velocity components, such as sink velocity, forward velocity, lateral velocity, or flight path velocity and attitude should be listed. All impact velocity and kinematic data available will be helpful in the reconstruction of the crash loading components imposed on the seat. Structural data also required include: extent of crush of the fuselage, fuselage penetration into the soil, type of impacted terrain, and length of skid as evidenced by marks. Examples of terrain categories include:

- Sod
- Trees
- Rocks
- Prepared surface
- Bog
- Water
- Snow
- Ice

These data, some of which are hard to obtain, are helpful in any crash reconstruction effort. When a computer program, such as the FAA Program SOM-LA,[4] is used to reconstruct the crash, specific occupant data and known seat characteristics are included in the model, and iterations are made to establish the crash environment. Crash environments are estimated, cases run, and measurable performance parameters noted in the crash investigation

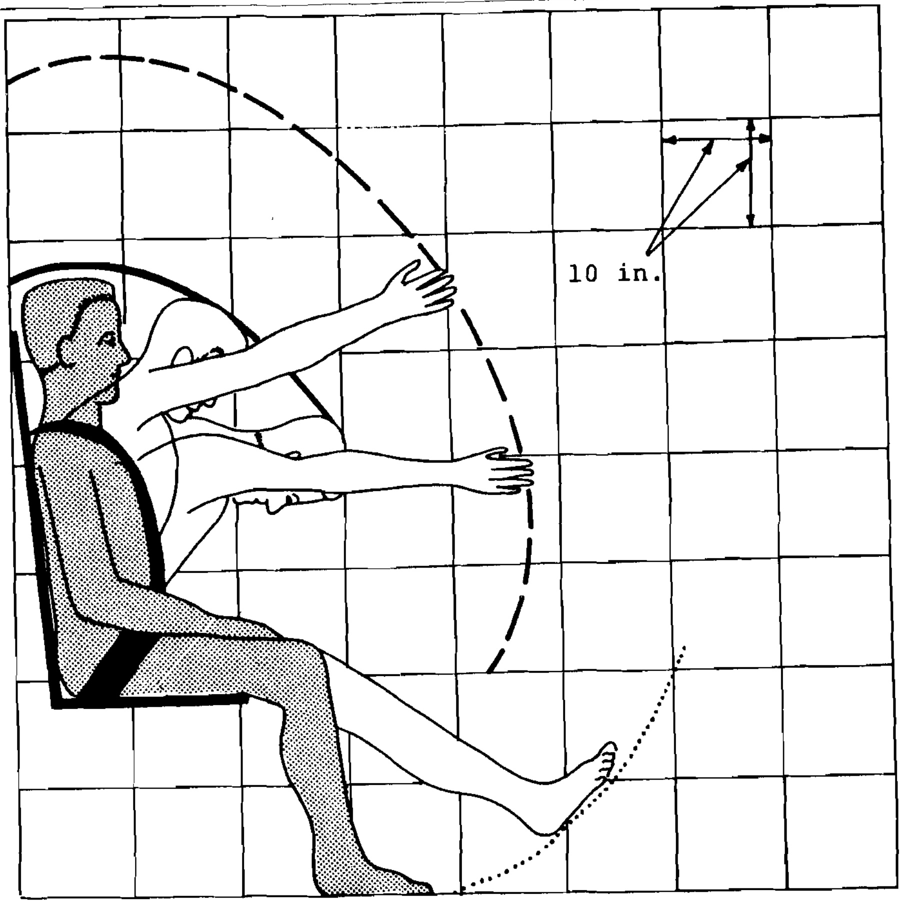


Figure 4. Full-restraint extremity strike envelope - side view.

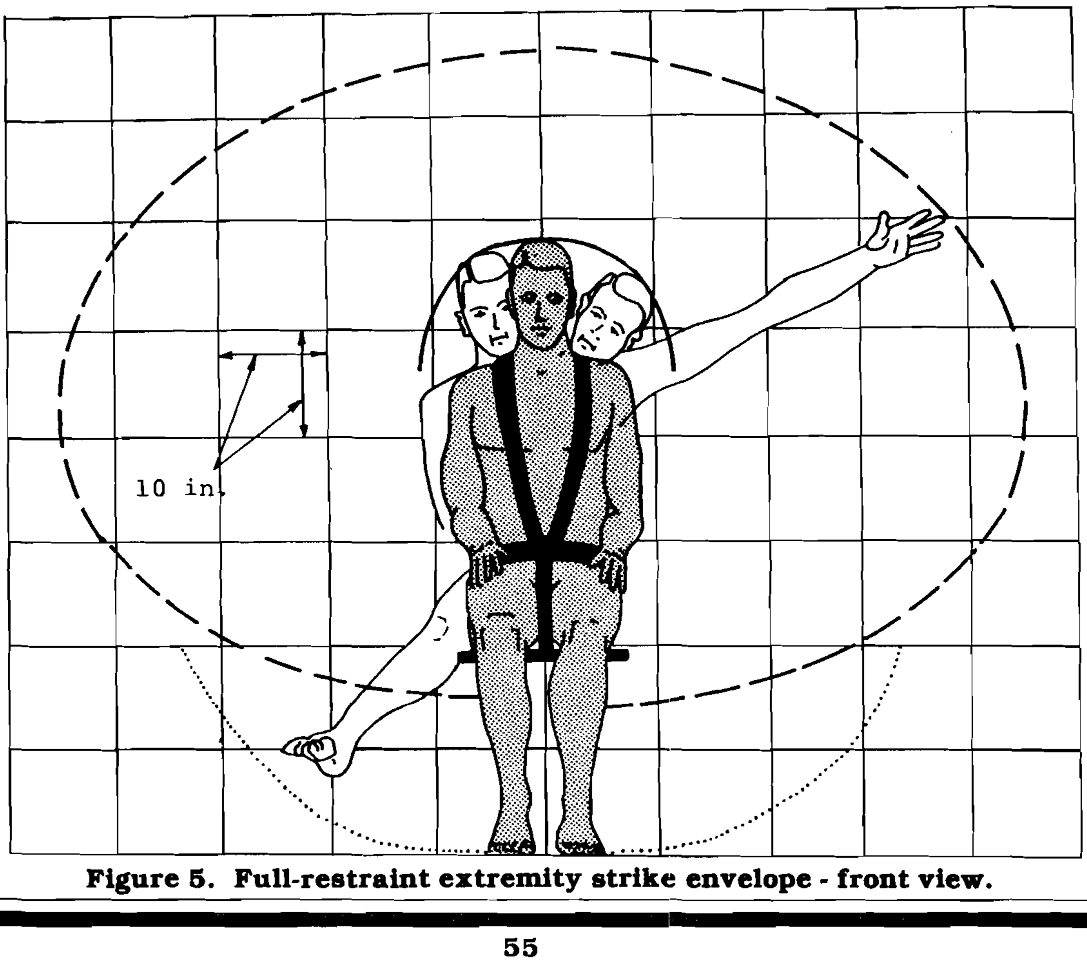


Figure 5. Full-restraint extremity strike envelope - front view.

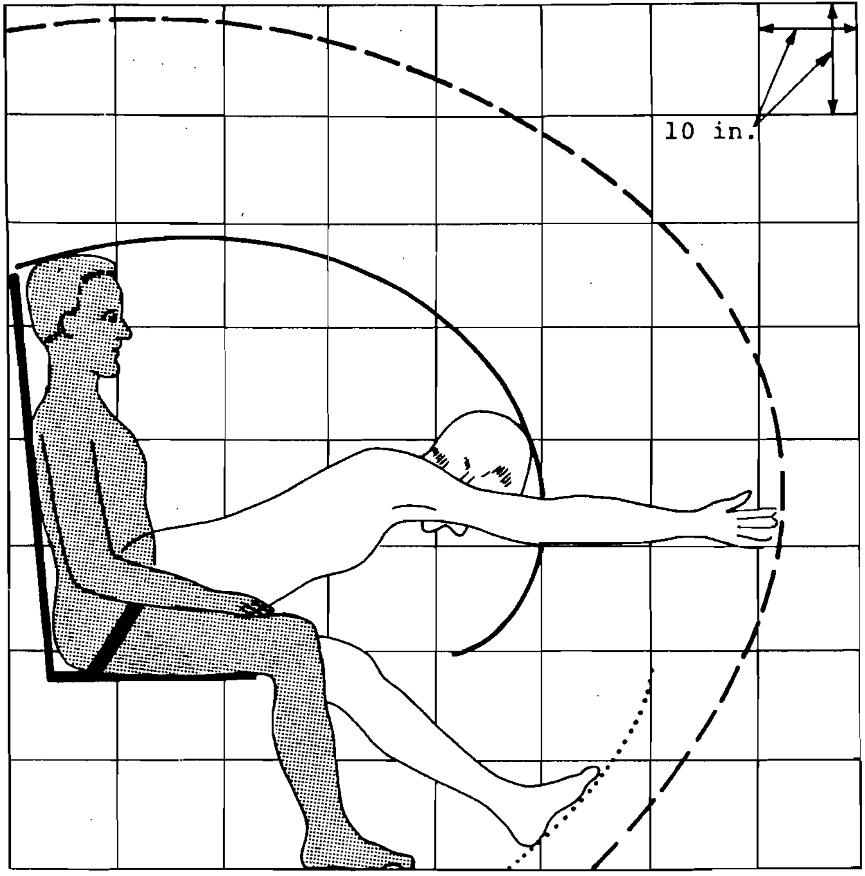


Figure 6. Lap-belt-only extremity strike envelope - side view.

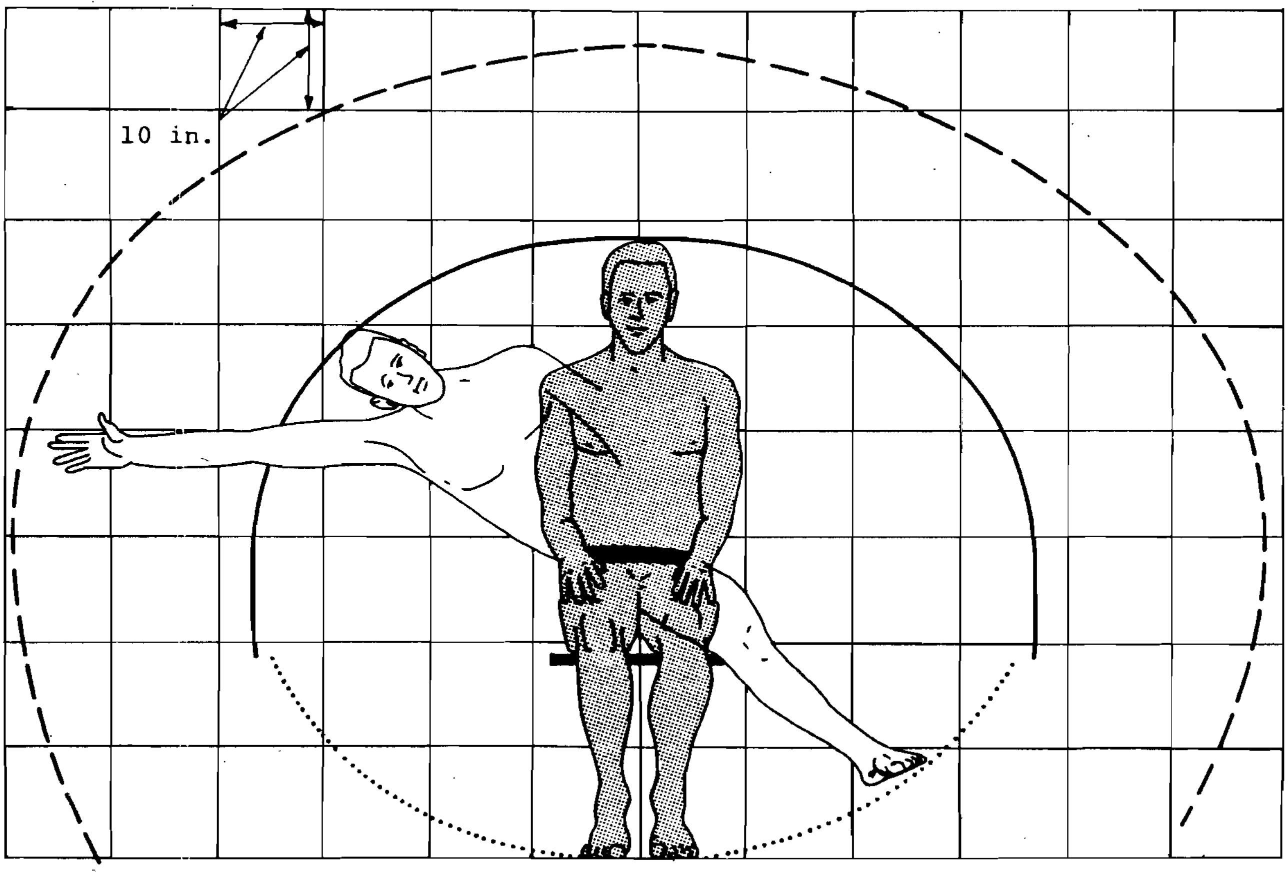


Figure 7. Lap-belt-only extremity strike envelope - front view.

are compared with computer predictions. When the actual crash results are predicted by the program, it is assumed that the crash environment has been closely approximated. Therefore, obtaining all data available on the aircraft and its impact environment is a great aid in establishing the crash conditions.

Occupant Data

The minimum occupant data that are needed are the occupant weight and height. It is also important to know how the occupant was restrained; e.g., lap belt and single diagonal shoulder strap, lap belt alone, full five-point restraint system, etc.

Secondary Impact Data

If it is identifiable, the position in which the seat was locked, both vertically (if it is a vertically adjustable seat) and longitudinally, should be identified. These data are necessary for accident reconstruction to position an occupant accurately within the aircraft.

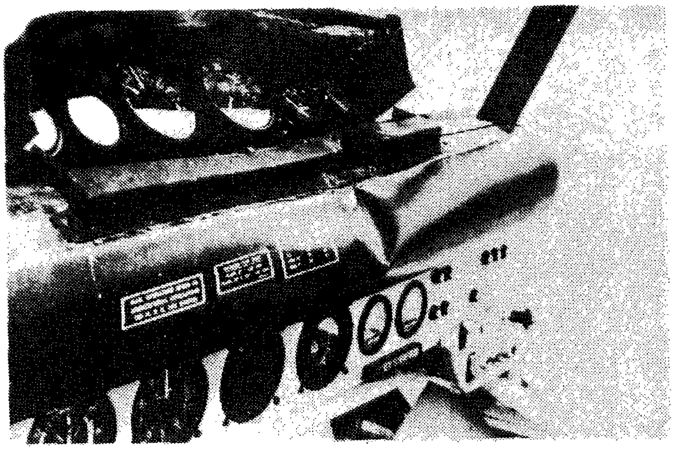


Figure 8. Instrument panel deformation of the type caused by head impact (from Reference 1).

Next, the location of any discernible body impact on surrounding structure, such as head impacts on glare screens or instrument panels, should be recorded. An example of deformation due to head impact is shown in Figure 8. It would be helpful to record the depth of permanent deflection of the impacted surface and the location of the impacted surface measured from some identifiable reference point in the aircraft, for example, the forward end of the inside or outside track for a cockpit seat, or the pitch of the cabin seats in a transport aircraft. This type of information aids in accurately positioning the occupant in the precrash orientation, which is necessary for adequate modeling and prediction of impact velocities and points of impact for various members of the occupant's body. The impact area should be defined in three axes, i.e., x, y, and z distances from the point chosen as a reference.

Floor Structure and Tracks

Tracks are used to attach the seat to the aircraft structure and can be of the upstanding Tee or of the flush-with-the-floor T-slot variety (Figure 9). If the floor strength is insufficient, inertial loads of the occupant and the seat can tear the track out of the aircraft structure, thus producing a restraint system failure. In some light aircraft there is essen-

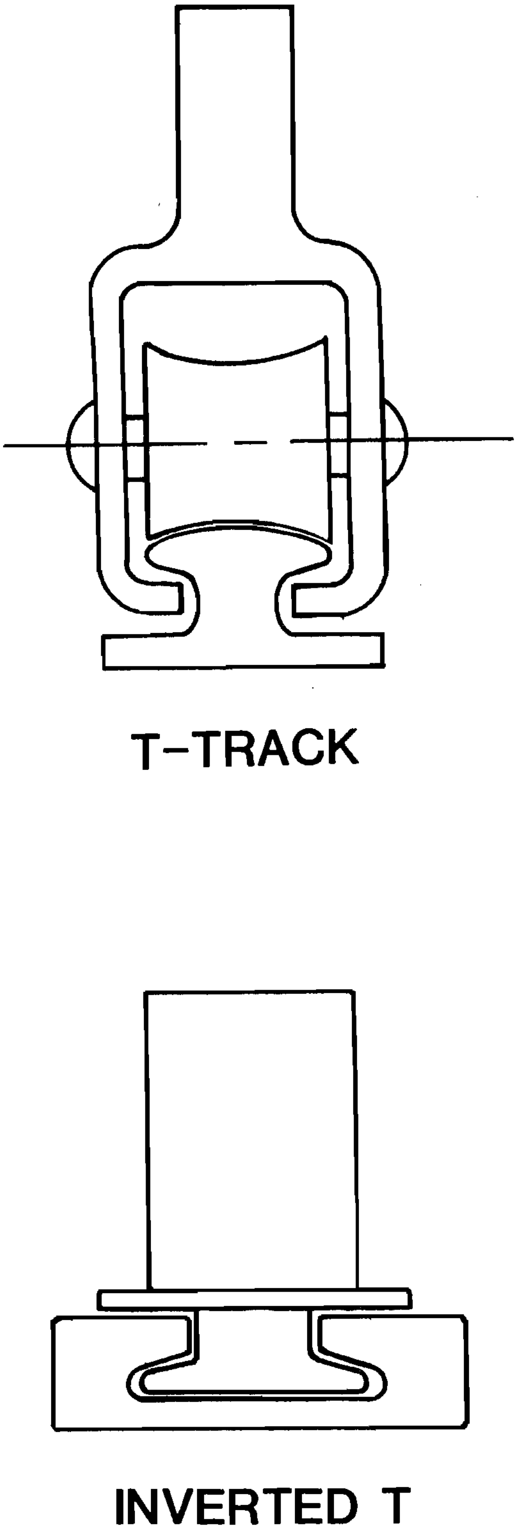


Figure 9. Basic seat-track attachment configurations.

Figure 10. This left seat track shows elongation of the hole where the seat locking pin had been apparently engaged (from Reference 1).

tially no beam structure under the floor supporting the tracks, but the tee track itself provides the support. For these systems, failure of the track is synonymous with failure of the supporting structure. Regardless of the structure, however, the mode of failure, including fracture or excessive deflection of the track, should be noted and any possible measurements taken and recorded. In analyzing the performance of the seat, it is helpful to know the restrained motion allowed by the deforming tracks or other floor structure.

Examples of information desired are:

- Did the floor structure fail and release the seat?
- Did the floor structure and track deform but restrain the seat? If the latter case is true, what is the maximum deflection and at which point relative to the seat was this deflection measured?
- Did the track fail by having its bulb, or tee, pulled from its web? If so, where and how long is the tear?
- With the flush-mounted slot-type track, the same questions apply except an additional failure mode would be the shearing off of the restraining flanges on the track channel-type slotted structure mounted in the floor, which releases the cap stud fitting attached to the seat legs. Other failure modes would be the shearing of the edges off the cap stud or the pulling of the cap studs from the seat legs.

Seat Attach Fitting

If the track was sufficiently strong, the seat could separate from the structure by failure of the attachment fittings connecting the seat to the track. Even if the track failed, deformation and partial failure of these fittings are also informative, and measurements and descriptions should be recorded. Figure 10 shows a track section in which elongation of an adjustment hole by the seat locking pin allowed the seat to slide off the front end of the track.

High rigidity of the interface between the track, the seat attach fitting, and the fitting attachment to the seat frame can also produce failures. If the floor warps in the crash and carries the track with it, the track fitting must follow the track. Rigid attachment of fittings to seat frames can produce excessive bending moments in the frame or the fitting attachments and failure of those attachments as a result of floor warpage. In Figure 11 is shown an attach fitting which has spread and allowed retraction of the locking pin. Figure 12 shows an attach fitting which was separated from its seat leg by rivet shear. Any kind of failure should be noted and quantitative data recorded. Describe the hardware involved and the details of the failures, including failure dimensions. Any information which can be indicative of the loads applied during the crash would be helpful.

Figure 11. The left front seat-to-track attachment was spread, and the seat track locking pin was retracted (from Reference 1).

Seat Structure

The performance of the seat structure is extremely important. If the seat integrity has been maintained and plastic deformation has occurred, a deceleration load would have been applied to the occupant and crash energy absorbed. Therefore, it is important to identify all of the permanently deflected members of the frame together with an estimate of the amount of deflection. Any specific information such as sheared rivets, rotated collars, cracked fittings, buckled tubes, etc., is important in the reconstruction of the seat and in the understanding of the loadings associated with the crash. An example is the fractured seat leg shown in Figure 13.

If the seat is an energy-absorbing seat, the deflection of the energy-absorbing devices should be carefully measured. Since the stroking characteristics of these devices will be known, an accurate assessment of the crash energy absorbed can be made from these measurements.

Restraint System Attachment Points

The failure of a restraint system attachment fitting will release the occupant at the first link in the structural chain attaching the person to the aircraft structure and is not acceptable. These interfaces must be designed to carry the restraint load into the structure and to be capable of withstanding the necessary loads to ensure that the occupant decelerates with the aircraft. Frequently these fittings are designed such that bending moments can be produced by normal loading of the restraint system. These moments can reduce the load-carrying ability of the system to magnitudes lower than those calculated using the structural properties of the members loaded in shear, tension, compression, or by simple moments. Any permanent deflection or failure mode of these members, including torsional deflection, should be carefully measured and recorded. Specific failures might include sheared fasteners, fasteners failed in bending, bolts that are sheared out of their restraining fittings, etc.

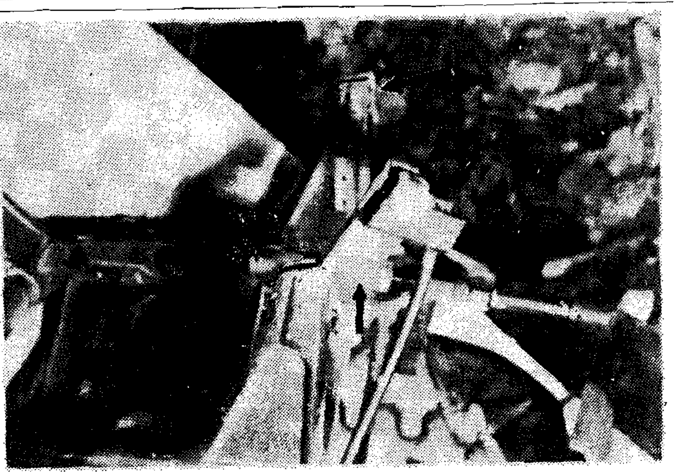


Figure 12. Seat-to-track attachments broken and free from the seat leg by shearing of the attaching rivets or shearing of rivets and fracture of the seat leg (from Reference 1).

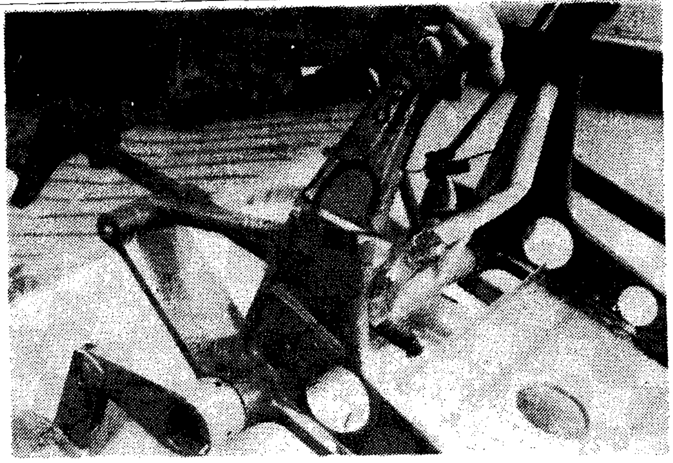


Figure 13. Mid-shaft break in right front seat leg. The seat was detached from the seat track (from Reference 1).

Restraint Systems

Restraint system comonents should be carefully inspected and any damage recorded. First, the end fittings should be observed and failures or imminent failures noted. As an example, failure of the shoulder harness D-ring shown in Figure 14 allowed the pilot's upper torso to travel forward against the instrument panel. The field investigator believed the parking lever then penetrated the left side of the chest. The forward movement of the pilot at impact was probably enhanced by fracture of the forward seat-to-track attachments and the movement of the seat off the track.[1]

Condition of the webbing should be evaluated and any partially failed webbing indicated by tears or broken strands should be observed. If the webbing is fairly new, any such evidence would be indicative of the magnitude of loads applied to the webbing. Older webbing may have been frayed from abrasion or weakened to the point that it would exhibit premature failure and is therefore not as valuable a load indicator unless samples of the webbing are tested to establish its ultimate strength. Stitch patterns should be reviewed to see if any stitches are torn free, also an indicator of loading magnitudes applied to the strap. The webbing and adjusters should be carefully inspected to see if the webbing was drawn through the adjusters allowing a restraint system slip. Usually webbing drawn under high load through an adjuster will show signs of abrasion as a result of the friction with the knurling on the locking cam of the adjuster. The length of the slipped section should be recorded if it can be determined.

Plug-in buckle fittings should be inspected to see if they are bent or if the edges of the slots which retain the fittings in the buckle are beveled as a result of excessive corner or edge loading. Failure could be the result of excessive loading producing deformation of the metal along the edge of the slot in the fitting, thus enabling a camming action to be exerted on the retaining dog, eventually releasing the fitting. Evidence of this should be noted and recorded. Bent fittings should also be measured and the bend recorded. Any evidence of inoperability of the release mechanisms should also be recorded. The plug-in fittings should be plugged in and the buckle handle activated to see if all the fittings can be released.

The inertia reel lead-in strap, if there is a shoulder harness, should be inspected carefully to reveal any evidence of excessive webbing being withdrawn from the reel during the crash loading. Damage to the reel or evidence that the real did not lock under decelerative loading should be determined and recorded. Any evidence of webbing withdrawn from the reel prior to late locking should also be noted. In a case reported in Reference 1, the lap belt and shoulder harness were undamaged, but the shoulder har-

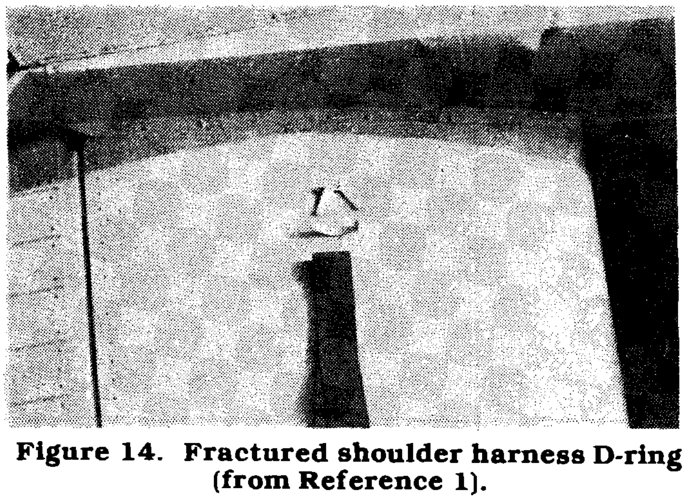


Figure 14. Fractured shoulder harness D-ring (from Reference 1).

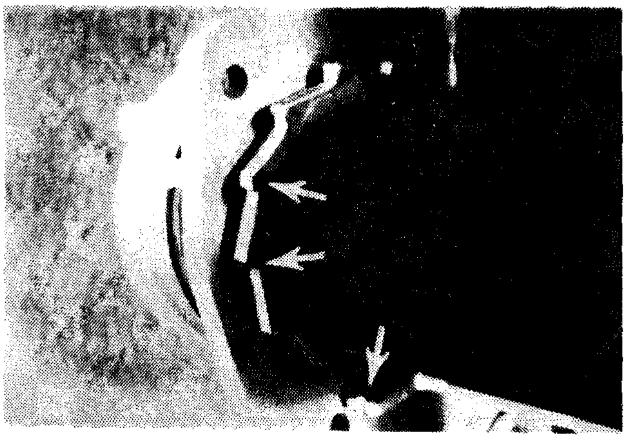


Figure 15. The reel ratchet gears were flattened, and the engaging pawl was grooved (from Reference 1).

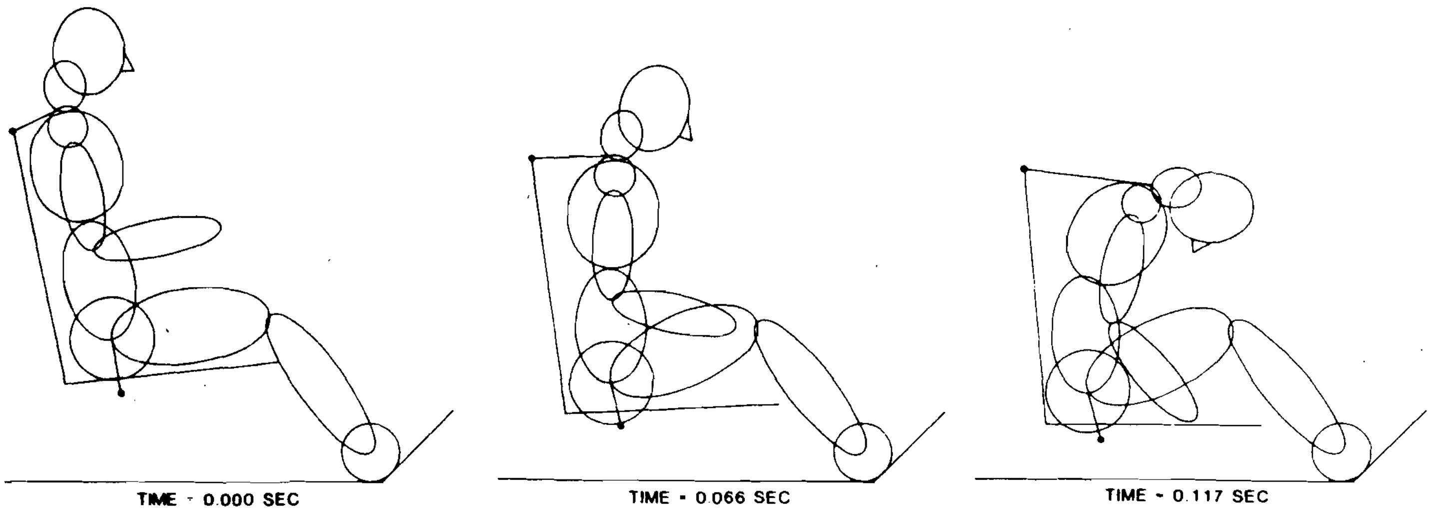


Figure 16. Example of occupant motion predicted by computer simulation.

ness was extended its full length from the inertia reel. The inertia reel housing was intact, but the tips of some of the reel ratchet gears showed impact flattening and the engaging pawl showed impact abrasive grooving (Figure 15). The forces in this accident caused the pilot to travel forward against the shoulder harness. Failure of the inertia reel to completely engage and hold, thereby letting the shoulder harness fully extend, probably accounts for the pilot's head striking the instrument panel. Fracture of the forward legs of the seat and the subsequent seat separation probably added to freedom of the pilot to come forward. A tendency noted in Reference 2 for certain inertia reels is a folding of the webbing on the spool which can obstruct the reel-locking mechanism. Diagonal straps or straps attached directly to structure should also be inspected and any pertinent data recorded.

Crash Simulation

It is important to locate and measure any structural evidence so that reconstruction analysis can be based on known strengths and known performances to allow a reasonably accurate estimate of the crash environment to be made. Methods for reconstructing these accidents are becoming more sophisticated with the development of appropriate computer programs such as the FAA-sponsored program described in Reference 4. This computer program is a sophisticated three-dimensional model of a restrained occupant in a seat, which has been developed and validated by comparison with data from tests of specific aircraft seats. It can, therefore, be relied upon for use as an analytical tool in not only the design of seats and analysis of the effects of modifications proposed for seats, but also in reconstructing the crash environment. An example of response predicted by the program is shown in Figure 16.

The accident reconstruction can most efficiently be accomplished by starting with an estimated crash scenario and predicting the results. Iterative analyses can then be run with different assumed environments until the predictions match the recorded results. Details of the response of the seat structure and the restraint system during the crash, as predicted by the computer simulation, can then be examined. Results can be used in designing the most effective improvements in the existing system.

Recommendations and Conclusions

It is recommended that all evidence obtainable from detailed inspection of seat and restraint system hardware, as well as surrounding structure, be recorded for future analysis and accident reconstruction. In this way the actual experience observed in the aircraft can be used to prioritize modifications which might be made to improve the crash safety of aircraft. It can also be used to determine the minimum crash loads present in any particular crash and thus be indicative of the crash environment. The extra time taken in detailed inspection and recording of data associated with the seats and restraint systems will be well worth the effort if the data are made available to those who will use it in either the development of technology or in the improvement of the specific designs of hardware in existing or future aircraft.

Acknowledgements

All photographs were provided by the Aviation Toxicology Laboratory, FAA Civil Aeromedical Institute, whose staff investigated the accidents. The assistance of that Laboratory, particularly Dr. William R. Kirkham, is appreciated.

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Case Study of A Cessna-206 Accident with Crashworthiness Improvements in the Seat

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Jungle Aviation and Radio Service, commonly referred to as "JAARS", is the Transportation and Communication Department of the Summer Institute of Linguistics and the Wycliffe Bible Translators, a scientific, educational missionary organization operating in "30 some" countries and working in 752 languages around the world, and was established for the purpose of translating God's word, the Bible, into some 2,000 unwritten languages of the world. This means reducing the language to writing by using the science of descriptive linguistics. Establishing an alphabet, comprising a dictionary, grammar analysis, writing primers and carrying on literacy programs are all integral parts of the program.

Since unwritten languages are generally spoken in remote areas of the world, the use of aviation with flying in its most basic form, and two-way radio communications are vital to our ability to complete our job. An estimated 50% of the airstrips we use are constructed by, or under supervision of, our personnel with assistance by the local population. Geographic location often limits the dimensions and type of approach to any airstrip. This type of operation offers a high exposure for accidents.

JAARS, along with Mission Aviation Fellowship, Wings of Hope and similar organizations, has sustained serious accidents resulting in injury and, on rare occasions, death. Coming into focus in recent years have been serious back injuries from high vertical deceleration. Also noted were other serious injuries and the rare fatality which was often connected with restraint problems and/or seats separating from connecting points.

There are about 30 missionary organizations flying more than 400 aircraft in countries all around the world. This fleet is comprised of a cross section of most single and light twin aircraft, such as the Helio Courier; Cessnas 180, 185, 206, 210 and various 400-series twins; Piper single engine aircraft of various types and Piper twins such as the Aztec and Navajo. Also included are Douglas DC-3's, Aero Commanders, a Twin Otter and rotor wing aircraft such as Hughes 500, Hiller and Bell.

A contact with Dwight McSmith of NASA Langley Research Center was made at Oshkosh, Wisconsin during an Annual Convention of the Experimental Aircraft Association. He described the extensive experimentation that was taking place on accident survivability. This contact, along with the injury-related accidents within the above-mentioned organizations, led us to feel much could be accomplished by pooling our efforts toward a common goal of crash protection. Hence MACC (Mission Aviation Crashworthiness Committee) was formed. One of the first items coming to our attention out of the NASA research was the use of Temper Foam and a solid pan for improving aircraft seats. Though our desire is to design and build a complete seat capable of absorbing high g-forces, it appeared at that time that this was still a few years in the future.

Early tests indicated the Temper Foam, when used over a solid pan, offered protection from greater g-forces than conventional seats. With this in mind, we at JAARS began very quickly to modify as many seats as possible with a solid aluminum pan and 3 inches of Temper Foam on the seat and 2 inches for the back. While making these modifications we were also designing an "S" frame seat with the hope of getting as much attenuation protection as possible within our space constraints.

Recently, NASA's Langley Research Center completed Test 20, a controlled crash of a light twin impacting at 60 mph, at a minus 15° flight path and 0° pitch. One of JAARS' newly designed "S" frame seats, complete with Temper Foam cushions, was installed in the pilot's section of the aircraft for this test. Accumulated computer data showed the anthropomorphic dummy on the "S" frame seat received 20 g's while the anthropomorphic dummy in the standard co-pilot seat took 36 g's. The "S" frame seat is said to have made the difference between "walking out" and debilitating or terminal injury.

A Cessna 206 that crashed in Papua New Guinea in February 1981 was one of the first to receive three basic modifications dealing with crashworthiness. Installed in the seats were a solid metal pan, Temper Foam cushions, bilateral shoulder harness and belts with metal-to-metal hardware. The accident occurred at Aiyura, the home base of operations. The Aiyura airstrip is 4,000 feet long, 5,280 feet msl, with an average 2% up-slope in direction of landing. High hills on each end and the south side of the airstrip essentially made this a one-way airstrip, with normally a 45° base leg and a relatively short final. Due to the length, it is considered one of the better airstrips we are using. This was a training flight. The pilot being checked out was relatively new to the field, was basically a rotor wing pilot, and had just completed a helicopter check-out. The instructor-pilot had several thousand hours in the Cessna 206 and had acted as chief pilot and official check pilot for several years.

Normal departure is to take off and make a 45° turn to the left into a valley. This particular model 206 had the newer 310 horsepower turbo-charged engine and is capable of higher angle and rate of climb while at gross load. Hence, the decision to make a right-hand circuit of the airstrip while practicing take-offs and landings. On the third take-off a simulated engine failure was given which, for various reasons, ended in a stalled configuration, and the aircraft impacted the ground with heavy vertical force. The aircraft continued on approximately 728 feet with a collapsed nose gear, and came to a halt on the side of the runway. The aircraft was at 3,500 pounds gross weight at the time of impact. The cargo was in the cargo pod, and the pod struck the ground preventing potential main gear separation.

Resultant damage was downward distortion of the wings and flaps. The vertical stabilizer showed wrinkles from the downward forces. The rear door and door frame were distorted, thus preventing proper operation of the door. The tail cone was distorted mainly from the downward g-forces. Both front seat tracks had a downward deformation of ¼ to ⅜ inch. Both of the solid pan seats had a ¼ to ⅜ inch deformation.

Our doctor gave each pilot a thorough physical immediately following the accident. The pilot when checked out was in excellent condition with no cuts, abrasions, sprains, or broken bones. The pilot in the right seat suffered a stiffness in the neck for several days. Other than that, he too was in fine condition.

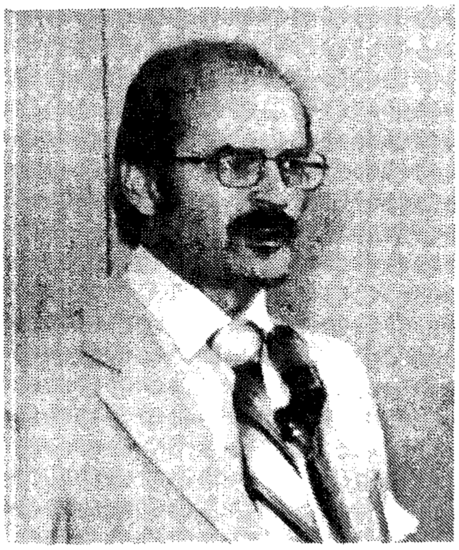
We have reason to believe the simple and relatively inexpensive modification ($300/aircraft in 8-10 hours) of the solid pan seats with Temper Foam cushions prevented back injuries in this Cessna 206 accident in Papua New Guinea in February, 1981.

In looking back over other accidents involving high vertical forces, three Cessna 185s and one Cessna 206 resulted in broken backs, plus other types of injuries including one fatality. The only back injury accident for which I have pictures available is that of a Helio belonging to JAARS. Ironically, he too was practicing an engine out emergency landing. It will be five years this October and the pilot is still in a wheelchair due to a broken back.

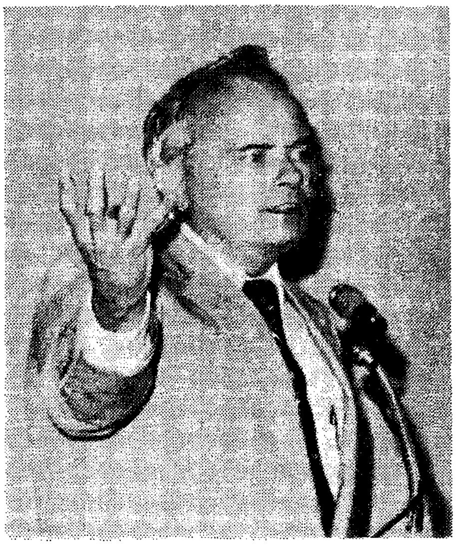
We intend to conduct more tests of production and modified equipment, and to install our "S" frame seats where possible. We are entering into contract with Dr. Robertson and Stan Desjardins to design modifications to improve the fire and impact crashworthiness of our aircraft. We have received a grant of a half million dollars to fund the improvements. They will be available to the public when they have been certified.


Robin McLeod


William H. Reed


Stan Desjardins


Dave Hall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Fire Crashworthiness Investigation

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Purpose

The purpose of this paper is to provide some basic guidelines for consideration when one is contemplating conducting a Fire Crashworthiness Investigation. Discussion areas include survivable and nonsurvivable accidents, typical crash fire scenarios, fire crashworthiness design considerations and lastly, the current common law test which measures the utility of a given design against the hazard posed by it.

Introduction

Rarely a day goes by that our Crash Research Institute is not contacted by someone, usually an insurance company or an attorney, who wants us to do a fire crashworthiness investigation. Some sort of vehicle (aircraft, car or truck) has been involved in an accident and someone was burned or killed. Usually the caller represents the injured parties directly, or represents someone who is being sued by the injured parties. In their opinion, the fire was obviously the "bad guy;" therefore the vehicle design is to blame. They obviously are looking for some way to reclaim their loss from the product manufacturer, or someone in the chain of custody who was responsible for the "dangerous" design.

Unfortunately, it is this author's opinion that most such inquiries are based on the desire to win a large settlement and not on the vehicle's crashworthiness or non-crashworthiness. It is the author's hope that this paper can serve to shed a little light on a fire crashworthiness investigation so that both sides, the manufacturer and the injured parties, can better understand the overall situation.

Survivable and Nonsurvivable Accidents

Aircraft crashes occur in an infinite number of ways. Most don't burn. In fact, depending on which year or model aircraft you wish to choose, only 7 to 15% catch fire.

Is it possible to keep those 7% to 15% from burning? The answer is probably yes—but does it make sense to do so? The answer to that question is probably no, but that "no" must be qualified somewhat.

Current crashworthiness thinking dictates that the occupant(s) be protected to some *reasonable* level. What is that reasonable level? Engineers have chosen as their reasonable level the upper limit "survivable accident."

Now for those of you who are not sure what I mean by an engineering "survivable accident," allow me to explain. To a statistician, a survivable accident is one in which all occupants survive; conversely, a nonsurvivable accident is one in which all occupants perish. A partially survivable accident is one in which there are both fatalities and nonfatalities.

For the engineer, however, this simple "bean counting" approach doesn't do the job. He needs hard, physical facts so he can begin his effort. His units of measurement for the "survivable accident" are quite different. For his accident to be survivable, two basic situations must occur:

1. The acceleration/time histories to which the occupants are subjected must be below their human tolerance limit, and
2. The livable space in the aircraft must remain large enough, throughout the entire crash sequence, so that the occupants are not fatally crushed.

Obviously, aircraft which can provide livable space and tolerable acceleration/time histories in very severe accidents are more crashworthy than those which fail to protect the occupant in the less severe accidents. The name of the game, so to speak, is to design an aircraft which can keep occupants alive in more and more severe accidents. Today's survivability severity level for military aircraft is reasonable, practical and way above that which is in current use by the civilian aviation fraternity.

This paper, however, is about fire. You will note that fire wasn't even mentioned in the engineering measurement of "survivable accident." Therefore, one must conclude, and quite correctly, that it is readily within the realm of practical design to incorporate fuel systems into civilian aircraft which can behave safely during the engineer's "survivable accident."

Current fire crashworthiness thinking, with which this author wholeheartedly agrees, is based on the following: AS A PRACTICAL DESIGN GOAL, TRY AND PREVENT DANGEROUS FIRES FROM OCCURRING IN ACCIDENTS UP TO AND INCLUDING THE UPPER LIMIT "SURVIVABLE ACCIDENT."

Typical Crash Fire Scenarios in Upper Limit "Survivable Accidents"

During an accident, the aircraft engines will displace, breaking fuel and oil lines, carburetor or fuel control components, filters and pumps. Fuel lines that run through the fuselage structure will be displaced and likely ruptured—especially those in the area of the landing gear, the door posts and connecting wing struts (if applicable), the wing to fuselage attachment areas, and the lower fuselage routings to drains, filters, sump tanks, etc.

Fuel tanks will spill their contents when structural displacement is such that the container (bladder or integral) is punctured, torn, ruptured due to overpressure (a rare occurrence by itself), or when components, such as the filler cap, the quantity sensor apparatus, the fuel and vent lines, and the drain valves are torn from the tank. Also, on multicell tanks, spillage occurs when interconnects are pulled from the tanks.

Once spillage has occurred, fuel ignition becomes a distinct possibility. It is important for the investigator, as well as the designer, to understand this fine point. *Spillage is the problem.* Several products, such as expanded aluminum foils and plastic reticulated foams, are often interpreted by the public as offering crash fire protection. While these products can offer protection from tank explosions due to a thermal overpressure, tank explosions are not the *big* crash fire problem—*spillage* is. These products not only offer little, if any, spillage reduction, in this author's opinion they can actually make the overall situation more hazardous because they tend to atomize the resulting spillage, thereby increasing the likelihood of spillage ignition.

Isolated fires can be tolerated if they are relatively small, or are located considerable distances from other spillages, the occupants or the exits. The problem is, however, that most spillages occur on or near the occupants, on or near the typical ignition sources, and often at the very location where the survivor must leave the aircraft—the exit.

What does all this mean to the Fire Crashworthiness Investigator?

The first thing he must do is try and determine whether or not the accident was an engineering "survivable accident." If it wasn't, common sense dictates that any fire crashworthiness litigation issues be dropped at this point. However, he should still try and determine the fire evolution, each point of spillage, and the possible ignition sources.

In addition, it is necessary to determine the cause of death. In many instances, a burned body is taken to indicate that the occupant died as a result of the fire. Unless thorough autopsies, including a fire toxicology workup is performed, often the *actual* cause of death is not determined.

If it becomes obvious that the accident falls well into the engineering "survivable accident" range, and that the occupant died as a direct result of the fire, the investigator may then wish to proceed with a more detailed "legal" fire crashworthiness investigation.

Fire Crashworthiness Design Considerations

The basic premise of crashworthy fuel system design is to control or eliminate fuel spillage. This can be done by designing the fuel system so that it moves and absorbs energy without rupturing, or by allowing the system to rupture at pre-designed locations without spilling fuel. Often, combinations of the two approaches are used in the same fuel system; i.e., a crashworthy fuel tank and a self-sealing breakaway valve at the engine fuel line attachment.

Each system must be designed for the specific aircraft it will go into. Ideally, fuel system components should be located away from major impact areas, ignition sources, and occupants. It is not always possible to achieve this goal, and compromises must be made, but they should be made to minimize the possibility of crash fires occurring in the most common types of accidents.

The *practical* current state of the art in crashworthy fuel system design includes:

1. Reasonable design philosophy.
   - A. Selective placement of components with respect to the occupants, the typical ignition sources, and the anticipated impact areas.
   - B. Thorough knowledge of how the subject aircraft will behave in *readily foreseeable* accidents.
   - C. Fuel system designs which will allow the following:
     - tank displacement without rupturing or tearing
     - filler cap staying on the tank or fuel staying in the tank if the cap separates
     - fuel line staying attached to the tank or separating without spilling fuel
     - fuel lines and components displacing safely or remaining safe without moving
     - wing separation or movement without rupturing the fuel lines
     - fuselage or wing crush without failing the fuel tanks or lines
     - engine displacement without spillage from the incoming fuel line, fuel filter, etc.
2. Use of crashworthy components
   - A. Crashworthy bladders
   - B. Self-sealing and/or frangible valves
   - C. Frangible fasteners for wires, tanks, fuel lines and miscellaneous components

Legal Test

As a final note to this paper, the author feels that a brief discussion is in order concerning the position our courts currently take on the overall subject of "Defective Design." Without trying to play lawyer, it has become painfully apparent to us all that the whole subject of crashworthiness can fall into that category. Whether or not a fuel system design is, in fact, a defective design, is now (in most states) measured by a test which weighs the utility of the design against the hazard posed by it.

As an example, it is a fact that most crash fires in a popular single engine, high wing aircraft, originate in the engine compartment when the engine is displaced, breaking the fuel line and allowing spillage onto the hot engine and, at times, exhaust gas flames.

In "survivable accidents," this situation is very dangerous to the aircraft occupants, but it can be easily remedied. The cost and weight penalty is minimal if the solution is to use a slightly longer flexible fuel line. The cost will be slightly higher if the solution is to relocate the line or to incorporate a self-sealing breakaway valve. In either case, however, the cost (utility) is quite likely less than the hazard (prevention of an otherwise anticipated fire).

On the other hand, requiring every aircraft (of the same make and model described above) to carry a completely crashworthy system, including fuel cells, fuel lines, and connecting self-sealing breakaway valves, involves considerable cost for retrofit, and a somewhat higher than normal cost and weight penalty if installed initially. However, these other components rarely fail in the "survivable accident" with this aircraft. Thus, this would be a prime example of where the utility of the design may not necessarily be justified by the hazard (the rarely occurring fire). Consequently, each aircraft design must be evaluated carefully and in conjunction with the anticipated aircraft behavior in an accident. Just putting crashworthy items in the fuel system without regard for the accident behavior patterns could, and probably would, place an undue burden on the manufacturer and the end user.

Conclusion

It is possible to design fuel systems into aircraft that will hold their contents safely in "survivable accidents." Carefully study of the accident behavior patterns for each specific aircraft can give the manufacturer the base line data to design and integrate the various needed crashworthy fuel system components into his aircraft. The fire crashworthiness investigator can play an important role in the data gathering process by applying his investigative skills in analyzing the various system behaviors during the upper limit "survivable accident" and passing this information on to the aircraft manufacturers, the FAA, and, as a last resort, the courts. Thus, the fire crashworthiness investigator can contribute immensely to upgrading the fire crashworthiness of the entire aviation fleet.

About the Author

S. Harry Robertson is an internationally recognized researcher in the field of fire crash survivability. His crashworthy fuel system designs are incorporated in most current U.S. military helicopters and the Indianapolis racing cars.

He is the President of Robertson Research, Inc., the parent company of the Crash Research Institute, and of Robertson Aviation, Inc.

For ten years he served as Head of the Hazards Section of Aviation Safety Engineering & Research (formerly a division of the Flight Safety Foundation), and for an additional 10 years he directed the Engineering Safety Center at Arizona State University.

He is an active aircraft accident investigator and is rated in most categories of aircraft by either the FAA or the military.

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Since the introduction of turbojet powered airplanes into commercial aviation, there has been monumental advancement in technology which has allowed airplanes to fly farther, faster, higher, more economically and safer. The industry has done the near impossible in satisfying the ecologists and environmentalists and will continue to improve in these areas while further improving the Aero Space system which includes everything and everybody, on the ground and in the air, having anything to do with moving people and freight by air. Techniques for investigating accidents have been improved, but have not kept up with the technology. Air safety investigation encompasses the entire aviation system, not just aircraft and pilots, controllers, engines, etc., and maybe the scope and complexity are part of the reason why investigation techniques haven't kept up with the technology mentioned earlier. Improvements such as the introduction of Flight Data Recorders (FDRs) and Cockpit Voice Recorders (VCRs) help immeasurably, but the investigating team at the accident scene still goes through the motions of documenting control switch and lever positions, possible instrument readings, landing gear position, engine operating condition, ad infinitum. Then the recorders are read, the evidence that has been recorded is weighed, and a best guess is established as to what was going on to cause the catastrophe which is being investigated. Documenting will always be an important part of investigation, but time is being wasted in documenting systems that really shouldn't be suspect if areas to concentrate on could be determined early in the investigation.

Before going further, it must be understood that the ideas offered in this paper are based on the premise that all ISASI members are on the same team; that is to say we all do want to determine the causes of airplane accidents and in doing so, make the system safer and prevent future accidents. Members represent manufacturers and component suppliers; operations: including airlines, pilots, and airports; governmental agencies: including NTSB, FAA and controllers; and let's not forget the legal profession. That is only a rough cut at the cross section of this organization, all with the singular, worthy goal; to make air travel safer! It makes you wonder sometimes when there is a hearing or one party or another feels put upon as a result of an investigation. We act more like adversaries then! We are not adversaries; we do, and must, share common goals.

The theme of this symposium is "The Investigation: Back to Basics". The present methods of accident investigation are pretty darn basic, and for the most part, tried and proven, but another dimension should be considered, a new and powerful device for the bag of investigative tools.

Before introducing this new dimension, however, consider a couple of analogies which you may find comparable to aircraft accident investigation today:

When a veterinarian attends to a sick animal a systematic and thorough examination of the patient is performed; including temperature, pulse, respiration, reflexes, condition of eyes, condition of the fur and other symptomatic indicators which training and experience have taught are necessary to come to a decision as to the most probable cause of the animals distress. The veterinarian may follow-up with a test or series of tests to confirm the diagnosis, and then a course of action can be prescribed to effect a cure.

Now let's visit a people doctor's office. This doctor has pursued a similar course of study to that of the veterinarian. The animal treated at this office is, as a system, in most ways identical to the animal that the veterinarian treats; size and method of perambulation are usually the principal differences. The doctor may attend to his patient in a much different way, however. Temperature, pulse, etc., may or may not be taken depending on what the patient tells the doctor. Communication between the patient and doctor permits an intelligent diagnosis of an ailment with much less examination. One note of caution though, the doctor must be wary that the patient does not purposely mislead him for one reason or another. As with the veterinarian, tests are in order to verify the diagnosis and prescribe a cure.

The point is that in diagnosing an illness it is possible to gather all of the physical symptoms, analyze them and come up with a most probable solution, or the patient's central data bank, which knows what hurts and where, can be interrogated and the most probable cause obtained more directly. In other words, the doctor is able to access the patient's brain, thus making most of the rote examination performed by the veterinarian unnecessary

One more example; a bank has been robbed, and there were witnesses. Experience has taught us that interrogating ten witnesses will likely result in at least nine different stories, and the witnesses will probably agree on only the most salient characteristics of the burglary. This is probably true even if the witness is directly involved; for instance the teller who is being confronted by the bank robber. In fact, because of the stress of the situation, the teller may not remember much of anything, except perhaps a threatening note, maybe a weapon, and handing over some money. The teller may be one of the least reliable witnesses in the bank.

After the thief is out the door with the money and has made good the escape, the bank examiners can perform an audit and, within certain tolerances, tell how much and what was stolen. If there was physical damage, or someone was hurt, that too can be documented. But assuming the robber got away, how can he be identified, and how are the investigators going to know exactly what took place at the tellers cage? Basics is the name of the game here today, right? Then why not take a picture of the scene and of the culprit!

That is exactly what is done in banks all over the country today when there is a robbery. Moving pictures are taken that show what the robber looked like, if a weapon was involved, how he acted, and generally what took place during the robbery. Had the robbery not been filmed, it is conceivable, and probable, that some pertinent evidence would be overlooked in the initial investigation, and if the investigators return at a later time the chances of recovering that evidence are very remote! On the other hand, film can be stopped and examined a frame at a time. So what does this lead up to?

Why don't we, the aircraft accident investigators, borrow a lesson from the doctor, and the banker; access the brain center of the airplane and record the action in the cockpit with a video recorder? For the sake of discussion we can call it a Control Cab Video Recorder (CCVR) to distinguish it from the existing Cockpit Voice Recorder (CVR). Why are aircraft accidents still investigated using methods and techniques similar to those of the veterinarian, when the events of the intelligence center of the airplane could so easily be documented with a video camera and recorder? It would be the perfect complement to the voice recorder, and when combined with the flight data recorder we would have a new dimension in aircraft accident investigation.

A new generation of large turbojet airplanes with highly sophisticated flight management systems will soon be flying in revenue service. Attitude information, horizontal situation information, engine indication and crew alerting information will be among the many data displayed on cathode ray tubes (CRTs). When airplane power is lost, many of these instruments will provide zero intelligence. On some navigation and communication equipment with digital readout, after power loss in an accident it may not be possible to even determine what frequency was set by the crew. These are problems associated with new technology equipment and systems, but even with today's mechanical instruments which often can be interpreted though badly damaged, investigators can only arrive at a best educated guess of what was going on in the cockpit when an accident occurred. If the crew doesn't survive, there is no one to interrogate, the course of the investigation is committed to sifting through the wreckage studying the clues and attempting to determine what the airplane did, and what the crew did, and when the investigation doesn't come up with a positive cause, such as airframe, engine, or ATC, the flight crew is likely to be named as the probable cause. If the crew survives, and the conclusions resulting from the investigation appear to contradict their statements, then investigators may doubt the crew and long and bitter discussions often follow. Does anyone doubt that in a potentially catastrophic emergency the flight crew is doing everything in their power to rectify the situation and save themselves, the passengers, and the airplane?

No one likes to blame the flight crew, so investigators keep looking for something in the system that caused the situation which the flight crew couldn't overcome; maybe it was in the training, or a service bulletin that wasn't incorporated, or ATC. Why not blame it on the manufacturer, or the operator airline or the government? Of course, this is facetious; responsibility for accidents is not awarded on a popularity, or perhaps unpopularity, basis. A Control Cab Video Recorder would be a great tool to assess the situation and more positively determine the cause, remove much of the guess work and doubt, and ultimately prevent a reoccurrence in the future. There is more intelligence in the cockpit of an airplane than in any other place on board and recording that intelligence with a video recorder, for use only is case of an accident or incident, could be the single most important investigative tool yet conceived.

All voice communications in the cockpit are recorded, many parameters on the controls, engines, and flight attitude are recorded, but making a visual record of what was going on in the cockpit has been sternly resisted.

Opponents to the Control Cab Video Recorder state that with the new Digital Flight Data Recorder (DFDRs) we record sufficient pertinent parameters, so a television camera recording the proceedings in the cockpit is not needed. Is this true? In at least two hull loss accidents it is suspected that someone other than the flight crew, someone probably hostile, was in the control cab, but because of the total destruction of the cockpit, this speculation cannot be proven. If an intruder contributed to these accidents, and the flight crew was not able to squawk 7500, a Control Cab Video Recorder could reveal that fact. Physical evidence sometimes will not correlate with what is recorded on the Cockpit Voice Recorder; could the pilot be flying an instrument that is indicating erroneously without showing a flag, or could the pilot disbelieve the instruments because of disorientation or distraction? It is argued that there are standby instruments to prevent that type of error, and after all there is more than one pilot in the cockpit. The argument is valid but the files contain histories of tragedies which can only be explained reasonably by a rationale wherein cockpit indications and pilot interpretation and action don't agree.

A video camera in the cockpit would record crew inputs to the controls; if the inputs are correct, then the investigators known they must look to conditions that caused the airplane to respond contrary to the control. System problems, electrical, hydraulic, pressurization, whatever, and corrective action taken by the crew, would be recorded. We tend to think in the normal; if a certain event happened, the crew would respond in a certain way; conversely, if the crew makes an input, the airplane reacts a certain way. When the normal is violated, and the input and response are other than expected, a video recording would show the discrepancy and speculation and conjecture would be avoided.

The objection to a Control Cab Video Recorder comes mostly from flight crews. After all, it is their actions which will be recorded. The fact is that the Crew Cab Video Recorder would reveal substantially more about the cockpit, but very little more about the flight crew than the Cockpit Voice Recorder presently does. It should certainly come as no surprise to anyone that during a flight, crews discuss subjects other than flying. The Control Cab Video Recorder would be documenting literally hundreds of physical conditions in the cockpit that no other recorder or group of recorders could possibly keep track of. Initially at least, the Control Cab Video Recorder should be considered only for Air Carrier Operations, FAR Part 121 airplanes. Rules for use of a Control Cab Video Recorder would have to be similar to the rules pertaining to the use of a Cockpit Voice Recorder. Bulk erase would be provided as it is for the Cockpit Voice Recorder. The recording time for a Cockpit Voice Recorder, one-half hour, is too short, but the CVR is not a topic for discussion here. Recording time is, however. A design goal for the Control Cab Video Recorder should be to make it capable of recording for a period at least as long as the longest flight possible for the airplane on which it is installed. For survivability, the CCVR should be located in the aft end of the airplane as the Flight Data Recorder and Cockpit Voice Recorder now are. The requirements for survivability relative to fire and impact "g" loads must be at least as stringent as specified for the existing recorders. To save weight and space, and to assure time correlation, the design could consider putting both video and voice on a single tape in a combined recorder.

It must be stressed that the rules for a CCVR would have to be such that the record would be used only for accident investigation and safety related problems. Currently the aviation system reacts such that if a flight crew makes a mistake and admits it, the individuals can be fined and furloughed. If a crew makes a mistake, tries a little coverup, and is found out, the individuals can be fined and furloughed. The crew is between a rock and a hard spot. George Washington always told the truth, and he got away with chopping down a cherry tree, but few of us are that pure, possibly because we fear the probably consequences will be more severe than George endured. Perhaps the only answer to the dilemma is amnesty for honesty, and that is another subject much too involved to be discussed now, but very important to successful accident investigation.

The CCVR will record the status of the cockpit and the actions of the crew. It will corroborate the crews testimony subsequent to an accident or incident and preclude a lot of arguments and insinuations. A CCVR certainly could not incriminate the innocent, and just as certainly would exonerate the crew who was doing their best in a white knuckle situation. Flight crews of transport airplanes should be the first to demand CCVRs in their cockpits.

Boeing installed a video camera with a recorder in a simulator cockpit over 15 years ago. The pilot in the left seat was left handed, and his watch was on his right wrist near the aisle stand. Even with that breadboard installation and only normal cockpit lighting, the recorded picture quality is such that the second hand can be seen going around on that watch. Imagine if, on your next investigation, you know exactly when power changes occurred, and how the engines responded; how the airplane behaved and what the cockpit indications were when flaps and gear were extended. Wouldn't it be nice to know if the airplane responded as commended when control inputs were made. At a later time, if you wanted to know when some other action was taken or you wanted to verify some of the cockpit procedure, the tape could be backed up and replayed to review exactly when, and how, the action was taken.

If 15 years ago the movement of the second hand on a wrist watch could be recorded, imagine what today's technology could provide in the way of a CCVR.

The average person can retain approximately 12 percent of an audio input for approximately 3 days; about 25 percent of a video input for the same period, and if you combine the two, audio an visual, most people can retain up to 65 percent. I mention this only because it illustrates the relative importance of our sight to our other sensory faculties especially when supported by the other senses. No one can be expected to remember everything they heard, saw, or did, even in the adrenalin stimulated moments of an accident environment. Flight data is recorded on the FDR which, by the way, can be difficult to read, and interpret, and correlate; cockpit communications are recorded on the CVR, but this too may be difficult to interpret on nonexistent for the event being investigated. Combined with a CCVR, however, the benefits of visual and audio inputs would be realized. The CCVR would be used to aid in the determination of accident causes. This works to benefit everyone in the aviation industry, and the traveling public; it would not work against any of us. It provides another tool; possibly more significant than any we have presently for accident investigation. Solving accidents is the first step toward preventing accidents.

Recent power-loss incidents, one involving loss of power on all engines of a four engine airplane, emphasize the need for a Control Cab Video Recorder. The elapsed time between power loss and landing exceeded the one-half hour recording time of the CVR, and thus cockpit communications during the incident were not available for the ensuing investigation. Flight test crews were able to duplicate the incident as recorded by the FDR parameters, but not as described by the flight crew of the incident airplane. Doubt is thus cast on the crew's recollection. A CCVR would exonerate the crew, or at the worst, might reveal that an honest mistake had been made. Because of the seriousness of this incident, hundreds of hours have been and are continuing to be expended by the engine manufacturer, the airframe manufacturer, the operator and the government in attempting to determine the cause. As it stands, the power loss is unexplained, corrective action cannot be taken, and another occurrence is possible.

Most of the technology already exists for a Control Cab Video Recorder; development, certification, and installation should be relatively simple, and cheap. However, before any manufacturer will volunteer to design the system, there will have to be a requirement. The investigative fraternity will decide whether such a requirement exists, and only you can move such a program to fruition by urging your friends and associates in the industry to support this necessary additional recorder.

A note to close on was recently published in one of the trade magazines; it went "Non-recognition or non-admission that a mistake has been made is the first step to disaster". The existence of a Cockpit Voice Recorder is evidence that we recognized that not knowing what took place in the cockpit of an airplane at the time of an accident was a mistake. Let's admit that we have made the mistake of not properly recording all of the available information, and then let's resolve to correct that mistake in the shortest time possible by developing a Control Cab Video Recorder. We owe it to ourselves and to the traveling public.

Biography

1982 will mark Bill Shumate's 30th year with Boeing. Bill joined Boeing upon graduating BSEE from Colorado University. All of his 29 plus years with Boeing have been in Customer Service; divided almost evenly between military and commercial customers. Bill's experience with the military included assignments as a Boeing Tech Rep at various Air Force bases and as Boeing coordinator on KC-135/C-135 accidents. On the commercial side of the house as Manager of Support Publications. Bill was responsible for all 707/727/737 and 747 Service Bulletins. Prior to returning to Air Safety Investigation in June of 1980, Bill was Boeing Customer Support Regional Director for Asia and Australasia stationed in Singapore.

Let Microprocessors Help

A Review of Programs for Hand Calculators and Desk Top Computers in Aircraft Accident Data Analysis

W. Gordon MacSwain MO2064

Introduction

The use of computers in aircraft accident investigation is certainly not new, but in the past, it has been the learned few who have know how, where, and when they can best be utilized. Most of us are somewhat intimidated by the computer experts who speak those funny-term languages, and we often find the programmer telling us what we want, instead of the other way around.

The purpose of my presentation is to help make you aware of but a few ways the new breed of reasonably priced micro-processors can help with your problems, and give you significantly more information from the raw data you acquire. When we talk about micro-processors, we mean hand-held programmable calculators, such as the ones made by Texas Instruments and Hewlett Packard, and table-top micro-computers such as the Apple, Radio Shack TRS-80, and the Commodore Pet. These have found widespread acceptance in the home with hobbyists, and user organizations or clubs have sprung up in most principal cities throughout the world. The hobbyist, or majority of them, are for the most part eager to take on a challenge or task, and will generally give the tutoring required or provide the programming assistance you may need to get started.

```
            Accident Accident Investigation

        Civil Aviation Department of Transport
                    Ontario Region
                    W. G. MacSwain
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 1  Density Altitude
 2  Sunrise/Sunset
 3  Impact Dynamics
 4  Turn Performance
 5  Great Circle Navigation
 6  Rhumbline Navigation
 7  Dead Reckoning Navigation
 8  Wind Effect on Take-off/Landing
 9  Impact Analysis
10  Weight and Balance
11  - END -

                  Selection Please ?
```

Figure 1

Figure 1 is a printout of a 'menu' that appears on the CRT screen for one program used on a Radio Shack TRS-80. It permits the investigator to select any of 10 separate tasks for the computer to perform by simply entering the corresponding number (1 to 10). The screen then clears, and the investigator is further prompted to entry of the necessary input. Following this, the results are calculated and scrolled onto the screen. Let's look at the program segments individually.

Density Altitude

Did you ever try to determine density altitude with any degree of accuracy from the normal, small-scale circular slide rule?

```
              Density Altitude Calculation

Field Evaluation            (Feet A.S.L.)       ? 563
Field Barometric Pressure   (Inches Mercury)    ? 29.27
Field Temperature           (Degree C.)         ? 23
 Density Altitude is 2447.1 Feet A.S.L.
         Press [enter] for another, [1] for menu
```

Figure 2

Figure 2 shows the 3 lines prompting for input. They appear on the screen, one at a time, with their question mark. When you have entered the variable and pressed the 'Enter' key, the next prompt line instanteously appears. Following the third entry, (field temperature), the density altitude is calculated and given to 2 decimal places within a second. (If a printer is connected, a hard copy printout of the screen's contents for any of these can quickly and easily be made for documentation purposes). The final line prompts the operator for another Density Altitude problem for a return to the original menu for a different task.

Sunrise/Sunset

No need for cumbersome tables and lots of interpolation to determine the time of darkness on some remote northern lake.

```
                      Sunrise/Sunset

  Month         (1 - 12)          ? 9
  Day           (1 - 31)          ? 30
  Latitude      (DDD.MMSS)        ? 38.5515
  Longitude     (DDD.MMSS)        ? 77.0358

  Sunrise is (HH.MMSS) 11.0950 GMT

  Sunset is (HH.MMSS) 22.4542 GMT

        Press [enter] for another, [1] for menu
```

Figure 3

Figure 3 shows that given the month, day, latitude, and longitude, the time of sunrise and sunset are quickly calculated.

Impact Dynamics

All Canadian Department of Transport accident investigators receive the Arizona State University 'Crash Survival Investigation' course as part of their compulsory training. This acquaints each individual with the why and potential benefits of crashworthiness investigation, as well as familiarization with what has been accomplished in the past. It also provides the necessary knowledge of what information is required from the crash site and how to use it in subsequent evaluation.

Even with all investigators qualified, the program (that was established on a national basis) didn't really get off the ground for the first year following implementation. I believe this was due primarily to the fairly large number of mathematic formulas and calculations that were necessary for each report. Additionally, when one wanted, for example, to evaluate several different pulse shapes or velocities for the same occurrence during the initial 'trial and error' period of learning, the calculations could become quite formidable to the average investigator. The results often contained simple mathematical errors which made time consuming verification necessary, and tended to discourage the investigator.

In 1977, a series of programs for Texas Instruments' programmable calculators was developed that eliminated the menial work and allowed the investigator to experiment freely and quickly with the 'numbers'. As interest grew, all regional offices were provided with the calculators, and one of our original 'crashworthiness' forms was simplified to ease reporting and evaluation (form C1, Appendix A). Results to date have been good, with enthusiasm growing steadily.

```
                  Aircraft Impact Dynamics

  Opening Velocity        (Knots)         ? 76
                          (Ft/Sec)          128.356
  Final Velocity          (Knots)         ? 0
                          (Ft/Sec)          0
  Flt Path Angle          (Degrees)       ? 8.5
  Vert. Stop Dist.        (Feet)          ? 3.75
  Horz. Stop Dist.        (Feet)          ? 51.5
  Pulse Shape (1-5)                       ? 3
 Vertical Velocity      19.0  Horizontal Velocity  126.9
 Vertical G's            3.0  Horizontal G's         9.7
 Resultant G's          10.2  Resultant Force Angle 17.1
 Pulse Time (Seconds)  0.784  Pulse Length (Feet)   50.3

        Press [enter] for another, [1] for menu
```

Figure 4

Figure 4 shows the computer screen following completion of an 'impact dynamics' calculation. Opening and closing velocities are entered in knots for convenience, but appear in feet per second as well. The flight path angle is entered in degrees, and both vertical and horizontal stopping distances (including crush) in feet. The pulse is then selected to correspond with 1 of 5 different rectangle, triangle, or half sine shapes. Again referring to form C1, Appendix A, it can be noted that the foregoing input is grouped to facilitate reporting. The output, as vertical and horizontal velocities, vertical, horizontal, and resultant G's, resultant force angle, pulse time and pulse length, is also grouped for ease of transfer and evaluation. The prompt line will quickly return you for different input should you wish to experiment with other variables.

Turn Performance

The formulas to calculate the time to complete a 360 degree turn, true airspeed, stall speeds, turn diameter, 'G' force, or bank angle are not complicated or lengthy. However, it is sometimes time consuming to figure out other variables first in order to eventually produce what is wanted. Using the computer, you simply enter the parameters you have available (Figure 5), and the rest are automatically calculated and displayed.

```
                    Turn Performance

  Time to Complete         (Minutes)       .290106
    360 Degree Turn        (Seconds)       17.4064
  True Airspeed            (Knots)         96
  Stall Speed -
    Straight Flight        (Knots)         55
  Stall Speed - in turn    (Knots)         79.2583
  Turn Diameter            (Feet)          900
  Force in Direction
    of Turn Radius         (G's)           2.07665
  Bank Angle               (Degrees)       61.2136

        Press [enter] for another, [1] for menu
```

Figure 5

To do this, the computer may go through what is available several times in order to produce, in an instant, the final result. A terse "unable" is printed if insufficient data has been provided for any one item to be calculated. Sometimes that additional piece of information, provided to the investigator, may start a thought chain that otherwise would not have been explored.

Navigation

Have you ever had to measure the distance and direction from an accident site to an airport or two? Maybe to several different navigational aids or INS/RNAV waypoints? How about to the nearest met reporting facility or Flight Service Station? How far are those radar position co-ordinates that you must determine speed and descent rates from?

Granted, any of the above can be plotted on charts, but the accuracy usually suffers, particularly in remote areas where large scale maps are not available, or a number of them have to be joined.

```
Great Circle Navigation

(Entry Format = DDD.MMSS)
Enter Starting Latitude           ? 43.4001
Enter Starting Longitude          ? 79.2354
Enter Final Latitude              ? 38.5515
Enter Final Longitude             ? 77.0358
The distance is 303.536 nautical miles, and the
initial true course is 158.949 degrees.
      Press [enter] for another, [1] for menu
```

Figure 6

Our computer program provides distance and bearing information in both Great Circle and Rhumbline modes quickly and accurately. For the most part, Great Circle is normally used, it being the shortest distance between two points. Radio signals such as VOR radials, ILS localizers, DF, and radar returns are Great Circle. Rhumbline applications are generally those involving VFR navigation over short distances.

Figure 6 shows the identical input required for Great Circle and Rhumbline. Both the starting and final latitudes and longitudes are entered in degree, minute, second format (with negative entries signifying southern latitudes and eastern longitudes). The output is given in degrees (true) and nautical miles.

```
Dead Reckoning Navigation

Enter Start Latitude     (DDD.MMSS)        ? 52.2943
Enter Start Longitude    (DDD.MMSS)        ? 118.0013
Enter True Course                          ? 317.5
Enter Distance           (Nautical Miles)  ? 1000
  Select: (1) Great Circle, or
          (2) Rhumb Line                   ? 1
The new position is (DDD.MMSS):          62.4243 Lat.
                                        143.0020 Long.
    Press [enter] for another, [1] for menu
```

Figure 7

Figure 7 is the screen format for 'Dead Reckoning' navigation. Again, a starting latitude and longitude are entered, but this time the true course and distance are too. After indicating your choice of whether Great Circle or Rhumbline calculations are to be performed, the appropriate new position is given in latitude and longitude.

Wind Effect on Take-off/Landing

The lack of reliable performance data on some older types of aircraft makes this little routine quite valuable and timesaving.

The runway heading and wind direction are both entered in degrees magnetic (Figure 8), and the wind velocity in knots. Zero wind take-off distance in feet and the take-off airspeed in knots, usually readily available, are also input. The calculated results take the form of the crosswind and headwind/tailwind components, along with the corresponding take-off (or landing) distance required.

Impact Analysis

The well know, and often used formular for determining R.P.M. or speed from propeller slash marks is straightforward, but even it can give trouble when gear ratios are involved.

```
Wind Effect on Take-off/Landing

Runway Heading    (Degrees Magnetic) ? 080
Wind Direction    (Degrees Magnetic) ? 200
Wind Velocity                (Knots) ? 14
Zero Wind Take-off Distance   (Feet) ? 2875
Take-off Airspeed            (Knots) ? 81
Right Crosswind Component of 12.1 Knots
Tailwind Component if 7.0 Knots
Take-off Distance required is 3393.39 feet
     Press [enter] for another, [1] for menu
```

Figure 8

With the computer, the distance between slashes is entered in inches (Figure 9).

```
Impact Analysis

Distance Between Slashes     (Inches) ? 14.5
Number of Prop/Rotor Blades
                       (Defaults to 2) ?
Engine to Prop/Rotor Gear Ratio
                     (Defaults to 1.1) ? 9.1
         Answer only one of the next two:
               (Speed or R.P.M.)
Groundspeed or Descent Rate
                   (Feet per Second) ?
Engine R.P.M.                        ? 3100
Diameter of Prop/Rotor        (Feet) ? 35.5
```

Figure 9

The next two lines ask for the number of propeller (or rotor) blades, and the engine to propeller gear ratio. If either is omitted, default values of 2 and 1.1 respectively are provided automatically. Only one of the next two items is required—either the groundspeed/descent rate, or the engine R.P.M. The last item, prop/rotor diameter, is optional and needed only if tip speed is to be determined.

Finally, a recap of input is printed on the screen, along with the calculated information, in tidy summary form (Figure 10).

```
Impact Analysis

Distance Between Slashes      (Inches) 14.5
Number of Prop/Rotor Blades            2
Engine to Prop/Rotor Gear Ratio        9.1
Groundspeed or Descent Rate
                         (Feet/Second) 13.9193
                               (Knots) 8.24169
Engine R.P.M.                          3100
Prop/Rotor R.P.M.                      344.446
Diameter of Prop/Rotor          (Feet) 35.5
Prop/Rotor Tip Speed     (Feet/Second) 640.249
                               (Knots) 379.095
    Press [enter] for another, [1] for menu
```

Figure 10

Weight and Balance

Manual weight and balance calculations too, are straightforward and relatively quick, providing the center of gravity limits remain the same for all weights. Complications arise or errors are sometimes made when arms are negative or when the specifications call for different limits for different weights—with "straight-line variation between points". This routine handles these were ease, considerably adding to the accuracy and speed of the overall weight and balance assessment process.

Following a prompt to determine if a printer is available and if a hardcopy printout is wanted, instructions are given for keying in weight, and either arm or moment for each entry (Figure 11).

```
210 Weight                46.5 Arm
60  Weight                -35.2 Arm
55  Weight                5000 Moment
     Totals -           Weight    3215.23
                        C of G    16.5458
                        Moment    53198.6
        Are straight line calculations required?
                  (Y)es  or  (Enter) Y
Enter upper weight with the corresponding fore and aft
  C of G limits (separate with commas)    ? 3500,17,24
      Enter lower weight with fore and aft limits
                                          ? 2500,12,26
     The C of G limit for 3215.23 pounds is from
                 15.5762 to 24.5695
        Press [enter] for another, [1] for menu
```

Figure 11

Total weight, moment, and C. of G. position is given when the 'Total' key is pressed, along with a query as to whether straight-line calculations are required. If they are, prompts appear for entry for the upper and lower C. of G. range. Finally, the C. of G. limits for the total weight that was calculated are given. If the printout option was previously chosen, a plain, but complete hardcopy of all entries and computations will have been made (Figure 12).

```
Weight        Arm           Moment
2450.23        13.45         32955.6
440            17.25         7590
210            46.5          9765
60            -35.2         -2112
55             90.9091       5000
3215.23        16.5458       53198.6 Totals

For 3500 pounds, limit is from 17 to 24
For 2500 pounds, limit is from 12 to 26
The C of G limit for 3215.23 pounds is from
     15.5762 to 24.5695
```

Figure 12

Midair Collision Analysis

A small Texas Instruments programmable calculator proved to be a very useful tool during the investigation of a recent midair collision between a Cessna 310 and a Cessna 150. The Cessna 310 was making an ILS approach in visual conditions when it struck the right rear quarter of the Cessna 150 that had just departed from another airport and was crossing the ILS approach path. The occupants of both aircraft were killed.

A program was written to analyze the apparent flight profiles in order to establish the most probable target position of the 'other' aircraft. Using the relative closing speed and angle as determined from wreckage examination, and the Cessna 310's assumed localizer track and glide path angle as constants, a series of different Cessna 310 approach speeds, wind directions and wind velocities were entered as variables.

The output, was in the form of airspeed, groundspeed, heading, track, descent/climb rate, and target angles (left/right and up/down) for both aircraft, as well as the vertical and horizontal feet/second closing rate.

A run using the Cessna 310's last two DART data plots to establish groundspeed (128 knots), average wreckage scatter pattern for wind direction (292 degrees true), and a correlated wind velocity of 12 knots, gave the Cessna 310 an airspeed of 138.5 knots. This was considered the probable upper limit of speed insofar as the maximum gear extension speed is 140 knots and the gear had been extended prior to the inflight collision.

Using maximum error for the Cessna 310's last two data plots established a groundspeed of 106 knots, and a computed groundspeed for the Cessna 150 of 60.6 knots. This hypothesis was considered to be slightly less than the minimum as far as speeds were concerned, but was used as the lower limit of the range analyzed.

The distance travelled by the Cessna 150 for a known time (approximation) pointed to a groundspeed of about 78 knots. This worked out to the following calculator-produced data for the most probable flight profiles:

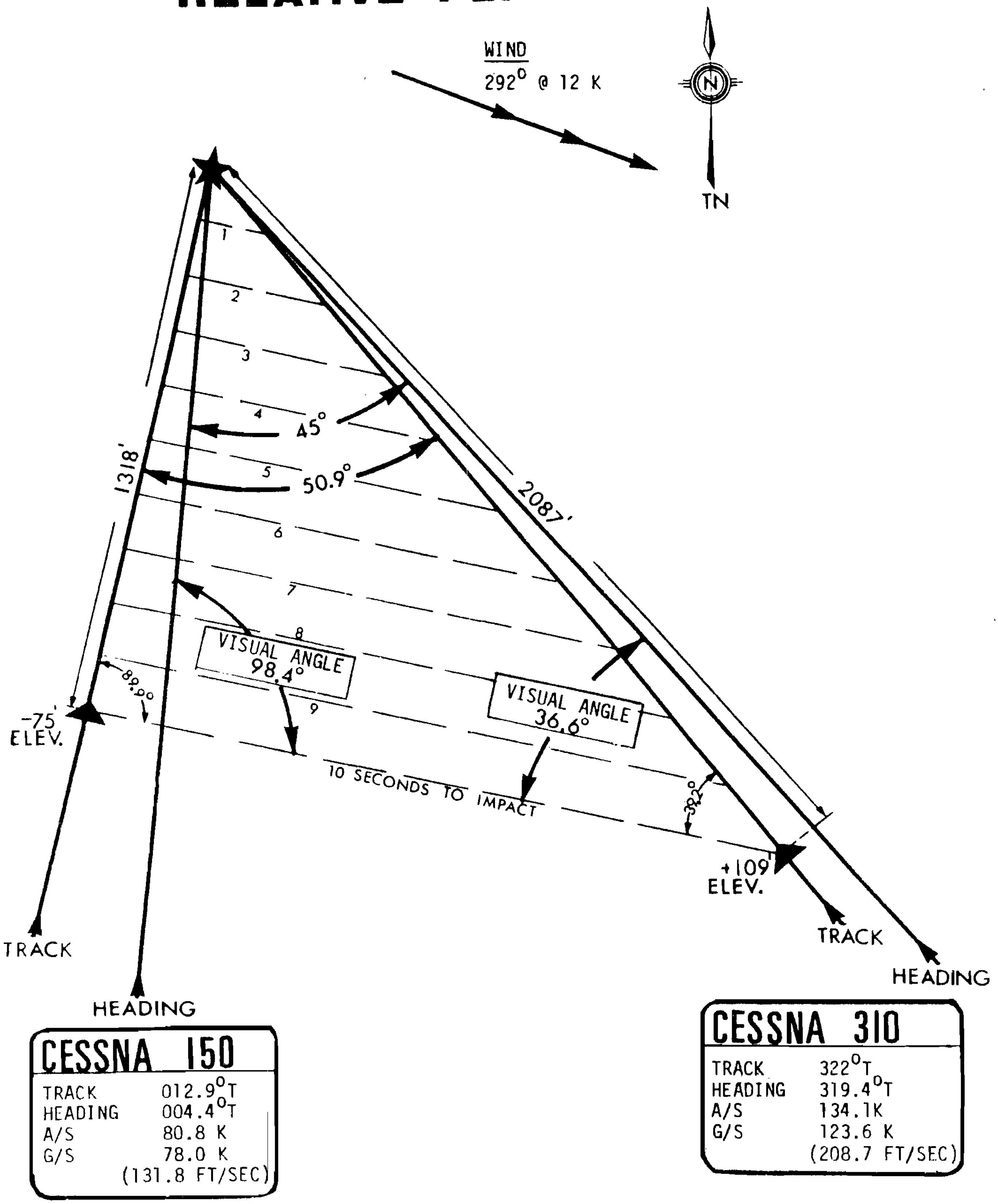
```
Cessna 310    Groundspeed          123.6 knots
              Airspeed             134.1 knots
              Heading              319.4 degrees T.
              Track                322.0 degrees T.
              Rate of Descent      10.9 ft/sec
              Cessna 150 target    36.6 degrees left
                                    6.5 degrees down
Cessna 150    Groundspeed          78.0 knots
              Airspeed             80.8 knots
              Heading              004.4 degrees T.
              Track                012.9 degrees T.
              Rate of Climb        7.5 ft/sec
              Cessna 310 target    98.4 degrees right
                                   6.5 degrees up
Closing Velocities - Horizontal    161.9 ft/sec
                     Vertical       18.4 ft/sec
```

Figure 13 is a scale drawing that depicts the computed data and vividly illustrates the pre-collision logistics.

Cockpit visibility studies, conducted to determine the field of view from each aircraft, indicated that the 'other' aircraft target would most probably be obscured to the crew members of both converging flights.

It is indeed worthwhile, in analyzing target angles during the investigation, to be able to input different parameters and see the resultant changes almost instantly.

RELATIVE FLIGHT PATHS

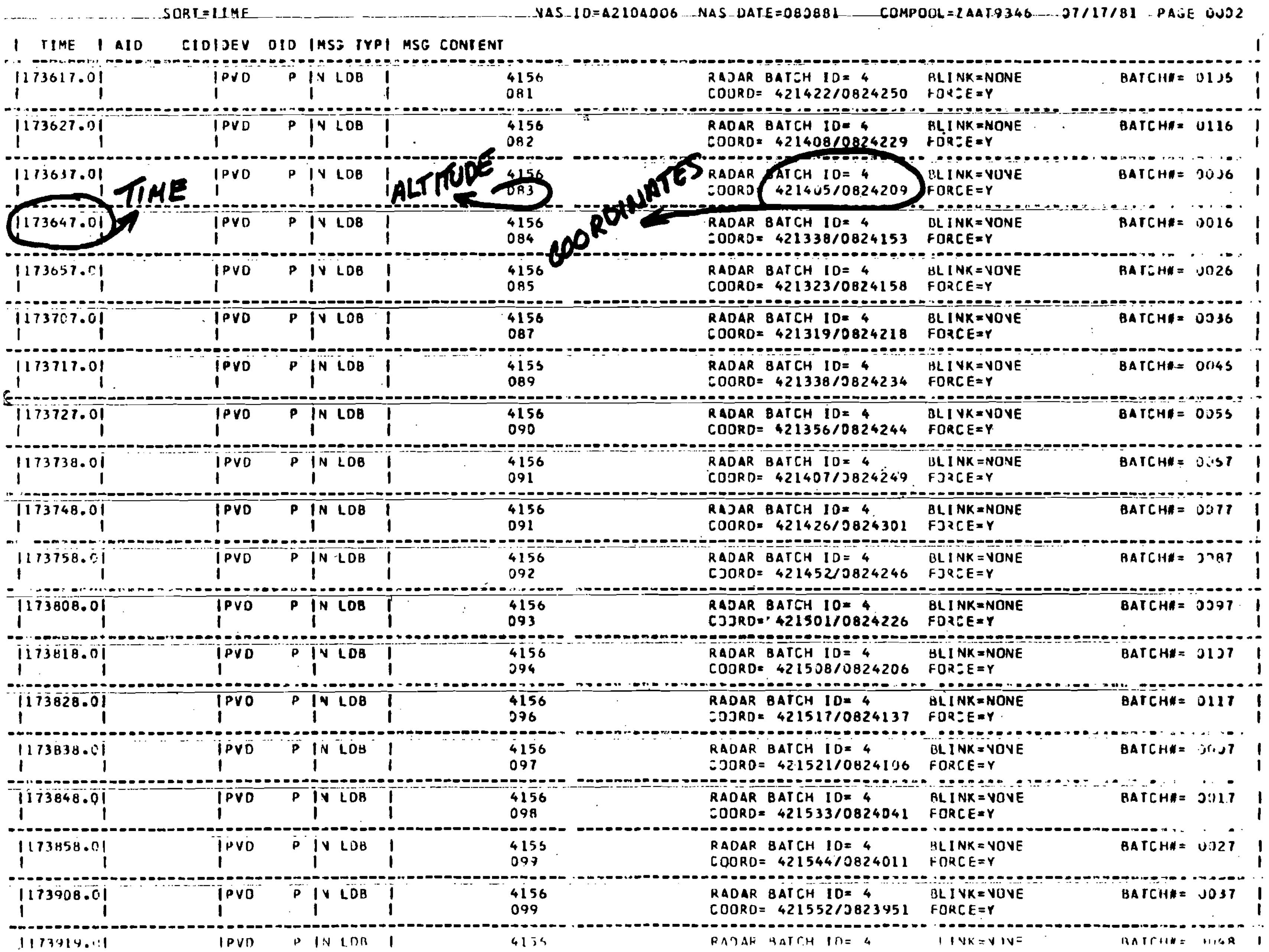


CESSNA 150

TRACK	012.9°T
HEADING	004.4°T
A/S	80.8 K
G/S	78.0 K (131.8 FT/SEC)

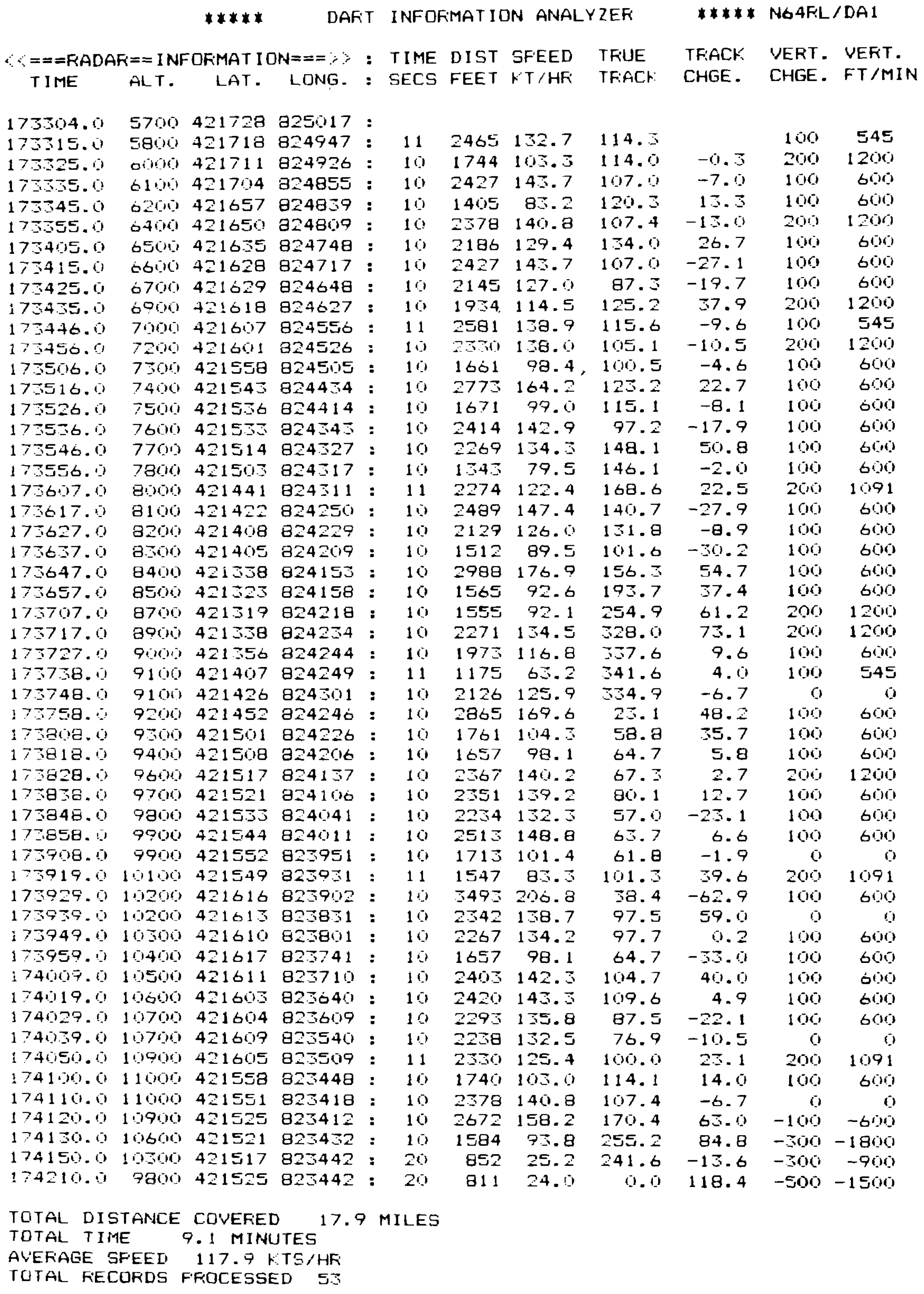
CESSNA 310

TRACK	322°T
HEADING	319.4°T
A/S	134.1K
G/S	123.6 K (208.7 FT/SEC)



```
SORT=TIME                          NAS_ID=A2104006  NAS_DATE=080881   COMPOOL=ZAAT9346   07/17/81  PAGE 0002
| TIME    | AID     CID|DEV  DID |MSG TYP| MSG CONTENT                                                                      |
---------------------------------------------------------------------------------------------------------------------------
|173617.0|         |PVD    P |N LDB  |          4156        RADAR BATCH ID= 4       BLINK=NONE          BATCH#= 0105 |
|        |         |           |       |          081         COORD= 421422/0824250  FORCE=Y                            |
---------------------------------------------------------------------------------------------------------------------------
|173627.0|         |PVD    P |N LDB  |          4156        RADAR BATCH ID= 4       BLINK=NONE          BATCH#= 0116 |
|        |         |           |       |          082         COORD= 421408/0824229  FORCE=Y                            |
---------------------------------------------------------------------------------------------------------------------------
|173637.0|         |PVD    P |N LDB  |          4156        RADAR BATCH ID= 4       BLINK=NONE          BATCH#= 0006 |
|        |         |           |       |          083         COORD= 421405/0824209  FORCE=Y                            |
---------------------------------------------------------------------------------------------------------------------------
|173647.0|         |PVD    P |N LDB  |          4156        RADAR BATCH ID= 4       BLINK=NONE          BATCH#= 0016 |
|        |         |           |       |          084         COORD= 421338/0824153  FORCE=Y                            |
---------------------------------------------------------------------------------------------------------------------------
|173657.0|         |PVD    P |N LDB  |          4156        RADAR BATCH ID= 4       BLINK=NONE          BATCH#= 0026 |
|        |         |           |       |          085         COORD= 421323/0824158  FORCE=Y                            |
---------------------------------------------------------------------------------------------------------------------------
|173707.0|         |PVD    P |N LDB  |          4156        RADAR BATCH ID= 4       BLINK=NONE          BATCH#= 0036 |
|        |         |           |       |          087         COORD= 421319/0824218  FORCE=Y                            |
---------------------------------------------------------------------------------------------------------------------------
|173717.0|         |PVD    P |N LDB  |          4155        RADAR BATCH ID= 4       BLINK=NONE          BATCH#= 0045 |
|        |         |           |       |          089         COORD= 421338/0824234  FORCE=Y                            |
---------------------------------------------------------------------------------------------------------------------------
|173727.0|         |PVD    P |N LDB  |          4156        RADAR BATCH ID= 4       BLINK=NONE          BATCH#= 0055 |
|        |         |           |       |          090         COORD= 421356/0824244  FORCE=Y                            |
---------------------------------------------------------------------------------------------------------------------------
|173738.0|         |PVD    P |N LDB  |          4156        RADAR BATCH ID= 4       BLINK=NONE          BATCH#= 0057 |
|        |         |           |       |          091         COORD= 421407/0824249  FORCE=Y                            |
---------------------------------------------------------------------------------------------------------------------------
|173748.0|         |PVD    P |N LDB  |          4156        RADAR BATCH ID= 4       BLINK=NONE          BATCH#= 0077 |
|        |         |           |       |          091         COORD= 421426/0824301  FORCE=Y                            |
---------------------------------------------------------------------------------------------------------------------------
|173758.0|         |PVD    P |N LDB  |          4156        RADAR BATCH ID= 4       BLINK=NONE          BATCH#= 0087 |
|        |         |           |       |          092         COORD= 421452/0824246  FORCE=Y                            |
---------------------------------------------------------------------------------------------------------------------------
|173808.0|         |PVD    P |N LDB  |          4156        RADAR BATCH ID= 4       BLINK=NONE          BATCH#= 0097 |
|        |         |           |       |          093         COORD=' 421501/0824226 FORCE=Y                            |
---------------------------------------------------------------------------------------------------------------------------
|173818.0|         |PVD    P |N LDB  |          4156        RADAR BATCH ID= 4       BLINK=NONE          BATCH#= 0107 |
|        |         |           |       |          094         COORD= 421508/0824206  FORCE=Y                            |
---------------------------------------------------------------------------------------------------------------------------
|173828.0|         |PVD    P |N LDB  |          4156        RADAR BATCH ID= 4       BLINK=NONE          BATCH#= 0117 |
|        |         |           |       |          096         COORD= 421517/0824137  FORCE=Y                            |
---------------------------------------------------------------------------------------------------------------------------
|173838.0|         |PVD    P |N LDB  |          4156        RADAR BATCH ID= 4       BLINK=NONE          BATCH#= 0007 |
|        |         |           |       |          097         COORD= 421521/0824106  FORCE=Y                            |
---------------------------------------------------------------------------------------------------------------------------
|173848.0|         |PVD    P |N LDB  |          4156        RADAR BATCH ID= 4       BLINK=NONE          BATCH#= 0017 |
|        |         |           |       |          098         COORD= 421533/0824041  FORCE=Y                            |
---------------------------------------------------------------------------------------------------------------------------
|173858.0|         |PVD    P |N LDB  |          4155        RADAR BATCH ID= 4       BLINK=NONE          BATCH#= 0027 |
|        |         |           |       |          099         COORD= 421544/0824011  FORCE=Y                            |
---------------------------------------------------------------------------------------------------------------------------
|173908.0|         |PVD    P |N LDB  |          4156        RADAR BATCH ID= 4       BLINK=NONE          BATCH#= 0037 |
|        |         |           |       |          099         COORD= 421552/0823951  FORCE=Y                            |
---------------------------------------------------------------------------------------------------------------------------
|173919.0|         |PVD    P |N LDB  |          4155        RADAR BATCH ID= 4       BLINK=NONE          BATCH#= 0048 |
```

Figure 14A



```
                *****      DART INFORMATION ANALYZER       ***** N64RL/DA1

<<===RADAR==INFORMATION===>> : TIME DIST SPEED  TRUE   TRACK  VERT. VERT.
  TIME     ALT.    LAT.  LONG. : SECS FEET KT/HR  TRACK  CHGE.  CHGE. FT/MIN

173304.0   5700 421728 825017 :
173315.0   5800 421718 824947 :  11  2465 132.7  114.3           100   545
173325.0   6000 421711 824926 :  10  1744 103.3  114.0   -0.3   200  1200
173335.0   6100 421704 824855 :  10  2427 143.7  107.0   -7.0   100   600
173345.0   6200 421657 824839 :  10  1405  83.2  120.3   13.3   100   600
173355.0   6400 421650 824809 :  10  2378 140.8  107.4  -13.0   200  1200
173405.0   6500 421635 824748 :  10  2186 129.4  134.0   26.7   100   600
173415.0   6600 421628 824717 :  10  2427 143.7  107.0  -27.1   100   600
173425.0   6700 421629 824648 :  10  2145 127.0   87.3  -19.7   100   600
173435.0   6900 421618 824627 :  10  1934 114.5  125.2   37.9   200  1200
173446.0   7000 421607 824556 :  11  2581 138.9  115.6   -9.6   100   545
173456.0   7200 421601 824526 :  10  2330 138.0  105.1  -10.5   200  1200
173506.0   7300 421558 824505 :  10  1661  98.4  100.5   -4.6   100   600
173516.0   7400 421543 824434 :  10  2773 164.2  123.2   22.7   100   600
173526.0   7500 421536 824414 :  10  1671  99.0  115.1   -8.1   100   600
173536.0   7600 421533 824343 :  10  2414 142.9   97.2  -17.9   100   600
173546.0   7700 421514 824327 :  10  2269 134.3  148.1   50.8   100   600
173556.0   7800 421503 824317 :  10  1343  79.5  146.1   -2.0   100   600
173607.0   8000 421441 824311 :  11  2274 122.4  168.6   22.5   200  1091
173617.0   8100 421422 824250 :  10  2489 147.4  140.7  -27.9   100   600
173627.0   8200 421408 824229 :  10  2129 126.0  131.8   -8.9   100   600
173637.0   8300 421405 824209 :  10  1512  89.5  101.6  -30.2   100   600
173647.0   8400 421338 824153 :  10  2988 176.9  156.3   54.7   100   600
173657.0   8500 421323 824158 :  10  1565  92.6  193.7   37.4   100   600
173707.0   8700 421319 824218 :  10  1555  92.1  254.9   61.2   200  1200
173717.0   8900 421338 824234 :  10  2271 134.5  328.0   73.1   200  1200
173727.0   9000 421356 824244 :  10  1973 116.8  337.6    9.6   100   600
173738.0   9100 421407 824249 :  11  1175  63.2  341.6    4.0   100   545
173748.0   9100 421426 824301 :  10  2126 125.9  334.9   -6.7     0     0
173758.0   9200 421452 824246 :  10  2865 169.6   23.1   48.2   100   600
173808.0   9300 421501 824226 :  10  1761 104.3   58.8   35.7   100   600
173818.0   9400 421508 824206 :  10  1657  98.1   64.7    5.8   100   600
173828.0   9600 421517 824137 :  10  2367 140.2   67.3    2.7   200  1200
173838.0   9700 421521 824106 :  10  2351 139.2   80.1   12.7   100   600
173848.0   9800 421533 824041 :  10  2234 132.3   57.0  -23.1   100   600
173858.0   9900 421544 824011 :  10  2513 148.8   63.7    6.6   100   600
173908.0   9900 421552 823951 :  10  1713 101.4   61.8   -1.9     0     0
173919.0  10100 421549 823931 :  11  1547  83.3  101.3   39.6   200  1091
173929.0  10200 421616 823902 :  10  3493 206.8   38.4  -62.9   100   600
173939.0  10200 421613 823831 :  10  2342 138.7   97.5   59.0     0     0
173949.0  10300 421610 823801 :  10  2267 134.2   97.7    0.2   100   600
173959.0  10400 421617 823741 :  10  1657  98.1   64.7  -33.0   100   600
174009.0  10500 421611 823710 :  10  2403 142.3  104.7   40.0   100   600
174019.0  10600 421603 823640 :  10  2420 143.3  109.6    4.9   100   600
174029.0  10700 421604 823609 :  10  2293 135.8   87.5  -22.1   100   600
174039.0  10700 421609 823540 :  10  2238 132.5   76.9  -10.5     0     0
174050.0  10900 421605 823509 :  11  2330 125.4  100.0   23.1   200  1091
174100.0  11000 421558 823448 :  10  1740 103.0  114.1   14.0   100   600
174110.0  11000 421551 823418 :  10  2378 140.8  107.4   -6.7     0     0
174120.0  10900 421525 823412 :  10  2672 158.2  170.4   63.0  -100  -600
174130.0  10600 421521 823432 :  10  1584  93.8  255.2   84.8  -300 -1800
174150.0  10300 421517 823442 :  20   852  25.2  241.6  -13.6  -300  -900
174210.0   9800 421525 823442 :  20   811  24.0    0.0  118.4  -500 -1500

TOTAL DISTANCE COVERED   17.9 MILES
TOTAL TIME    9.1 MINUTES
AVERAGE SPEED  117.9 KTS/HR
TOTAL RECORDS PROCESSED  53
```

Figure 14B

```
               *****     DART INFORMATION ANALYZER     ***** N64RL/FLO

TIME <------TRUE TRACK------>:<-----GROUNDSPEED---->:<---ALTITUDE(X100)--->
     0   90   180   270   360:24       115       207:57        83       110

3304 ........................:......................:A.....................
3315 .......T................:.............S........:A.....................
3325 .......T................:.........S............:.A....................
3335 .......T................:..............S.......:..A...................
3345 ........T...............:.......S..............:..A...................
3355 .......T................:.............S........:...A..................
3405 ........T...............:............S.........:...A..................
3415 .......T................:..............S.......:....A.................
3425 .....T..................:............S.........:....A.................
3435 ........T...............:..........S...........:.....A................
3446 .......T................:.............S........:.....A................
3456 .......T................:.............S........:......A...............
3506 ......T.................:........S.............:......A...............
3516 ........T...............:................S.....:.......A..............
3526 .......T................:.........S............:.......A..............
3536 ......T.................:..............S.......:........A.............
3546 .........T..............:.............S........:........A.............
3556 .........T..............:......S...............:........A.............
3607 ...........T............:...........S..........:.........A............
3617 .........T..............:..............S.......:..........A...........
3627 ........T...............:............S.........:..........A...........
3637 ......T.................:........S.............:..........A...........
3647 ..........T.............:..................S...:...........A..........
3657 ............T...........:........S.............:...........A..........
3707 ................T.......:........S.............:............A.........
3717 .....................T..:.............S........:.............A........
3727 .....................T..:...........S..........:.............A........
3738 .....................T..:....S.................:.............A........
3748 .....................T..:............S.........:.............A........
3758 .T......................:.................S....:..............A.......
3808 ....T...................:.........S............:..............A.......
3818 ....T...................:........S.............:...............A......
3828 ....T...................:.............S........:...............A......
3838 .....T..................:.............S........:................A.....
3848 ....T...................:............S.........:................A.....
3858 ....T...................:..............S.......:.................A....
3908 ....T...................:.........S............:.................A....
3919 ......T.................:.......S..............:.................A....
3929 ..T.....................:.....................S:..................A...
3939 ......T.................:.............S........:..................A...
3949 ......T.................:.............S........:..................A...
3959 ....T...................:........S.............:...................A..
4009 .......T................:..............S.......:...................A..
4019 .......T................:..............S.......:...................A..
4029 .....T..................:.............S........:....................A.
4039 .....T..................:.............S........:....................A.
4050 ......T.................:............S.........:.....................A
4100 .......T................:.........S............:.....................A
4110 .......T................:.............S........:.....................A
4120 ...........T............:...............S......:.....................A
4130 ................T.......:........S.............:...................A..
4150 ...............T........:S.....................:..................A...
4210 .......................T:S.....................:................A.....
```

Figure 14C

Since I put this talk together several weeks ago, our office began investigating an accident involving an American Cessna 210 that departed Detroit, IFR, for Boston. Just after reaching an altitude of 11,000 feet over Canadian territory, it suddenly dove almost vertically into the ground. The FAA provided a DART printout (Figure 14A) which lists time, the encoded altimeter reading, and geographic coordinates for radar sweeps that are normally about 10 seconds apart.

Our Canadian system does not have provision for recalling such data, so when accidents occur close enough to the border to be within FAA radar coverage, we normally do the plotting by hand, as accurately as possible on large scale maps.

However this time, because of the unusual nature of the accident, an evening was spent developing a program to provide the expanded information the investigators needed.

In operation, the time, altitude, and geographic coordinates are entered following prompts on the screen for each radar position. The computer quickly completes the line with the time (in seconds) between each plot, the distance in feet, the groundspeed in knots, the true track in degrees, the change in degrees (plus or minus) from the last track, the vertical height change in feet, and the vertical rate in feet per minute. Following the last entry, the total distance covered in nautical miles, the total elapsed time, and the average speed is given, along with the total number of records processed (Figure 14B). I might add that this information is simultaneously stored on magnetic media for further use, so that it need only be entered once.

The next logical step was to portray the information a little better, and another evening was spent expanding the program slightly. The result is shown on Figure 14C. The time base is replicated, and graphic plots are printed for track, groundspeed, and altitude. The track, of course, is from 0 to 360 degrees. The groundspeed and altitude scales are set automatically by their respective minimums and maximums.

Combined, the two pages provide a pretty good investigative aid, and an example of what can be accomplished quickly and easily.

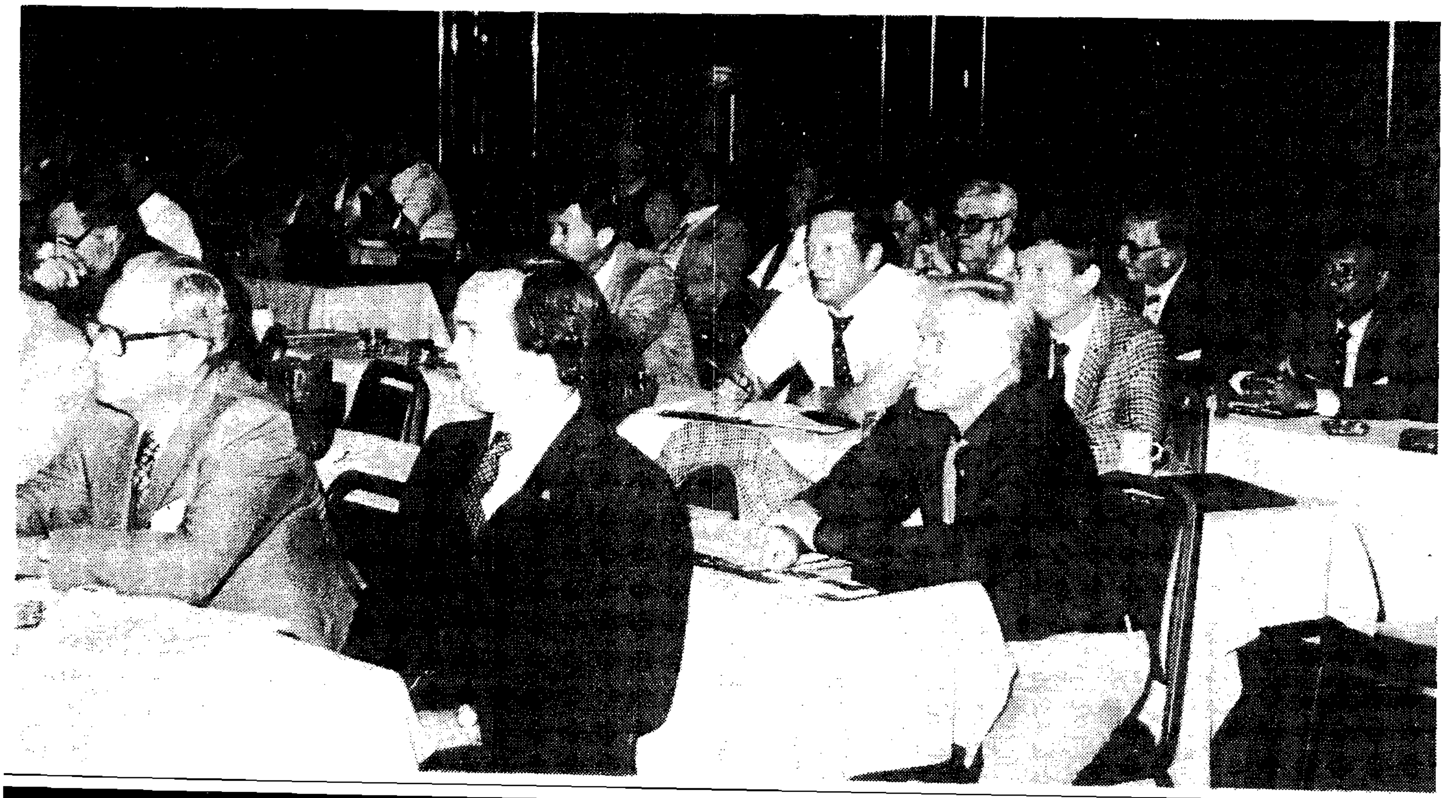
Conclusion

It should be stressed that microprocessors rarely can produce information that, given sufficient time, cannot be calculated manually. Their true advantages are in speed and accuracy.

A few hours spent on a carefully written program, which is little more than stepping through all the necessary calculations to obtain the final result once, will continue to take a wide selection of different input data and process it exactly the same, time and time again, usually in a matter of seconds. The inquisitive investigator gets a chance to try a variety of parameters, watch the interaction, and be rewarded with an abundance of newfound knowledge.

We have just been looking at the tip of the iceberg as far as the accident investigator and microprocessors are concerned. Desk top computers are sophisticated word processors that make the transcribing of field notes, statements, and the writing of reports very efficient and certainly more pleasant for both operational and support staff. They will retain and permit instant updating of safety and response manuals, programmed investigative procedures, and assistance directories. They can store safety recommendations and follow-up action by category, type, operation, etc. They can assist management and supervisors with mundane office chores and free the time for more productive, safety related endeavors.

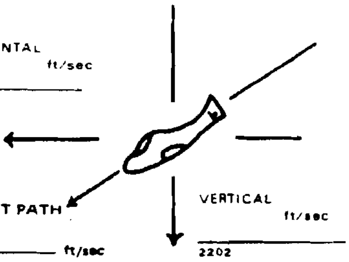
Besides, computers have to be one of the most relaxing hobbies available, and a natural challenge for anyone associated with aviation.



CRASHWORTHINESS–KINETICS

INITIAL VELOCITIES

HORIZONTAL ________ ft/sec
2201



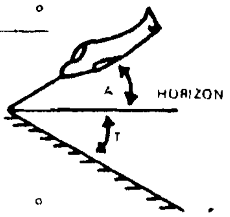
FLIGHT PATH ________ ft/sec

VERTICAL ________ ft/sec
2202

☐ VERIFIED ☐ ESTIMATED
2203

FLIGHT PATH ANGLE & TERRAIN ANGLE

A ________ °
2204

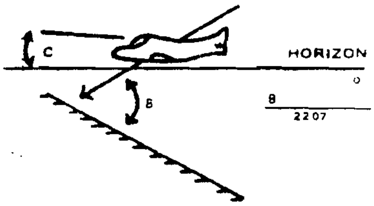


T ________ °
2205

☐ VERIFIED ☐ ESTIMATED
2206

IMPACT ANGLE & ATTITUDE

C ________ °



B ________ °
2207

2208 **OPEN TERRAIN (Select up to two)**

A	CONCRETE	G	FRESH LOOSE SNOW
B	ASPHALT	H	DRY CULTIVATED SOIL
C	DRY PACKED CLAY	K	WET CULTIVATED SOIL
D	DRY SOD	L	BOGGY
E	WET SOD	M	WATER
F	PACKED SNOW	N	ICE
Y	OTHER		

2209 **OBSTABLES (Select up to three)**

A	ROCK FACE	H	TREES 8'' TO 9'' DIA.
B	RIGID STRUCTURE	K	TREES 9'' TO 12'' DIA.
C	WOOD FRAME STRUCTURE	L	TREES 12'' DIA. +
D	BOULDERS 0.5 TO 1.0 FT DIA.	M	SCRUB TREES
E	BOULDERS 1 TO 2 FT DIA.	N	WIRES
F	BOULDERS 2 TO 3 FT DIA.	P	POLES
G	TREES 3'' TO 6'' DIA.	Y	OTHER

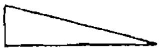
WATER DEPTH	ICE THICKNESS	TOTAL STOPPING DISTANCE FROM FIRST IMPACT	LATERAL VELOCITY
ft	ft	ft	ft/sec
2210	2211	2212	2213/2214

DIRECTION
L LEFT
R RIGHT

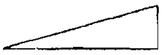
MOST SEVERE IMPACT

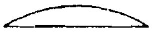
PULSE TYPE

A ☐


B ☐


C ☐


D ☐


E ☐

2215

INITIAL VELOCITY Vo ft/sec

FINAL VELOCITY Vf ft/sec

FLIGHT PATH ANGLE θ_{Fp} deg.

VERTICAL
Crush (1) ________
Stop Dist. (2) ________
(1 +2) Sv ________ ft

HORIZONTAL
Crush (1) ________
Stop Dist. (2) ________
(1 + 2) Sh ________ ft

COEFFICIENT OF FRICTION
μ

WEIGHT AT IMPACT
lb.

VERT. VELOCITY CHANGE (Vo - Vf) Vv ft/sec

HORIZ. VELOCITY CHANGE (Vo - Vf) Vh ft/sec

VERTICAL DECEL. Gv G

HORIZONTAL DECEL. Gh G

RESULTANT DECEL. Gr G

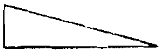
PULSE DURATION T sec

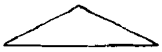
DISTANCE OF PULSE (Vo to Vf) S ft

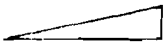
SECOND MOST SEVERE IMPACT

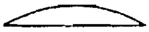
PULSE TYPE

A ☐


B ☐


C ☐


D ☐


E ☐

2223

INITIAL VELOCITY Vo ft/sec

FINAL VELOCITY Vf ft/sec

FLIGHT PATH ANGLE θ_{Fp} deg.

VERTICAL
Crush (1) ________
Stop Dist. (2) ________
(1 + 2) Sv ________ ft

HORIZONTAL
Crush (1) ________
Stop Dist. (2) ________
(1 + 2) Sh ________ ft

COEFFICIENT OF FRICTION
μ

WEIGHT AT IMPACT
lb.

VERT. VELOCITY CHANGE (Vo - Vf) Vv ft/sec

HORIZ. VELOCITY CHANGE (Vo - Vf) Vh ft/sec

VERTICAL DECEL. Gv G

HORIZONTAL DECEL. Gh G

RESULTANT DECEL. Gr G

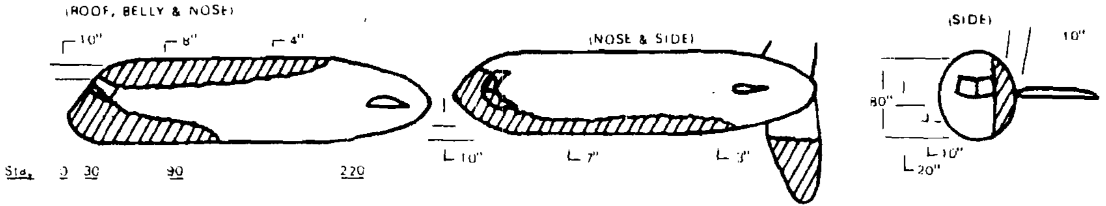
PULSE DURATION T sec

DISTANCE OF PULSE (Vo to Vf) S ft

CRASHWORTHINESS–DEFORMATION

FUSELAGE INWARD COLLAPSE OR DEFORMATION

DEFORMATION & COLLAPSE EXAMPLE—3 VIEWS



FUSELAGE AREA	INWARD DEFORMATION (In inches)	STATION NO.		FUSELAGE AREA	INWARD DEFORMATION (In inches)	STATION NO.		FUSELAGE AREA	INWARD DEFORMATION (In inches)	STATION NO.	
		FROM	TO			FROM	TO			FROM	TO
a. ROOF				c. LEFT SIDE				e. BELLY			
								f. NOSE			
b. FLOOR				d. RIGHT SIDE							
								g. REAR			

MAJOR COMPONENT DISPLACEMENT

COMPONENT	DISPLACEMENT IN INCHES						ENTERED COCKPIT	ENTERED PASSENGER AREA
	UP	DOWN	FWD	AFT	LEFT	RIGHT		
ENGINE 1								
ENGINE 2								
ENGINE 3								
ENGINE 4								
PROP 1								
PROP 2								
PROP 3								
PROP 4								
LEFT WING								
RIGHT WING								
MAIN ROTOR								
FORWARD ROTOR								
AFT ROTOR								
TRANS. MAIN								
TRANS. FWD								
TRANS. AFT								
OTHER								

LANDING GEAR DEFORMATION

GEAR LOCATION	PERMANENT DEFORMATION IN INCHES						BROKEN	TORN FREE
	UP	DOWN	FWD	AFT	LEFT	RIGHT		
LEFT FRONT								
RIGHT FRONT								
LEFT REAR								
RIGHT REAR								
CENTRE FRONT								
CENTRE REAR								

NOTES

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CRASHWORTHINESS–SYSTEMS & PROCEDURES

SYSTEM/ PROCEDURE GENERAL	SYSTEM/PROCEDURE SPECIFIC		NEEDED	ON BOARD OR AVAILABLE			USED/ WORN			PRODUCED/ CONTRIB. TO INJURIES			MINIMIZED/ PREVENTED INJURIES			FAILED		
				YES	NO	?	YES	NO	?	YES	NO	?	YES	NO	?	YES	NO	?
RESTRAINT SYSTEM CREW	LAP BELT	2401/2402																
	SHOULDER HARNESS	2403/2404																
	LAP BELT TIE DOWN STRAP	2405/2406																
	INERTIA REEL	2407/2408																
	SHOULDER STRAP GUIDE	2409/2410																
RESTRAINT SYSTEM PASSENGERS	LAP BELT	2411/2412																
	SHOULDER HARNESS	2413/2414																
	LAP BELT TIE DOWN STRAP	2415/2416																
	INERTIA REEL	2417/2418																
	SHOULDER STRAP GUIDE	2419/2420																
SEATS	SEAT/PILOT	2421/2422																
	SEAT/COPILOT	2423/2424																
	SEAT/JUMP	2425/2426																
	SEAT/PASSENGER	2427/2428																
IMMEDIATE ENVIRONMENT COCKPIT	DESIGN	2429/2430																
	LOCATION	2431																
	RESTRAINT	2432/2433																
IMMEDIATE ENVIRONMENT CABIN	DESIGN	2434/2435																
	LOCATION	2436																
	RESTRAINT	2437/2438																
CABIN BAGGAGE	LOCATION	2439																
	RESTRAINT	2440/2441																
CARGO	LOCATION	2442																
	RESTRAINT	2443/2444																
EMERGENCY EVACUATION	AIRCRAFT DOORS	2445/2446																
	EMERGENCY EXITS	2447/2448																
	CHUTES	2449/2450																
	ROPES	2451/2452																
	EXIT LIGHTING	2453/2454																
	INTERIOR EMERGENCY LIGHTING	2455/2456																
	SUPERVISION	2457/2458																
	WARNING	2459/2460																
	OTHER	2461/2462																
WATER LANDINGS	LIFE VESTS-ACCESSIBILITY	2463/2464																
	LIFE VESTS-TYPE	2465/2466																
	LIFE RAFTS-ACCESSIBILITY	2467/2468																
	LIFE RAFTS-TYPE	2469/2470																

Accident Prevention Through Investigation, Reconstruction and Litigation

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Introduction

This paper will deal primarily with general aviation accident investigation, reconstruction, analysis, litigation and prevention. It will overlap into other aviation areas which are common to general aviation.

Private Consultant or Expert

This paper is from the view of an independent or private consultant. Many of you might wonder, what is, and how do you become a private consultant? It's quite simple. If you have an area of expertise, all you do is prepare a glamorous resume, hang out your shingle, forward this resume to attorneys throughout the country who specialize in plaintiff's or defendent's litigation of the specialty area of which you consider yourself qualified. An example is overall aviation expertise. This is not really the way it happened to this writer, who had just retired after thirty years. About seven or eight years ago an attorney from the West Coast called and asked me to do him a favor. At first I was rather skeptical about being called an expert. Every person in this room is an expert. It is just a matter of defining the area of your expertise. Early in this business I asked the attorney who hired me what were the qualifications to be an expert in the state which we were working. His answer was, if there are ten people on the street and you know more about a certain subject than five of them do, then you are classified legally as an expert. I don't know if that holds up in all states or not but it did in the state where the work was being done at the time. It has been said that an expert is a witness who is somewhat smarter than the jury.

The group of consultants working in aviation throughout the country today come from a variety of disciplines. There are quite a number of retired FAA personnel; air traffic specialists, maintenance and records people, investigators, and meteorological types. Also some fixed based operators participate in addition to operating their business. You will find many college professors, because of their very high qualifications in a specific discipline, involved as experts. In aviation litigation there are a considerable number of metallurgists, chemical engineers, mechanical engineers, aeronautical engineers, engine people (reciprocating and turbine), propeller specialists and a few former industry personnel. They will consist of test pilots, production people and general safety experts. Another group which is quite strongly represented is the system safety engineering people, along with crashworthiness engineers. These experts are not limited to aviation litigation; they are also hired in motor vehicle, industrial, and health related areas.

Attorneys doing litigation in technical areas have a need for consultants and experts. The consultant is the individual with sufficient knowledge in a broad area to investigate, reconstruct, analyze and research. The consultant must know when to ask for an expert and where to find him. The consultant who becomes the expert in every area will soon meet a real expert, usually provided by the opposition.

Fatal Accidents

A couple of years ago at the Seattle meeting, a presentation was made by George B. Parker entitled, "Why Doesn't Aircraft Accident Investigation Prevent Accidents?"[1] I would like to make the following quote from Mr. Parker's conclusion. "It is sad to say but it may be possible that there are not enough people concerned about fatalities in general aviation to shoulder the responsibility and costs to prevent these accidents." Note the chart of the transportation fatalities rose from 1,436 in 1977 to 1,690 in 1978,[2] and in 1980 dropped to 1,280.

NTSB 1972-1976 Study

Two years ago the National Transportation Safety Board released a special study on general aviation accidents.[3] It dealt primarily with single engine aircraft and noted that in the period from 1972 to 1976 there were more than 6,900 fatalities. Going back to that portion of Mr. Parker's statement that there are not enough people in general aviation concerned about these fatalities, it is certainly a valid statement. We all have concern but do we have sufficient concern to take the required actions necessary to prevent some of these fatalities? The answer to that collectively is a flat NO! We do not have sufficient concern.

The study published by NTSB certainly was not welcomed wholeheartedly by all segments of the general aviation industry. It is hoped that studies such as these continue and become even more definitive. NTSB is to be commended.

Mr. Parker talked about "costs to prevent these accidents.' When we refer to costs, we equate directly to dollars, and any dollar cost in general aviation is paid by the aircraft owner or operator. The general aviation owner and operator is being shortchanged because sufficient efforts are not being utilized and expanded to eliminate the so-called fatal

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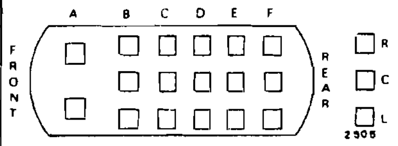
CRASHWORTHINESS--INJURIES

	IDENTIFICATION 2501		DEGREE OF INJURY 2502		AUTOPSY 2503
A	PILOT				
B	CO-PILOT			A	PHYSICIAN
C	OTHER FLIGHT CREW	F	FATAL	B	PATHOLOGIST
D	CABIN CREW	S	SERIOUS	C	FLIGHT SURGEON
E	PASSENGER	M	MINOR	D	OTHER
F	PERSON OUTSIDE AIRCRAFT	N	NONE	E	CAM. PRESENT



ROW ______

2504

	FACING 2506
F	FRONT
S	SIDE
R	REAR

EVENT CAUSING INJURY	
STRUCK INTERIOR OF AIRCRAFT AT IMPACT	A
STRUCK BY FLYING OBJECT INSIDE AIRCRAFT	B
BURNS ONLY	C
BURNS FOLLOWING OTHER INJURIES	D
CRUSHED IN WRECKAGE	E
CONTACT WITH PROP/INTAKE/EXHAUST	F
FELL FROM AIRCRAFT (OR THROWN)	G
STRUCK BY AIRCRAFT	H
PULLED UNDERWATER	J
STRUCK BY MAIN ROTOR	K
STRUCK BY TAIL ROTOR	L
STRUCK INTERIOR OF AIRCRAFT IN TURBULENCE	M
STRUCK BY DISPLACED COMPONENT/STRUCTURE	N

THERE IS SPACE BELOW FOR SPECIFYING UP TO TEN INJURIES FOR THE PERSON COVERED BY THIS PAGE. THE "EIGHTH REVISION, INTERNATIONAL CLASSIFICATION OF DISEASES, SECTION XVII WILL BE USED TO CATEGORIZE ALL INJURIES.

ENTER THE PROPER CODE IN THE SPACE PROVIDED AS WELL AS A NARRATIVE DESCRIPTION OF THE INJURY.

ENTER THE APPROPRIATE CODE FOR THE "EVENT CAUSING INJURY" AT THE RIGHT.

		CODE	
	2507		2508
	2509		2510
	2511		2512
	2513		2514
	2515		2516
	2517		2518
	2519		2520
	2521		2522
	2523		2524
	2525		2526

NOTES:

accidents and the accidents involving serious injuries and property damages.

Products Liability

The average products liability loss in the time frame from 1965 to 1973 increased 686% while there was only a 60% increase in the general price index.[4] It has risen considerably higher in the past five years. This is what is known as the "Consumerism Era". Naturally, the aviation manufacturers must protect themselves by purchasing products liability insurance coverage. The larger companies such as Beech, Cessna and Piper are able to purchase their products liability coverage for premiums ranging from 1½% to 3½% of their gross annual sales.[5] These percentages at face value do not apear to be exorbitant. When you apply them to gross sales in excess of 1.5 billion dollars in 1978,[6] it becomes a very large figure for the manufacturers to pay for their liability protection. In plain words it is protection against design defects, lack of quality control, inadequate testing and failure to warn. As stated earlier these dollar costs are paid by the aircraft owners and operators.

The products liability suits arise primarily in accidents where fatal and serious injury occur. If the accident is lacking a serious injury or a fatality, the manufacturer is rarely involved in a products liability suit. The costs of legal defense for these claims accounts for over thirty cents of each dollar paid in insurance premiums.[7] What we are seeing is strictly after-the-fact actions and exorbitant costs which are being passed on to the consumer in general aviation. Millions of dollars are being paid because of simple and easily correctable design defects which would make the general aviation aircraft much safer and reduce these large numbers of fatalities and serious injuries.

Who is to blame for the accidents we are having in general aviation that are so costly? Is it the FAA, NTSB, aircraft manufacturers, aircraft owners and pilots associations or insurance underwriters? I could go on and name several other groups or participants. General aviation has no one group responsible for accident prevention, and until such time as all forces are pooled together, the very costly and serious accidents will continue to plague us.

Litigation

Litigation has been cited as an accident prevention tool in the title of this paper. Several example cases will be discussed in which litigation was taken in the past several years. Accident prevention is not the purpose of litigation. It is only a by-product. The purpose is solely for collection of damages; be it a widow, surviving children or a person receiving an injury. Million dollar settlements are not uncommon today.

Before going into the examples it must be stated that litigation is definitely the most costly known way of preventing accidents. An effort will be made not to disclose, even though identifiable, specific type aircraft, manufacturer or personnel involved. The finding of accident causes is a form of criticism and it must be considered as constructive for accident prevention purposes.

Case Number One

This case involved an aircraft which has one of the best fuel systems in general aviation. As we all know, documents have been written on fuel system design recommending simplicity. The main reason for design simplicity is to take the work load from the pilot, thus eliminating or reducing the pilot's chance for an error. Why have the pilot worrying about switching tanks in the final minutes of his flight, trying to find which tank has the most fuel? The single "On" type system has been utilized in many aircraft and has proven to be safer than where the pilots have to be continually switching fuel tanks. With this type system the pilot in his final minutes of the flight can concentrate on his approach, other traffic and flying the aircraft.

The system to which I am referring has one overboard vent for both tanks. The vent is located on the left tank and there is no vent on the right tank. The thinking on the part of the manufacturer evidently was to place a line from the air space in the right tank to the air space in the left tank, thus adequate venting would be provided for the system. The airworthiness standards require a vent for each tank. It was evidently felt that the cross vent line met the minimal airworthiness standards. Redundancy is non-existant in this type of system.

In 1970 an accident occurred in which serious injuries were involved with this type aircraft. It was found by the NTSB investigators that the vent on the left tank was plugged by foreign matter such as dirt and insects. This caused the engine to fail as a result of fuel starvation after approximately one hour and ten minutes of flying time. The same type of accident has occurred at least five or six times since the 1970 accident. Usually, since it is a low performance aircraft, forced landings are executed with success, or minimal to severe aircraft damage, and without injury. In accidents such as these the insurance carrier on the hull pays the owner for the damages to the aircraft. The aircraft is then repaired or replaced, much as you would do if your car were damaged or totaled.

Another such case occurred about five or six years after the original accident. This case had two fatalities. In 1977, during the course of litigation, the manufacturer came out with a Service Letter providing a free fuel cap to all owners of this type aircraft for the right fuel tank. That fuel cap is vented, thus providing redundancy now for both tanks as far as the venting system is concerned. You decide who is to blame for not putting that vented fuel cap on after the original accident was found by the NTSB investigator to be caused by a plugged fuel vent. Was it NTSB? Was it FAA? Was it the manufacturer? Was it one of the insurance carriers? The high litigation costs involved, the aircraft that were destroyed, the persons either fatally or seriously injured, can be charged to some or all of the groups. Any one of the groups mentioned could have taken sufficient action to have caused this simple but serious deficiency to have been corrected. A vented fuel cap should not cost any more than a couple of dollars. The manufacturer finally took the action which is to be considered commendable. However, one year after the manufacturer's actions, in Huntington Beach, California, an aircraft crashed with substantial damage and three serious injuries; several have since occurred. The NTSB investigators found engine power loss caused by fuel starvation as a result of lines clogged by dirt and insects. Possibly an Airworthiness Directive would have been appropriate as further action. On these most recent accidents, the manufacturer certainly should not be held at fault.

Case Number Two

In 1969 an NTSB investigator, accompanied by a manufacturer's representative, went to Rockford, Illinois and their investigation revealed the pilot, who was fatally injured, attempted to take off with the control locks engaged. This is an obvious pilot error accident. The pilot in this type aircraft, doing a proper pre-flight and utilizing his check list, would have had at least five or six opportunities to determine that the control locks were engaged. The pilot of any aircraft, being human, is subject to making an error. The error, if possible, should not be quite so catastrophic! Once again the airworthiness standard plainly states that the pilot must receive an unmistakable warning if the control locks are in the engaged position when he applies the power for take off. This pilot did not receive the unmistakable warning until it was too late. The investigator on this accident in his findings made some very good recommendations. It is possible to install the control locks properly and then remove them in such a manner that the ailerons, elevators and rudder would remain in the engaged position when and after you have applied the throttle to both engines. The investigator recommended a modification of the control locking system. He recommended that they be locked in such a manner that the aircraft could not rotate. Here again, general aviation suffered through a series of these accidents in the same type of aircraft. One at Chamblee, Georgia; one at Titusville, Florida; then one at St. Petersburg, Florida killing four people. After the St. Petersburg accident, the manufacturer finally took action to develop a new control locking system which is considered to be fail-safe. The control column pin hole was also redrilled giving two degrees nose down elevator and twelve degrees right aileron when the locking pin is in the engaged position. With these conditions the aircraft cannot possibly become airborne. The manufacturer has also designed it in a manner in which the aileron, rudder and elevator must be disengaged prior to the release of the throttle guards. This modification and lock was put on the market for purchase at the owner's discretion and it is on all newly manufactured models. Now I ask you, what about some two thousand aircraft still out there in general aviation with the old type control lock mechanism? Who is going to show sufficient concern to see that they will be changed for the fail-safe model? Or will inaction prevail again? We are sometimes slow to learn. KLM Airlines in the early 1940s had an accident as the result of the control locks being engaged on a DC3. An accident occurred over thirty years later with the same type aircraft and the same identical cause. The pilots in these accidents were all high time pilots subject to human error. Let's not fill the cockpit and owner's manuals with cautions and warnings. Let's put system safety engineering to work on the drawing board or correct existing problems to eliminate possible errors the pilot could make.

Case Number Three

The recent NTSB studies[3] on the most popular aircraft by type plainly points out the most serious aircraft in general aviation regarding the fatal accident picture. The NTSB is again commended as "the report names names and the cold figures pull no punches"[8]. This case will address one type aircraft, usually used for training, involved in litigation as a result of numerous fatal accidents. The accidents involve stall-spin fatalities.

An instructor pilot with a student was asked by the control tower to make a right 360° turn for traffic spacing on his downwind leg. Upon executing the turn at traffic pattern speed, the aircraft stalled, entered a spin and struck the ground in a flat spin configuration. Another two fatalities occurred while an instructor pilot working with another pilot to obtain his instructor pilot rating was observed doing a series of turns at about 1500 feet above ground level. The aircraft, in a turn, stalled, entering a spin which developed into a flat spin killing both occupants. A later accident occurred with a private pilot experiencing engine failure due to fuel starvation. The pilot was practicing touch and go landings, when engine failure occurred after take off at approximately 150 feet AGL. The aircraft fell off on the right wing, entering an incipient spin producing a fatal injury. These accidents all appear in the NTSB studies and statistics as "the pilot failed to obtain/maintain sufficient air speed.[11]

At the conference in Seattle Mr. Schleede[10], in his presentation regarding pilot error accidents, made a good observation in that we must "look beyond" the statistics produced by NTSB studies. This same aircraft has a long history of stall/spin accidents not just with low time student pilots but also with instructors and high time pilots.

The aircraft upon certification was not required to be placed into a fully developed spin to determine if it were recoverable.[11] At a later date a test pilot intentionally entered a spin which went flat, and after twenty-seven turns and making every effort to recover, bailed out. Two instructor pilots in Canada intentionally spun the same model aircraft, entered a spin which went flat; every effort to execute a recovery was made with negative results. Fortunately, they survived the crash. Airworthiness standards require that any spinnable aircraft be recoverable. If this aircraft was never allowed to develop into a full spin, how was it certified to be recoverable? How did the manufacturer determine his pilot's handbook procedures for recovery from an "inadvertent" spin? This spin type accident is also recorded in two other files where pilots have survived, usually crippled for life.

This same aircraft has a long history of engine failures due to fuel starvation. In "looking beyond", this aircraft has a three-position selector valve, *Off, Left* and *Right*. This requires constant pilot attention, frequently switching tanks in order to maintain lateral balance. The pilot is required to look full ninety degrees to the right and full ninety degrees to the left down by his leg to read the manometer type fuel gauges, to determine the amount of fuel in each tank. This type gauge of WWII vintage has a history of being extremely inaccurate. As a result of an accident investigated by NTSB in West Virginia, the investigator found one-fourth to one-third of a tank of fuel in both the right and the left tanks. It was determined that the cause of the engine failure was due to fuel starvation. The aircraft was at traffic pattern altitude on his downwind leg. The air was somewhat turbulent causing an unporting condition which led to the engine failure. NTSB then requested that this fuel system be evaluated again by FAA and the manufacturer. This evaluation was conducted and according to reports in various publications the fuel system was given a clean bill of health.

In a later model of this same aircraft, modifications were made on the fuel system to include fuel tanks located inboard on the wing each with a sump tank and thus eliminating the long tubular spars as tanks. The manometers were replaced with conventional electric type gauges mounted in full view, in the center of the console. This is reflected in a marked reduction of fuel starvation accidents in this series aircraft.

The recent NTSB report shows that your chance of being involved in a fatal accident in this aircraft is more than five times higher than in a Cessna 150. If you, your son, or your grandson are going to learn to fly, have a good look at the records and by all means choose the Cessna 150 over the aircraft discussed here.

This line of aircraft was in the last year purchased by another company. The president was asked what he was going to do regarding the products liability claims which have been numerous against this aircraft. His comment was he would let the insurance people take care of that.[12] Evidently, the aviation underwriters have taken care of it because it has been since announced that this model aircraft would no longer be produced.[13]

Case Number Four

The final case study to be presented in this paper pertains to an accident where a disconnect in a throttle linkage occurred. The part is a ball socket which costs $1.18 and has given problems in that the ball detaches from the mating socket. Numerous incidents of this have occurred as well as several injury producing accidents.

The FAA on June 21, 1974 published an Airworthiness Directive for an aircraft utilizing this specific throttle ball joint. The ball joint was replaced with a rod end bearing which provided a fail-safe redundant connection at the carburetor. The manufacturer has continued to use this same identical ball joint in many other aircraft since the Airworthiness Directive was published. The manufacturer published a Service Letter on May 28, 1975 for inspection of the ball socket. The mechanic is to "firmly grasp the unit and pull, twist and rotate the ball end. If excessive wear exists, replace with new ball joint (PN 31747-00) or applicable kit". The mechanic has no guidelines for excessive wear.

In the same Service Letter the manufacturer listed an appropriate kit which is a rod end type throttle connection as was required in the earlier Airworthiness directive.

Since the Airworthiness Directive, which was limited only to one series of a model, the manufacturer in 1977 came out with another Service Letter, where nine models of aircraft were affected because, "There have been a few reports received from the field describing inadvertent detachment of the engine controls (i.e., throttle, prop governor and/or mixture) at the control cable ball joint attachment assembly. Failure of this ball joint assembly renders the particular control system inoperative----- --". The Service Letter announces availability of a safety device (retainer) that, when installed on the ball joint assembly, prevents disengagement of the ball from the socket. This retainer costs $.08, and it provides a fail-safe system, yet it is not required in all cases where the ball joint is utilized in a critical area. In April of this year, General Aviation Airworthiness Alerts addressed this aircraft as follows, "Throttle rod ball joint comes out of the socket at the carburetor". I ask you whether $.08 is too high a price to pay to prevent accidents? The $.08 fail-safe device would have prevented the accident discussed which involved four injuries, one of which was serious. It also would have prevented litigation wherein the manufacturer paid a settlement. The price paid in that settlement could have put the fail-safe device on every ball joint utilized in the model aircraft involved.

The case studies which have briefly been touched upon all produced corrective actions to reduce or eliminate the fatal accident causes revealed. This is really the back door approach to accident prevention.

Earlier you saw the huge dollar cost paid for manufacturer's liability insurance by three of the major general aviation companies. Thirty percent of the premium is the amount paid for legal defense of the allegations made.[7] The one common courtroom defensive statement is that the manufacturer of the aircraft met U.S. Government airworthiness standards. The FAA Act provides authority for the establishment of *minimum* standards. It also states such standards constitute the *optimum* to which the regulated should strive.[9] All manufacturers should strive to far exceed the airworthiness standards in critical areas, not just meet them.

Mid-air Collisions

On September 25, 1978, the subject of mid-air collisions became very prominent, and for several months after the San Diego disaster. Hearings were held and TV coverage was at the maximum. Then along came the DC-10 engine mount problem at O'Hare. The subject of mid-air collisions for news coverage was placed on the back burner. This problem has been with us for many years, and it will remain and get worse, until we get "sufficient concern."

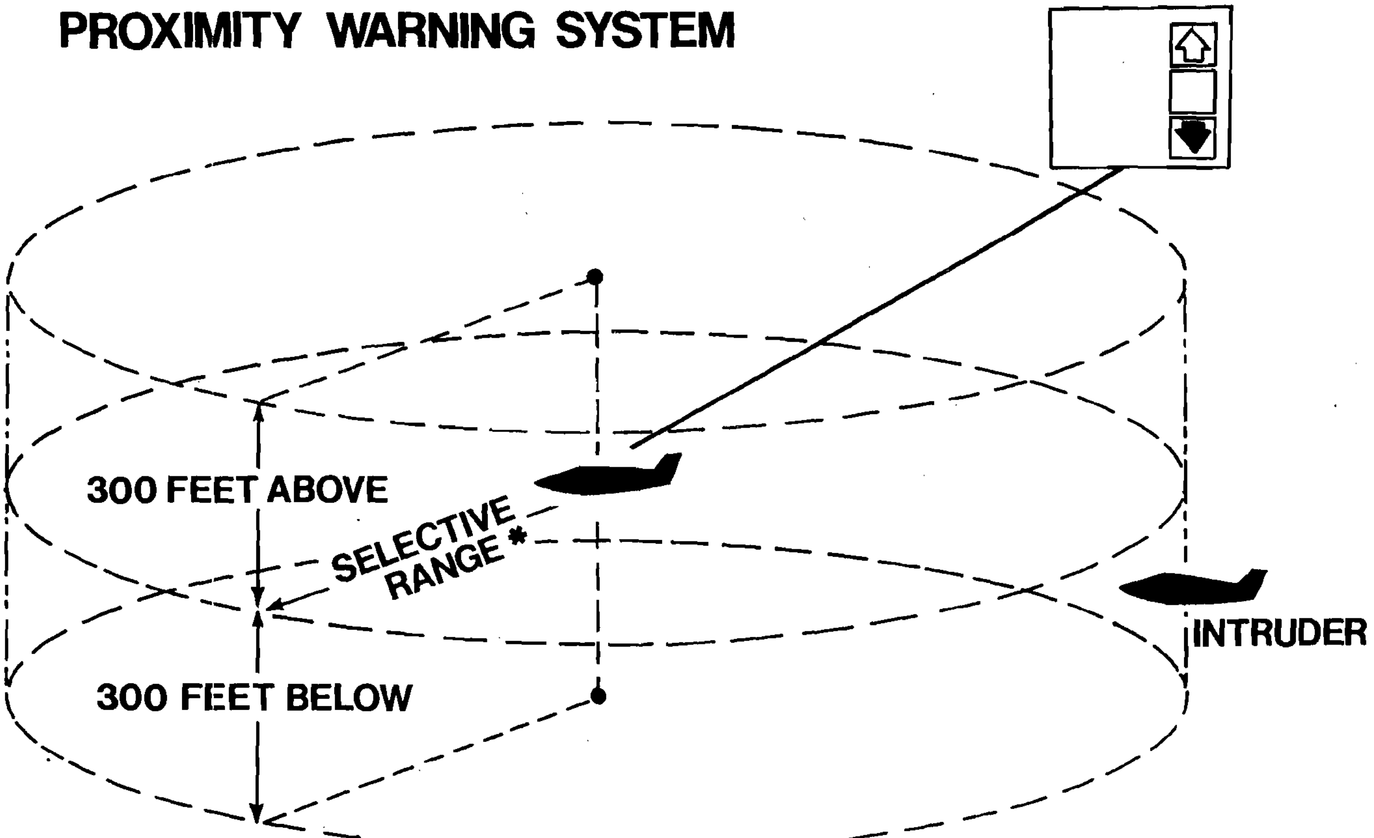
Forty-three years ago an article was written concerning the high density of operations at Newark Airport. At that time Newark Airport had sixty-four scheduled arrivals and departures each day. A quote from that article is, "Only by constant watch over all ship movements may traffic be handled safely by busy airports".[17] That was over forty years ago. That article was written by none other than Mr. Jerome Lederer. The "see and avoid" concept has been proved to be inadequate for our present day aircraft movements, especially around busy airports and in approach areas.

The mid-air collision potential will increase drastically in the next decade. General aviation aircraft alone are expected to grow from 187,000 to 291,000. Air carriers will also be flying an additional 600 aircraft. Instrument operations at FAA controlled airports will increase by more than 76%.[2] We can ill afford to spend the next ten years with the inactivity that we have displayed in the past ten years. The serious problem of mid-air collisions is facing us and becoming greater every day.

In 1971 a statement was made before the Senate Sub-Committee on Transportation, Aviation and Communication, when it was meeting on the subject of mid-air collisions. The statement made was as follows: "We believe that the efforts of a national group representing all of the aviation community are needed if a viable air derived collisions program is to evolve. What is needed is an active group rather than an advisory or coordinating group". The same identical statement was submitted to Congressman Thomas Harkin, Chairman of the Sub-Committee on Transportation for the hearing which commenced on June 27, 1979.[14] The author of this paper agrees that an action group is needed. We have had numerous advisory groups and coordinating groups in the past years on the subject of mid-air collisions. We can prevent the next San Diego! San Diego, as was brought out earlier, was a headliner for the news media.

The NTSB study to which I have referred several times shows 196 mid-air collisions. These mid-air collisions are in general aviation and also can be prevented if actions are taken or if "sufficient concern" is shown.

In Mr. Lederer's article he cited a suggestion from England which proposed to carry a small transmitter to emit constant radiation of warning signals from the other aircraft and be warned of the direction of approach. During WWII a pilot flying in Great Britain was able to pick up the barrage balloon signals which would give him the warning to reverse his course and fly away from the danger area.



***SELECTIVE RANGE OF 1000, 3000, OR 5000 FEET**

At the U.S. Army Aviation Training Center at Fort Rucker, Alabama, from November 1966 to November 1968 seven mid-air collisions occurred. Twenty-four lives were lost and resulted in a material loss of about two and a half million dollars. At that time it was necessary to have as many as 750 aircraft airborne at one time. Sufficient concern was shown and actions were taken at Fort Rucker to have developed an airborne proximity warning device.

Several manufacturers at their own expense from the "State of the Art" put together black boxes and brought them to Fort Rucker. They were evaluated by the Army Aviation Test Board at Fort Rucker and the best unit was selected. The manufacturer was then asked to produce several sets which were further tested in the Apalachacola, Florida area.

Twenty-two hundred of these devices have been installed on Army aircraft, and since their installation there have been no mid-air collisions. The device has adequately warned on many occasions. It is capable of providing pilots with selectable warning ranges of 1,000, 3,000 and 5,000 feet omni-directionally in azimuth. It also provides warnings 300 feet above and 300 feet below the aircraft, telling you the intruder is above, at or below your altitude. It will also tell you if he is right or left of your center line, in front or to the rear of your position. Should a second intruder invade your surveyed air space, it will show you the quadrant in which he is located. It is possible to obtain this coverage with antennae patterns so that no point in azimuth will display nulls or depressions sufficient to degrade the required warning ranges. An audio warning is also generated and injected into the intercom whenever an intruder penetrates the protected airspace volume.

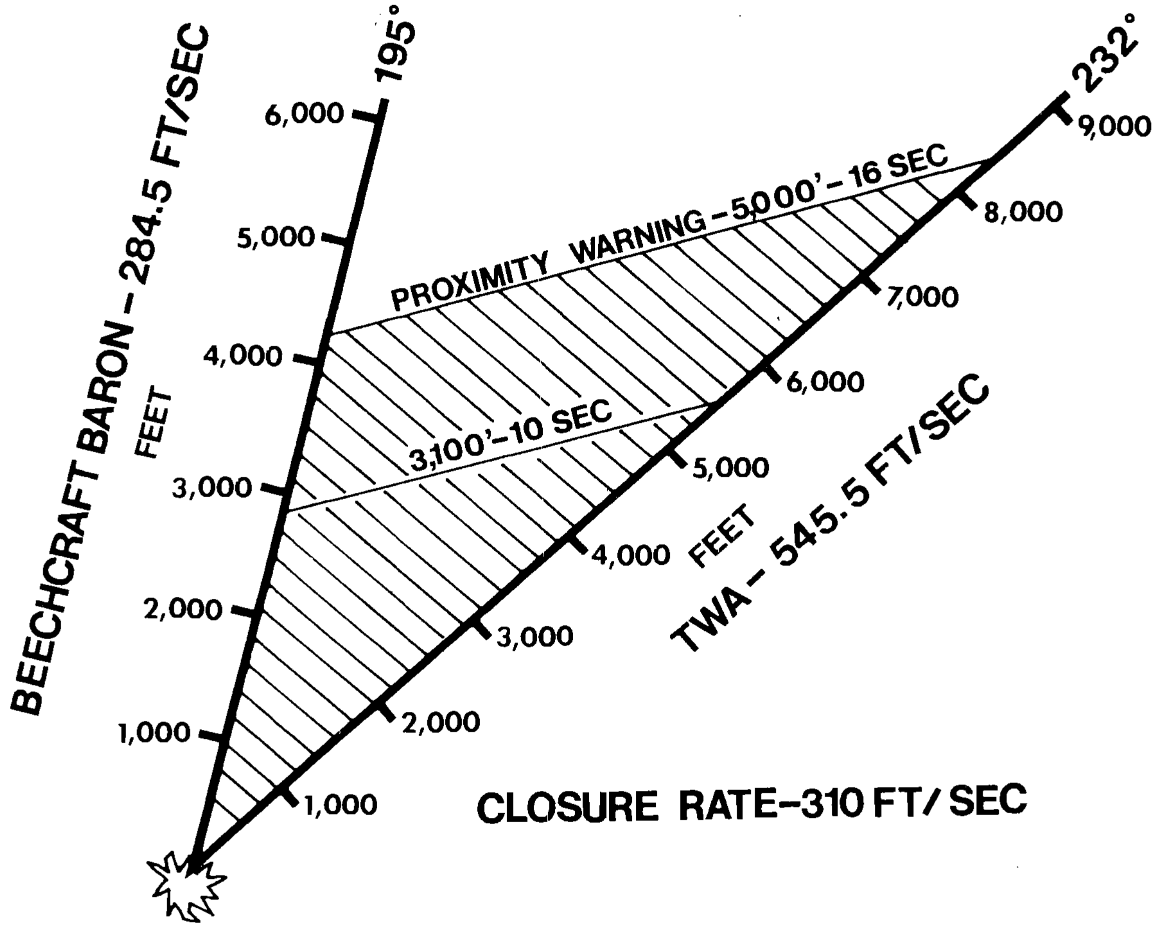
On a simple pilot questionnaire distributed in December 1971 to 222 instructor pilots, 203 were returned, 100% indicated that the proximity warning device created no interference with their training. Forty-two indicated that the device had prevented them from having at least one mid-air collision. We can't say that forty-two mid-air collisions were prevented. What we can say is that in forty-two cases the pilots were alerted of a possible mid-air collision. In the Senate Sub-Committee meetings held on November 2 and 3, 1971 the price of this device was given in the range of $650,000 to $850,000.

On July 23, 1969, John H. Reed, then Chairman of the National Transportation Safety Board, wrote to John H. Schaffer, Administrator of the Federal Aviation Administration: "We therefore recommend that the Federal Aviation Administration support the expeditious development of low cost collision avoidance systems for all civil aircraft."[15] The answer from Mr. Schaffer on September 9, 1969 was that the "FAA is actively cooperating with the ATA Collision Avoidance System program. Man-power and test facilities are being made available to test all new items---." A similar recommendation was made by Board Chairman James B. King on October 27, 1978, before a joint hearing of the Senate and House.[3]

Transport Mid-air Collisions

Except for Grand Canyon most of the transport mid-air collisions have occurred in good visibility at an altitude below 5,000 feet, and usually with a descent and possibly a turn involved. Reduced speeds for approaches have been

BEECHCRAFT BARON/ TWA
MARCH 9, 1967 URBANA, OHIO



set up. The worst spot for a mid-air potential for our current jet aircraft is to have a target in front and below. The closure rate has been much lower than the cruising speed of either aircraft in most cases.[16]

Charts have been prepared of the air transport accidents at Urbana, Indianapolis, Whittier and San Diego where the pilots would have had a minimum of five to fifty-one seconds' warning prior to impact. If we care to look back to the Grand Canyon accident, this device would probably have provided at least eight to twelve minutes' warnings of the impending collision.

Urbana Mid-air

The first accident to be discussed occurred March 9, 1967, twenty-five nautical miles northeast of Dayton municipal airport, near Urbana, Ohio. The collision was between TWA 533 and a Beechcraft Baron B-55. There were twenty-six fatalities.

The TWA flight was descending from 20,000 feet to 3,000 feet at a rate of descent of 3,500 feet per minute on a heading of 232°, with an airspeed of 323 knots. Visibility was five to six miles. (See Urbana chart)

The Baron aircraft was on a heading of 195° in level flight at 4,500 feet MSL with an airspeed of 194 mph.

Dayton Radar Approach Control had established radio and radar contact with Flight 553 one minute and fourteen seconds prior to collision. The Baron was detected by the radar controller twenty-five seconds before collision. An advisory was immediately issued, "TWA five fifty three, roger, and traffic at twelve thirty, one mile, southbound, slow moving". The captain of flight 553 acknowledged, "Roger". The collision occurred fourteen seconds later.

To look at the scaled chart of this accident, both pilots would have had a warning in excess of five seconds of the impending near-miss or collision. The time of warning would have been shortened in this case because of the 3,500 feet per minute (58.3 feet per second) sink rate of the DC-9. The warning would have told the flight crew of Flight 553 the intruder was "*below, in front* and *to the right*". According to the Board conclusion and findings "Approximately five seconds should have been sufficient to detect the target and initiate a change in direction of the DC-9."[16]

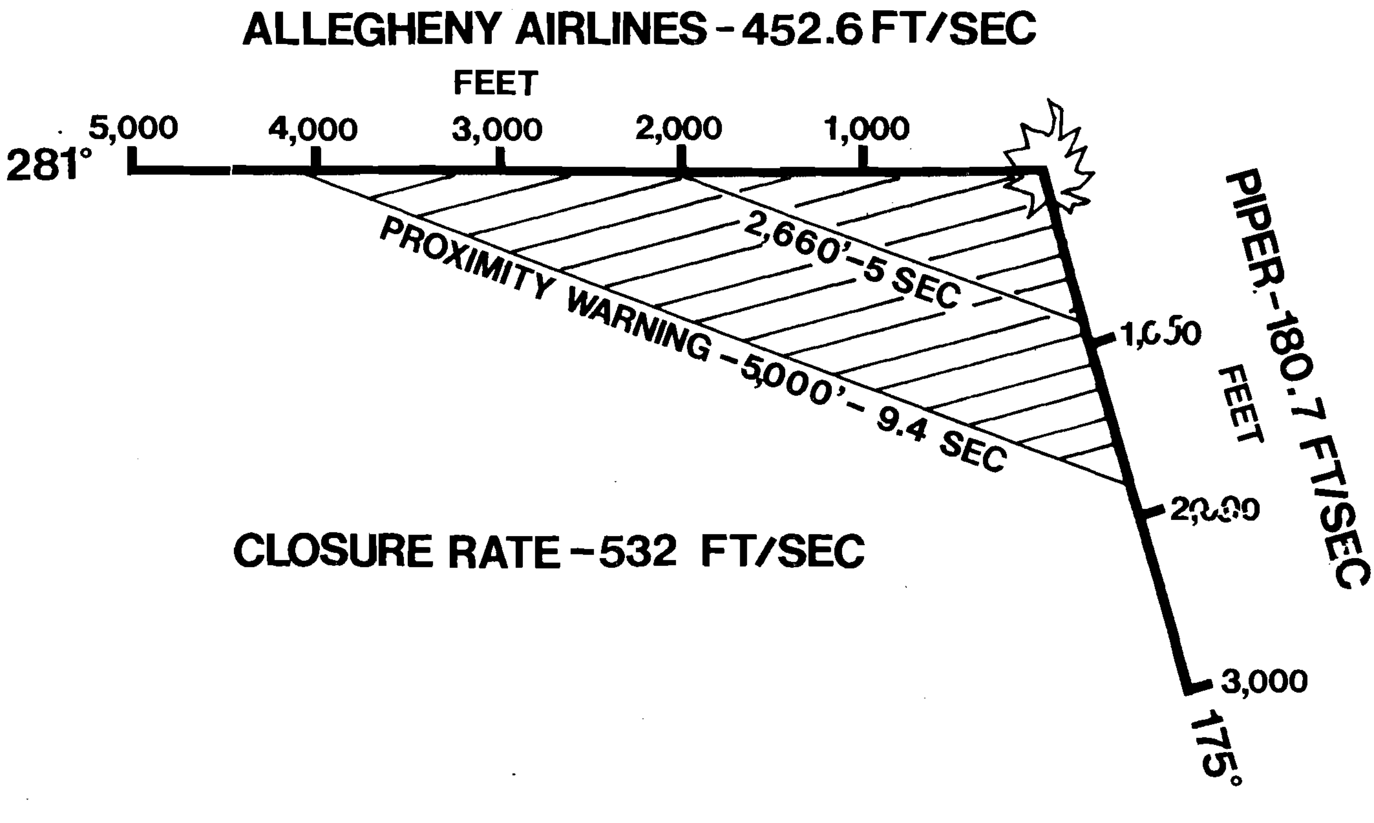
The Baron pilot would have had an "*above, to the rear, to the left*" warning.

Fairland Mid-air

This accident occurred near Fairland, Indiana on September 9, 1969. It involved an Allegheny Airlines DC-9 and a Piper PA-28. (Fairland Chart) There were 83 fatalities. The DC-9 was on a heading of 281° at 268 knots, descending at 2,460 feet per minute, from 6,000 feet to 2,500 feet under positive radar control. Visibility was at least fifteen miles. The PA-28 was on a heading of 175° at 107 knots in level flight and was not detected on radar[16] so therefore, no traffic advisory could be issued to the DC-9.[18]

The aircraft's lateral rate of closure computes about 460 feet per second and vertical closure at 41 feet per second. Had the developed device been used there would have been in excess of nine seconds on the horizontal warning and 7.3 seconds on the vertical warning for each aircraft. According to NTSB this is ample time for a DC-9 crew to take necessary evasive action. The Board determined, "the probable cause of this accident to be the deficiencies in the collision avoidance capability of the Air Traffic Control (ATC) system of the Federal Aviation Administration in a Terminal Area wherein there was mixed Instrument Flight Rules (IFR) and Visual Flight Rules (VFR) traffic."

ALLEGHENY AIRLINES / PIPER
SEPT 9, 1969 FAIRLAND, INDIANA

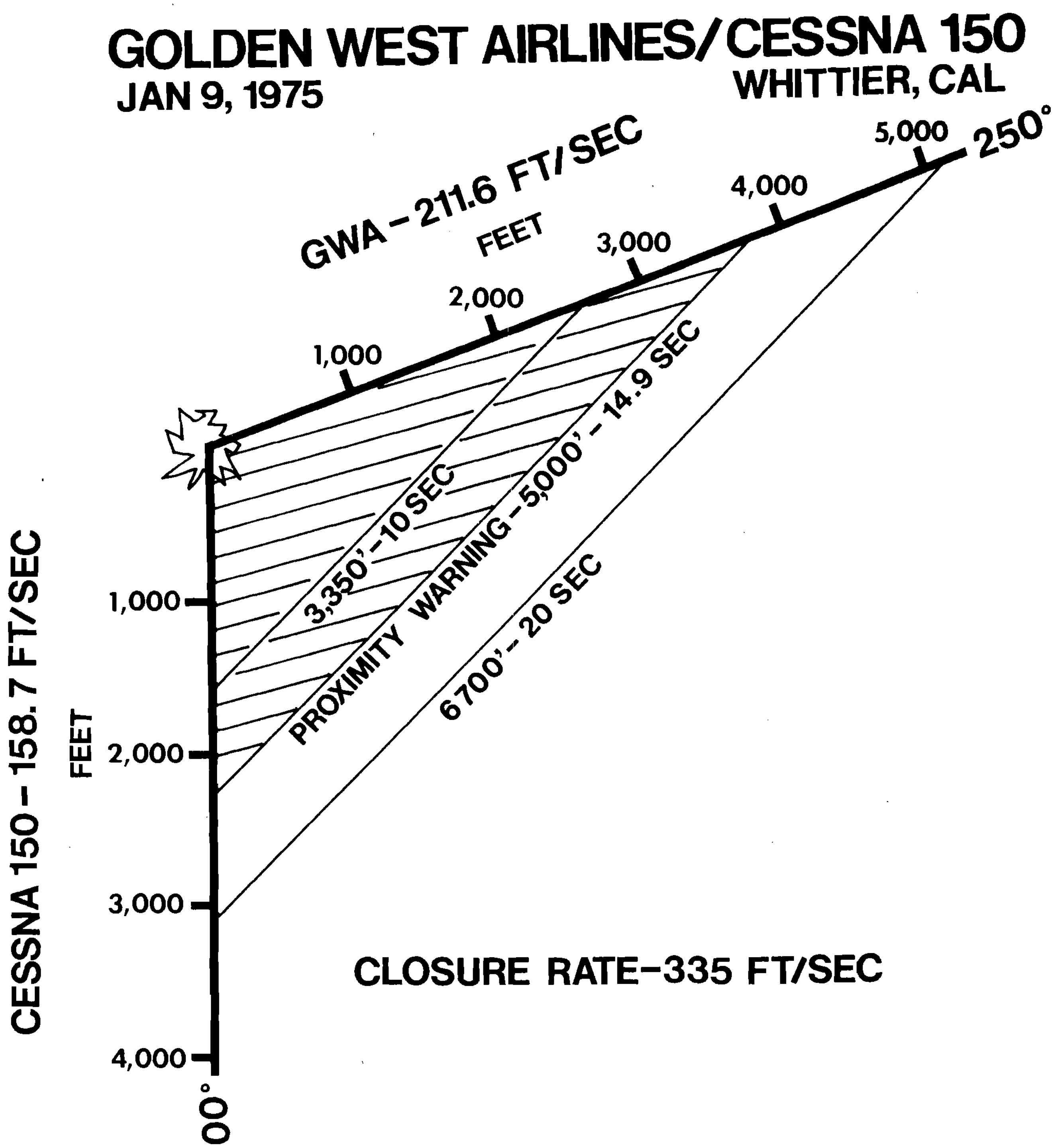


Whittier Mid-air

This accident was Golden West Airlines Flight 261 and a Cessna 150. It occurred near Whittier, California, on January 9, 1975, and there were fourteen fatalities.

Flight 261 was descending from 2,800 feet to 2,200 feet on a heading of 250°. His airspeed was 150 knots and rate of descent was 315 feet per minute. The aircraft was in radar contact and was cleared for Los Angeles Terminal Control Area (TCA) No. 2 arrival to runway 24 Left. Arrival radar gave Golden West three traffic alerts on a northbound police helicopter but never reported the Cessna 150, which was also northbound at 94 knots.[19]

The closure rate of the two aircraft ws 342.5 feet per second horizontally and 5.25 feet per second vertically. This would have given about a fifteen second warning to the pilots horizontally and a fifty-seven second vertical warning, had the proximity warning device been in use. (Whittier Chart)



San Diego Mid-air

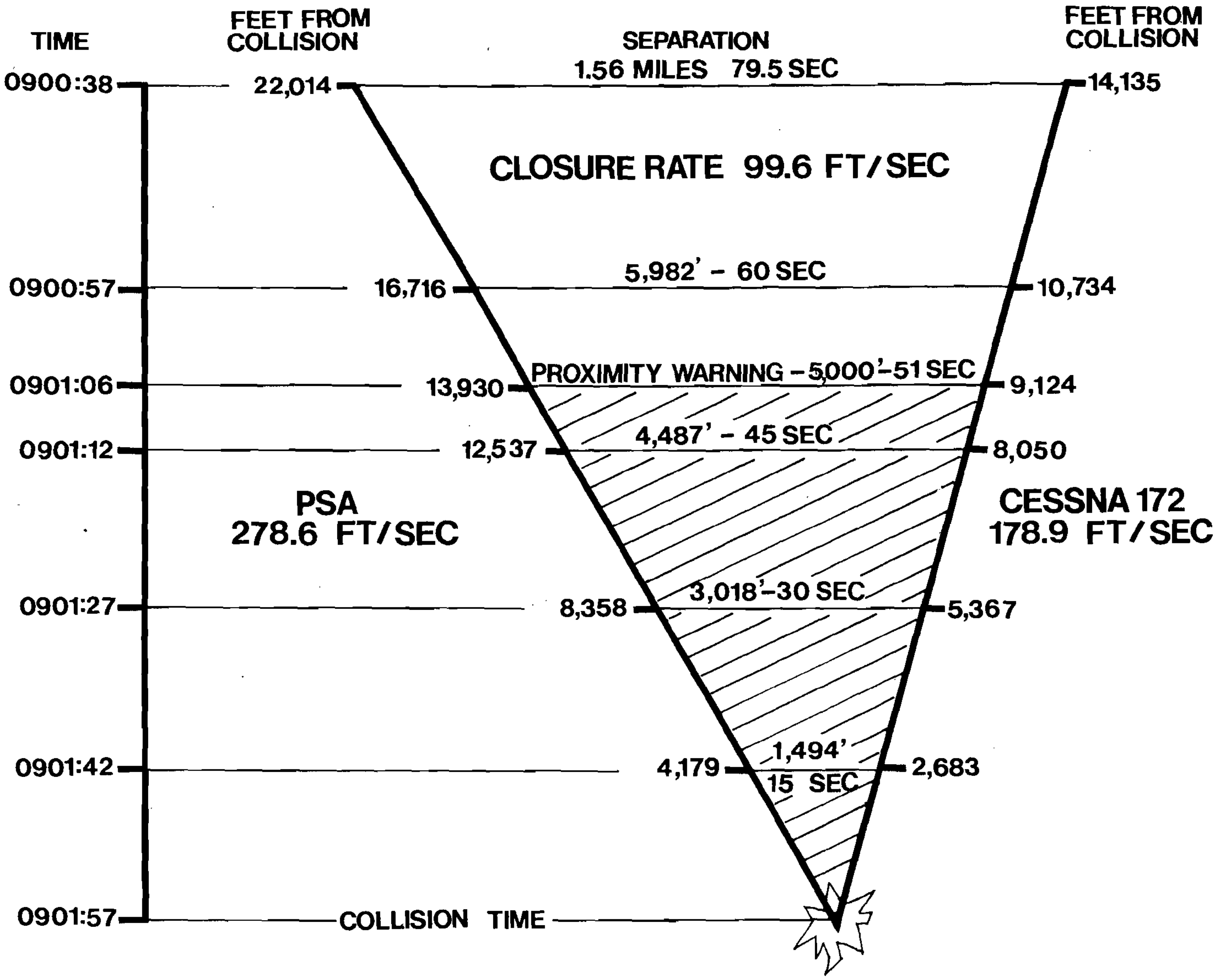
This accident needs no introduction. It occurred at San Diego on September 25, 1978. There were 144 fatalities and it involved Pacific Southwest Airlines, Flight 182, a B-727 and a Cessna 172, belonging to Gibbs Flite Center, Inc.[20]

PSA Flight 182 was descending at a rate of about 450 feet per minute on a heading of 090° at an airspeed of 160 to 165 knots. Visibility was ten miles.

The Cessna 172 was also on a heading of 090° at an estimated airspeed of 122 miles per hour.

The approach controller gave several traffic advisories and cleared Flight 182 for a visual approach to runway 27. Approach Control transferred Flight 182 to the tower one minute and twenty-four seconds before collision. The tower, at one minute and nine seconds prior to collision, said "PSA

PACIFIC SOUTHWEST AIRLINES/ CESSNA 172
SEPT 25, 1978 SAN DIEGO, CAL



182, Lindberg Tower, ah, traffic twelve o'clock one mile a Cessna". Forty seconds prior to collision the tower cleared Flight 182 to land, which was acknowledged by the Captain. At this point the aircraft would have been separated by less than 4,000 feet horizontally and 300 feet vertically. The horizontal closure rate in this accident was 99.7 feet per second while the vertical closure rate was 7.5 feet per second. Utilization of the Fort Rucker proximity warning device would have provided the pilots with a fifty-one second lateral or a forty second vertical alarm, more than ample time for suitable evasive actions by both flight crews.

The state of the art has been here for many years; it is here today and it will be here tomorrow to provide light weight, relatively low cost mid-air collision prevention devices. The device mentioned here is not considered by this writer to be the optimum, but it does prevent mid-air collisions. It has been developed, tested and proved effective over the past 13 years.

We have without a doubt the finest air traffic control system in the world. It is obvious that radar on occasion does miss target, how often we do not know. The "see and avoid" concept is antiquated will not prevent mid-air collisions. To enhance the radar coverage with a proximity warning device will eliminate almost all mid-air collisions.

The devices will cost a considerable sum of money. The four accidents reviewed here have cost a considerable sum of money. To have optimum effectiveness a unit must be placed on each registered aircraft in this country. Today there are about 200,000 registered aircraft.

Financing

Who should pay for this purchase and installation, which will probably cost several hundred million dollars? This author suggests that it be paid from Trust Fund monies, or over the next several years by the individuals, groups or companies needing protection (or insurance) against mid-air collisions. Let's start with the three hundred million passengers who will be riding our commercial airlines this year. Then followed by the airlines, the one hundred and eighty seven thousand owners of general aviation aircraft, and their underwriters. If done on a fair share basis, the cost will not be too large for any one segment.

After all existing registered aircraft are equipped, then it should become part of standard equipment on all new aircraft. A program such as this should include but not be limited to FAA, NTSB, AOPA, ALPA, Airline Passengers Association, aviation underwriters, manufacturers, and the Air Transport Association.

Conclusion

Fatal aviation accidents and their high associated costs can be greatly reduced. It will take an honest joint effort of all segments of the industry. It is recommended that the aviation underwriters assume an active posture as Chief of Aviation Accident Prevention with sufficient concern by all segments to become committeed and not just involved.

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Biography

Bill Gaines received a BS Degree (Math & Science) from Pennsylvania State College in June 1940, completed Navy Flight Training May 1941, and served in the Navy until 1946, attaining the rank of Lt. Commander. He entered full-time accident prevention work in 1951 as a Safety Engineer at the Chemstrand Corporation, Pensacola, Florida, and later as Chief of Accident Prevention Office, U.S. Army Aviation Center Fort Rucker, Alabama, until retirement in 1972. From 1974 to date he has been involved in accident investigation, reconstruction, analysis and research for law firms as a consultant.

Luncheon Speaker Frank McGuire

Bob McMeekin, M.D.

"How Important Is Safety Education?"

George B. Parker MO0999
Associate Professor of Safety
Institute of Safety and Systems Management
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Los Angeles, California 9007

Competence of the Investigator— Back to Basics

The time seems to be opportune for criticism of civil aircraft accident investigation. Ira Rimson, editor of the International Society of Air Safety Investigators (ISASI) ***forum*** informs us that the recent Air Law Symposium at Southern Methodist University included at least five speakers who presented opinions and evidence very critical of the government air safety investigations. Rimson continued, telling us that we should be aware of the fact that:

> "The perceptions among the knowledgeable public are that accident investigations, especially pertaining to general aviation, are superficial, inadequate and, as often as not, inaccurate. No matter how we cut it, that perception reflects adversely on the professional reputation of us all."[1]

We see the same criticism evident in the C. O. Miller petition to the National Transportation Safety Board (NTSB), which says that:

> "Unfortunately, in recent years the system [NTSB]...has deteriorated....The Board's aviation investigations...leave very much to be desired. This criticism applies primarily to general aviation cases...with the condition becoming less apparent as one goes up the scale towards major inquiries..."[2]

The investigator is the most basic element in the system and most of the criticism is directed towards him and his competence. Many ISASI members are concerned about this problem and have contended that there is a need to establish investigator standards to deal with a lack of quality in investigation.

Both Rimson and Miller feel that the problem of investigative quality rests more with general aviation accident investigation than air carriers. This feeling is widely agreed upon by investigators and attorneys who are involved with litigation of general aviation accidents. Statistics support their view. Over the years, general aviation accidents and fatalities have remained relatively constant while air carriers have kept going down. For example, in 1980 the general aviation fatalities numbered 1,352 compared to 1,317 for 1979. In 1980 the air carrier fatalities dropped to 14.[3] From this point of view, the investigative effort produced very little in the way of aviation safety for general aviation.

Despite the record of air carrier safety, there have been many who have expressed concern for the effectiveness of some of those investigations, particularly in the determination of probable cause. The author has discussed some of these problems in past papers[4,5,6]. This paper will seek to identify the problem with aircraft accident investigation, examine the problem, and offer what is felt to be the only effective solution.

The Need for Knowledge— Back to Basics

The state of the art has been offered as the cause of the problem of investigative quality. Many feel that the sophistication of today's aircraft is where the problem lies. There is no doubt that the airplane and its systems have become more complex. But to identify that as the problem with investigation is to ignore the concept of *root cause*, a concept we preach but do not practice very often.

The root cause of dealing with the changes and complexity of today's aircraft is not the changes and complexity but the obvious ignorance on the part of the people doing the investigation. Ignorance is a void in knowledge. Both Rimson and Miller have identified the lack of knowledge as a factor in the investigation problem. Rimson mentioned this when he told us:

> "Our profession is no different from others; it takes continual education, training and study to

> stay abreast of the state of the art. Investigation is as much as intellectual exercise as a mechanical skill...."[1]

It may seem a moot point, whether the problem lies in the state of the art or in the ignorance. In this case, the sophistication is the effect—to be dealt with—while ignorance is the cause. Man uses knowledge to overcome his ignorance. All men are ignorant about that which they do not know.

To know one's ignorance is the best part of knowledge.

Lao-tsze
(500-600 B.C.)

The investigator, like the pilot, must know his limitations. The managers of the invetigation must know the limitations of their people—both investigators and technical advisors. Above all, the need for knowledge—the need for education—must be realized and satisfied. Knowing that one must increase his knowledge to meet the changes and challenges of aviation is a very basic investigative requirement. If we wait until we have an accident to investigate to realize that we have a deficiency in knowledge—ignorance— we will always be behind the times and ineffective. Worse yet, to proceed in one's ignorance, trying to prove something you are ignorant about, is futile and counterproductive.

The competence of the investigator is judged by his level of knowledge. Correspondingly, the success or failure of the investigation will be determined by either the investigator's knowledge or ignorance.

Dealing with Ignorance—Back to Basics

How important is education? Education is man's way of dealing with his ignorance. He does this by (1) formal education, (2) experience, and (3) continuing education. To be competent an investigator will have to use all three methods.

The greatest drawback to ignorance is that one often does not realize his lack of knowledge. For reasons of pride and ego, a person will become complacent in his ignorance and not realize his deficiency. We have all had the experience of trying to deal with a person who, in his ignorance, is highly opinionated. The greater his ignorance, the more opinionated he is. This is a characteristic that can overtake an investigator. Through luck or simplicity of circumstances he is successful as far as his limited knowledge takes him. But he will eventually encounter accidents that are not simple and which do not match the circumstances with his knowledge. Rather than getting the qualified help he needs, he will muddle on, often finding nothing of significance, or, dwell in his vast resource of ignorance and make the evidence fit improper conclusions.

To be ignorant of one's ignorance is the malady of the ignorant.

Amos Bronson Alcott

Unfortunately, there are people investigating accidents who meet only the minimum requirements of competency. There are others who have had some education and/or experience, but who resist the need for further knowledge. They use their ignorance as a defensive shield. The greater the need for knowledge, the larger the shield becomes.

To be sure, being intellectual doesn't mean one will become a good investigator. Knowledge is very important, but one can be educated and be lacking in other requisites that make one adaptable to investigation. The person will need intelligence, inquisitiveness, perseverance, common sense, a reasonable level of mechanical aptitude and logical reasoning, and the strength and stamina to endure some of the hardships. But, even with all those attributes, you cannot succeed without knowledge.

An interdisciplinary process. At the Fourth Annual ISASI Seminar, Toronto, Canada, 1973, George Saunders presented a paper that created a lot of press interest and a great deal of consternation among ISASI members. The press quoted George as saying:

> "In many cases, clients, unknowingly, are being seriously let down by either incorrect analysis of physical evidence, or, more often, by a cursory interpretation of physical evidence in favor of other areas in which (the investigators) are more familiar, such as operational and piloting factors."[7]

George felt that the minimum requisite for an aircraft accident investigator was a bachelor's degree in engineering. He had obviously encountered the work of non-engineers who had ignored technical evidence or misused it. His reference to piloting factors would indicate that he felt investigators with pilot experience were prone to find pilot factor as the cause in an accident that involved technical problems. Pilot factor just happens to be the favorite non-supported cause and would indicate that Saunders was right. Of course, any determination of cause without evidence is wrong.

Eight years later, the critics of investigation have again brought up the fact that most general aviation investigations lack qualified technical analysis. If this deficiency concerned only engineering it would be rather easy to rectify. Actually, investigation encompasses numerous specialty areas. To be complete and effective investigation must include the analysis of any and all disciplines that could have contributed to the accident. Investigation is not the sum of one man's experience. Investigation is an interdisciplinary process. A list of the disciplines involved would include:

Pilot experience
Operations/training
Environment
Maintenance
Aerodynamics
Design engineering
Manufacturing/quality control
System safety engineering
Structures/metallurgy
Power plants
Flight control systems
Electrical/electronics
Fuel systems
Oil systems
Hydraulic systems
Chemistry
Oxygen systems
Pressurization systems

Pneumatic systems
Communications/navigation
Instrumentation systems
Air traffic control
Flight data/cockpit voice recorders
Aviation medicine
Pathology
Psychology
Human factors
Life sciences
Witness interviewing
Airfield/ground safety
Fire/explosion analysis
Wreckage recovery/preservation
Wreckage reconstruction
Investigative analysis
Computer simulation
Records and statistics
Rules and regulations
Documentation of evidence
Photography
Report writing

The above list is not complete; it only begins to identify the various disciplines that become involved in an investigation. In many of the areas listed there is further specialization that would expand the list. No one can become or remain competent in very many of these fields. It is obvious that an engineer cannot handle all of these involvements, nor could a pilot.

Formal education. The quickest and easiest way to gain a lot of knowledge is by formal education. Formal courses can often cut years from the time it would take an ordinary person to gain that much experience. Most formal courses in accident investigation are interdisciplinary. Unfortunately, most of them are short courses and cannot qualify the graduate to be an aerodynamicist, a flight surgeon, and a wreckage analyst in two weeks. These courses concentrate upon the investigative procedure and provide the principles and basics of the interdisciplinary areas. Courses can be taken that deal just with a specialty within a discipline. For example, most universities offer courses in metallurgy, chemistry of fires, statistics, etc. Specialized formal education can be taken that will provide certain kinds of knowledge used in accident investigation. Some of these courses are part of degree programs, some are not. The information is there if you seek it out. Thirsting for knowledge is not enough, you must drink from the cup.

Experience. You have to practice your art to become proficient. Just as a pilot must stay proficient, so must the investigator. Investigation is a practical concept that improves with use.

There are many successful investigators who do not have college degrees; some who have never attended a formal short course. They learned the trade by hard work and experience. There is nothing wrong with this approach.

Experience is a good school, but the fees are high.
Heinrich Heine

The only problem with experience is that it takes so long and it is difficult to direct your efforts to fulfill the knowledge requirements in a changing world. And at some time or another everyone runs out of experience. If one expects to rely on experience, one must understand that repeating the same experience over and over does not provide much education or new knowledge. To be useful, experience must teach us. We must learn from it.

Continuing education. The need for continued education is obvious. New knowledge is required to meet new and differing investigative situations. This could be a new or different kind of airplane, a fly-by-wire flight control system, a variation of environment, the need for special technical analysis, or a human factors evaluation. It is necessary to be prepared to fil the ignorance gap, and it is getting more difficult to do just that. It is even more difficult for one man to deal with the entire investigation. Unless one spends a lot of time in obtaining new knowledge, he will find himself restricted to only certain kinds of investigation.

Knowledge is of two kinds. We know a subject ourselves or we know where we can find information upon it.
Samuel Jonson

The true expert is a learner. The more competent the investigator, the more he will supplement his store of knowledge. He will seek out and attend pertinent formal courses, read every applicable book and publication, attend seminars and workshops, consult with other experts, and do whatever research he has the time and means to accomplish.

The competent investigator is a *learner*. He enjoys finding out about new concepts, facts and techniques. He will do anything reasonable to resolve the evidence leading to the determination of root causes. By definition (Webster), an investigation means to search into, examine in detail, uncover facts and determine the truth. It can be seen from this definition that ignorance seldom leads to the truth.

It was the author's recent pleasure to spend many hours discussion investigation with H. V. LaChapelle of the General Electric Company. Vince LaChapelle is considered by reputation to be the most experienced turbojet engine accident investigator in the world. He has completed over 200 investigations. With that much experience a man develops a philosophy about his work. Vince, above all, seeks out the truth. He feels that too often a cause is determined by arranging circumstances to fit conjecture. He says that:

> "The greatest obstacle any investigator will encounter...is his own eagerness; the eagerness to accept a result as a cause or contributing cause factor. It has been written, 'A cause undetermined should be considered a personal defeat'. To this I state 'MORE NOBLE IN PRINCIPLE IS A DEFEAT THAN THE ASSIGNMENT AS FACT A SPECULATIVE OR ERRONEOUS CAUSE FACTOR'."[8]

It is interesting that a man with so much experience would impress you with his desire for knowledge. You would think that he has done it all and would not need to keep searching. But LaChapelle is an inveterate learner. His eyes light up when he tells you about something new that he has discovered. He gets excited about some new facts he has learned from someone else. As the true professional, he does not profess to know it all. He continuously seeks out new knowledge to fill in his ignorance gaps.

To know that we know what we know, and that we do not know what we do not know, that is true knowledge.
Henry David Thoreau

When you have spent most of your eighty years in aerospace safety, and done about everything there is to do in the field, you would think that you wouldn't have to bother to learn any longer—or that there isn't anything else to learn. But Jerome Lederer is a learner. Despite his advanced years and reputation he is eagerly learning all the time. He is certainly a model for all investigators to emulate.

After nineteen years spent in the classroom teaching aircraft accident investigation, the author can fully appreciate the old axiom: "Who teaches, learns" (Anonymous). The more you seem to learn, the more you realize how much there is to learn. Of the many thousands of students who have studied in your class you form opinions about people and learning. The closed minded student is usually the one who feels he knows it all and who is usually the most ignorant. The most experienced student is the one who learns the most. He probably knows what to expect, understands that he doesn't know everything, and wants to learn.

It is only the ignorant who despise education.
Publilius Syrus

The Value of Education—Back to Basics

Up to here, this paper has discussed proof that education provides the investigator with the knowledge necessary to combat ignorance. Education needs to teach certain basics that are essential to know. Whatever type of education is used, the following must be learned.

1. *The purpose of investigation is prevention.*

Prevention: the most basic of all investigation criteria. It is the most fundamental, the most agreed upon, the one that no one seems to argue with. Yet it is the most ignored and misused of all investigation concepts, even in the most severe disasters. Prevention is the objective; the purpose of the investigation. It is the product of the investigation process. With this objective, the investigation takes on character and sincerity. It is truly altruistic.

The prevention oriented investigation is distinct from that conducted with the purpose being to determine responsibility for the accident or to recover damages. This is why the U.S. Air Force has been so successful in its flight safety program. In spite of operating high performance aircraft on hazardous missions, the Air Force has been able to achieve and sustain very low accident rates[9]. The Air Force mishap investigation program is directed to prevention of future mishaps and absolutely nothing else.

A few months ago the author met with an NTSB field investigator who had graduated from one of his military classes many years ago. He was emphatic about his different approach to investigation, compared to most of his contemporaries. He felt the difference was simply in the fact that he was taught to prevent accidents—a concept he, at first, assumed everyone in accident investigation understood. When he became a civilian investigator he noticed a lack of motivation and little sense of purpose among other investigators. Very few of them had had his type of formal safety education. They were often satisfied with less than the truth and did not seek out the real causes.

"When there's a will, there's a way."
George Bernard Shaw

The concept of prevention is the most important of all investigation basics. The investigator's education must include this philosophy. With an understanding of it he will have the motivation to success. Some people come by this understanding on their own. It should be provided others by education. Education without it is shallow and cheats the student. With the right motivation a person will find it much easier to fulfill his other needs for knowledge.

Attorneys often defend litigation as a very effective method of preventing accidents. In certain cases this has been true; if it had not been for the lawsuit some accidents would still be happening. The litigation in those cases determined what the cause was and the high cost of damages resulted in correction of the problem. Tom Davis presented a paper at the San Francisco Pilot Factor Symposium that told about several cases of litigation resulting in the correction of serious cause factors. One of these, the Baron flat spin problem, resulted in more than twenty-two accidents and went on for over ten years.[10]

Everyone should be disturbed when a problem lasts so long, and finally has to be identified and corrected by the legal rather than the safety system. This denounces the civil investigative and regulative agencies. And we certainly cannot depend upon the law to prevent our aircraft accidents for us. The courts are so slow it would take forever to prevent accidents. It took the legal system ten years to crack the Baron problem. That is way too long, even if it did work.

Perhaps, someday, the right people will understand that investigation failure contributes as a cause of accidents just like any other cause. If it fails to do its job, the accident will continue to repeat itself. The public trust ends up violated. Wouldn't it be better to make the system work than to turn it over to the courts?

2. *Investigation is a process.*

There is nothing very complicated about this basic. To be effective an investigation must involve a careful, accurate and thorough process of evidence being recovered, documented and analyzed. The investigators who work in support of litigation are often critical of the government investigation field reports that they must use as a source of evidence. They complain that the evidence often has not been recovered, has been lost and/or has been altered by careless handling. Diagrams are often inaccurate and lacking in details. Photographs are of poor quality, seldom document the right evidence and are too few to properly cover the evidence. The list goes on and is an indication of a lack of a proper investigative process. It is a methodical process that does not guess or jump to conclusions. Analysis is accomplished after the evidence is collected and accurately documented. Many erroneous causes are determined by just plain sloppy procedure.

3. *Determine the root causes.*

A review of most civil accident reports, both general aviation and air carrier, show a serious lack of understanding of what a root cause is. The function of the investigation should include asking *why*, and keep asking *why* until it is not necessary to ask it anymore. Most accident reports don't even answer the first *why*. They seem well satisfied with answering *what*. Prevention is not possible without knowing why the accident evolved. If it were a human failure, it is essential to know why the human did or did not do what he did, it is not that important to know only that he did or did not.

The author provided the theme for the semiannual symposium of the San Francisco Chapter of ISASI. It became the Pilot Factor Symposium and was directed toward the truth about pilot factor. The author's paper presented statistics showing that pilot factor was determined to be the cause of over 50 percent of air carrier accidents and around 85 percent of general aviation accidents.[11] These causes repeat over and over, indicating that they produce little prevention. The reason being that pilot factor is an act, not a root cause. Until the investigations determine *why* the pilot acted as he did, pilot factor causes will be unproductive.

If the pilot factor problem could be resolved, aviation safety would make a significant advance. The finding of pilot factor is bad enough, in itself, but to allow it to continue is evidence of how strong is the ignorance in civil investigation. There is a crying need for education about this subject.

Trial attorneys may boast about the corrections of safety problems through litigation. Those corrections are almost all in the area of product liability: material or technical problems. Litigation has had little or no affect upon the pilot factor caused problems.

4. *Apply the lessons of history.*

Learning from his mistakes has been basic to the education of man since the beginning of time. Unfortunately, this truth is not apparent in aviation safety. It is a mistake to treat an accident as a one-time event rather than as part of a continuum of well established repeat causes. Each year the NTSB publishes a list of the ten most prevalent causes of general aviation accidents.[12] The list is the same every year; even the order of listing is pretty much the same. They prove that they are part of a continuum. The repetition is also proof that the investigation system is not producing prevention.

We should not have to be told that today's accidents are nothing more than a reflection of yesterday's. Today's accidents are caused by the same problems as yesterday's—one year ago, ten years ago, even twenty or more years ago. It is but yet another fact that means we have a problem larger than any one accident cause. Santayana was right. We are ignoring the history of our problems and we are repeating our mistakes, over and over and over. The only difference is that now, investigation is one of the mistakes.

5. *Obtain and use new knowledge.*

Saunders was wrong when he suggested that engineering would rectify all of our investigation problems of competency. True, the cases he was referring to needed better technical expertise—still do need it—but the technical involvement in accidents is small compared to other areas that also need better expertise.

The predominance of pilot factor accidents points out the lack of expertise in dealing with their root causes. Human factors is finally becoming recognized as an important aspect of aircraft accident investigation. A great deal has been learned in this area in recent years. But little of this research has been implemented into civil investigation. In fact, there is evidence of resistance to the involvement or use of human factor investigation and analysis.

Concerned airline pilots like William Price have spent years learning about the human factor problems that apply to accidents and trying to get appropriate agencies to listen. Price, Dr. Daniel Holley (San Jose State University), and Dr. Charles Winget (National Aeronautics and Space Administration) all presented papers on human factors to the Pilot Factor Symposium.[9,14,15] The specific work being researched by these men has to do with the reasons why pilots make the mistakes that they do. Their work is also being studied by the U.S. Air Force and NASA, both of which are involved in multi-million dollar research projects into these areas. The Air Force School of Aerospace Medicine is very much interested in the human factors causes of accidents.[16,17] The Air Force now has a special human factors team that is sent to participate in any accident that indicates a human factors problem as causal. In many of these investigations the determination of cause was significantly changed as a result of human factors recognition.

One of the major contributions of the human factors investigation is that it finally provides a method of dealing with pilot factor. It should be carefully noted: pilot factor and human factor are not the same. Human factors is the study of why humans make mistakes and how we can prevent recurrence. Whereas, traditionally, pilot factor has to do with identity of who performed the act involved in the mistake and not why the mistake occurred or what induced it. We cannot deal with pilot factor as a *what*, except to strengthen supervision. If there was a lack of supervision apparent, this is not the responsibility of the pilot, but that of whoever does the supervising. If there was a lack of proper supervision, then the cause was not pilot factor but supervisory factor.

We can deal with the *why* behind pilot factor, which is human factor. If we know what caused the pilot to do something we have something to work on. It has to be recognized however, that correcting the causes of human error is not always well understood. But at least it gives us a tangible factor to deal with. The only thing that prevents pilot factor accidents, as individual failure of responsibility, is to bury the pilot and his mistake, or make a disciplinary example of him. Neither of these alternatives is supposed to be part of the air safety investigation.

Except for some military involvement, the knowledge about human factors investigation rests with researchers. It is not being used in the field. The need for education of investigators with this knowledge is urgent. Particular attention should be given to the subjects of fatigue, circadian desynchronization, sleep loss and work shift changes, inattention and distraction. The areas cross over both physiological and psychological disciplines.

Human factors are involved in every accident, but involvement in four major air carrier accidents has been researched and found to be significant. Three of these were among the worst accidents of all time. All were determined to be pilot factor caused, by the respective government investigation boards. In fact, the pilot factor was so pronounced it could have the inference of pilot error. The accidents included:

1. Pan American and KLM 747 take off accident at Tenerife.
2. PSA/Cessna 172 midair at San Diego.

3. United Airlines DC-8 air freighter in Utah.
4. Western Airlines DC-10 approach accident at Mexico City.

All of these accidents had some common human factors involvement. All of them involved pilot fatigue, either from long work days or from shift changes. Air traffic control was involved in all four, contributing to two accidents as determined by the investigation board. Cockpit crew coordination was a concern in all accident.

A friend of the Western Airlines DC-10 captain had talked with him just six days before his fatal accident. He found him noticeably upset about the trip to Mexico City. He expressed serious concern about the approach to the airport and the hassle he usually received from the air traffic control. In addition, he was having enough of a problem with his crew that he had requested several times to have them replaced. He was concerned about their work and their compatability. His flight manager had promised to give him a different crew if he would fly this one last flight with them. Include these with the other problems he would have to deal with: a fog bound low visibility approach, an instrument letdown to a closed runway and a difficult transition to the parallel operating runway at an airport with a surface altitude of over 7,000 feet. On top of all this, the crew was fatigued from flying all night, landing at 0542.[18]

The scenario adds up to a sequence of events that is just right for a mistake and an accident. The inducement of the accident had to be one of human factors. What else would explain how a 31,500 hour pilot, who liked to fly so much that he owned a T-6 and flew for fun, made such a mistake?

The sad thing about this accident is that not one of these human factors were identified by the investigation board. As a consequence, they will not be dealth with; they will not be used to prevent other accidents. If such an experienced pilot can become the victim of such circumstances, how about the poor general aviation pilot, what chance has he?

Even sadder is the fact that all four of those major air disasters had to occur and that all of the investigations lacked the knowledge to deal with the human aspect identified as the cause of each accident. With the U.S. Air Force and NASA setting the pace, maybe there is hope for a change on the distant horizon—at least for air carrier investigations—general aviation will probably have to wait a long time.

> **"Educated men are as much superior to uneducated men as the living are to the dead."**
>
> *Aristotle*
> *(150 B.C.)*

The most effective—the only—solution to the investigation problem of competence is knowledge. How important is safety education? It is very important. It is the answer to the problem.

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Panel Discussion of C.O. Miller's Petition before the National Transportation Safety Board

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Chief of Investigation,
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Note: Mr. Roed did not provide written remarks. His paper published previously in this issue expounds the philosophies of the Swedish Board of Accident Investigation with regard to participation of parties in investigations in that country.

Background Remarks

C. O. Miller MO0343

I. INTRODUCTION

A. Back to basics . . .

1. Accident investigation as part of prevention
2. Credibility and effectiveness of recommended remedial actions depends upon the accuracy and completeness of investigations

B. The plight of the investigator all too often . . . and me today

II. THE PETITION

A. Forwarded by 13 persons Mar. 25, 1981

1. 10 members of ISASI
2. Highly qualified/experienced
3. Do not need the business

B. Concern for the adequacy of aviation accident investigations . . . especially general aviation

1. Significant accident prevention information is not being obtained
2. Rights of potential parties are not being protected as:

   a. Possible litigants (plaintiff or defense)
   b. Persons whose reputations may become damaged

C. The petition is in three parts

1. The basic text including "requested relief"
2. A sampling of illustrative cases
3. Biographical data of petitioners

D. The petition acknowledged today's:

1. Economic situation
2. Legal system
3. Practices by parties

E. The petition proposes (in the final analysis):

1. Certification of all non-NTSB persons permitted to participate in the field fact finding phases according to professional standards delineated by the Safety Board
2. Opening up participation during the field fact finding phase to such qualified persons from any source, still within the discretion of the IIC as to need and control
3. Communication of factual findings and such other related information as necessary in a timely manner to allow parties or observers to continue the investigation further beyond NTSB's need without the risk of evidence being lost or destroyed

III. HOW HAS THIS SITUATION COME TO PASS
(The diminished quality of NTSB reports and needed new approach)

A. The steady erosion of resources allocated to the NTSB's aviation accident investigation function in comparison to the job it has been asked to do (for nearly a decade)

B. The elimination of an independent accident investigation quality control function within the Board (1973-4)

C. The overall degradation of the aviation accident investigation function at NTSB by:

   1. Downgrading the aviation function literally as well as conceptually by the elimination of the Bureau of Aviation Safety
   2. Placing the "technical" chief(s) in a line reporting position to a non-technical, politically appointed General Manager
   3. Dilution of effort of the former senior aviation personnel who assumed broader responsibilities under the reorganization
   4. Emphasis on form rather than substance of investigations in the name of "productivity"

D. The awareness by manufacturers, the FAA and others of a constantly expanding exposure to tort liability

E. The failure of the Congress and OMB to ensure the non-dilution of the aviation accident investigation function as called for in the Act of '74 . . . either through resource allocation and/or oversight

F. The failure of the Safety Board to enforce its own rules to ensure objectivity in the fact finding process

G. The abdication of aviation accident investigation leadership by the Safety Board

   1. Limiting training and liaison of staff personnel with the aviation community (e.g. SFO ISASI)
   2. Failure to accept/promote "all cause" concept
   3. Use of videotape (had it in early 70s)

H. The apparent unwillingness of the Safety Board to seek advice from outside sources concerning Board operations or even reasonably consider unsolicited suggestions from qualified external sources. (e.g. the Downingtown meeting and ideas submitted by COM)

   NOTE: The responsibility for these Board shortcomings rests squarely with Chairman King and the other Board Members . . . They have been aware of these things-or should have been-since neither I nor others have been bashful about bringing such matters to their attention

IV. THE BOARD'S RESPONSE TO THE PETITION (Aug. 3, 1981 . . . totally negative)

   A. Never even held a Board meeting to discuss it!

   B. Basic theme . . . nothing has changed since 1959!

      1. Not even:

         a. Resource allocation
         b. Party participation in investigations
         c. Public awareness of accidents
         d. Tort law (e.g. what constitutes a report)

      2. The 1959 policy cited applied to hearings, not field investigations!

   C. Denies any role in lawsuits although:

      1. Every person/organization (especially every government employee/agency) has an obligation to avoid injustices to citizens
      2. NTSB personnel are already in it (e.g. Banks)

   D. Does not appreciate that litigation will actually decrease under the system proposed

   E. Does not in any sense acknowledge a problem exists re:

      1. Poor investigations
      2. Inadequate resources for job expected
      3. Injustices perpetuated consciously or unconsciously by existing parties (including the FAA)

V. CONCLUDING REMARKS

   A. What I and many, many others have seen:

      1. Accident prevention potential lost because of too many lousy accident investigations.
      2. Gross injustices to all parties at one time or another; i.e. to the manufacturers and the FAA let alone the pilots and operators (albeit more of the latter)
      3. Unnecessary litigation
      4. Degradation of the reputation of people whom I have respected in the past and whom I respect now . . . including several in this audience
      5. Destruction of the morale of many dedicated ASI's

         a. Some have left the Board in disgust
         b. Those remaining face the prospect of limited professional growth . . . and some damn fine people remain there. (Witness their presentations the other day)

   B. I don't like what I've seen and I've tried to do something about it:

      1. Several major writings:

         a. "The Public's Total Stake in Aviation Accident Investigation" ISASI, Arlington, VA, 1976 (Recall the recommendations?)
         b. Two papers made public through SMU
         c. The first was sent to the Board over two years age . . . no substantive response

      2. Have attempted to communicate personally with Board Members within ethical bounds on these subjects over the years with little or no positive response

         a. Possible exception on the human factors protocol (originally in 1974 or before)
         b. Last time was in anticipation of this panel
         c. Included a willingness to discuss alternatives

            - AOPA "safety officers" concept
            - Technical Advisory Command Center (Per NRC)
            - Others such as Bruggink's ISASI case review idea

      3. I initiated the petition to be sure; but . . .

         a. It contains many thoughts besides mine
         b. It also is supported by many persons whose employment does not permit them to endorse it publicly

      4. I have encouraged Congressional and media personnel to attend this panel discussion to hear for themselves whatever sides of the story anyone wishes to present.

C. I've gone as far as I know how to do now . . . or perhaps intend to . . . It depends, frankly, on the reaction to this meeting (though I will be speaking to AOPA next week)

D. My personal involvement notwithstanding, where to from here?

   1. New Chairman at NTSB
   2. New Administration policy of getting more of the private sector involved
   3. Court's resolution of the AMSI situation
   4. Depends upon YOU . . . it's your profession!

E. Let me close with a quote from Justice O. W. Holmes . . . and where you hear the term "law", substitute "air safety investigation profession" (or NTSB)

> I take it for granted that no hearer of mine will misinterpret what I say as the language of cynicism . . . I trust that no one will understand me to be speaking in disrespect of the law because I criticize it so freely. I venerate the law, and especially our system of law as one of the vastest products of the human mind . . . But one may criticize even what one reveres. Law is the business to which my life is devoted, and I should show less than devotion if I did not do what lies withinme to improve it.
>
> [Holmes, Oliver Wendall, *Collected Legal Papers*, at 174 (1920)]

Remarks

Joseph R. Bailey MO0821
President, Aerospace Management Services International Incorporated

I certainly do not wish to leave out the International Community of Air Safety Investigators and ISASI Members, and I have no intent of doing so . . . however, the subject I will be addressing will be directly applied to the situation existing here in the U.S. today. I feel that what we're seeing today will be forthcoming in other countries as the "legal picture" continues to develop. I know many of you are aware that two organizations have recently filed petitions with the NTSB in an effort to help clarify the meaning of certain regulations with reference to parties or participants to an accident investigation. AMSI, the company I'm associated with, has operated freely and with the board's approval since 1976 as representatives of certain manufacturers of products involved in aviation accidents. The board is now, as it has been for the last year and a half, trying to revoke that privilege, alleging that AMSI is also an insurance company and thus falls under the interpretation of their regulation 49 CFR 831.9(C). This I might add, is a re-evaluation of the original interpretation which gave us access to participate for our client manufacturers based on the decision of the Investigator in Charge. The Investigator in Charge still must determine: (1) need, and (2) expertise. AMSI was in 1976 and is now, a wholly owned subsidiary of United States Aviation Underwriters Incorporated.

At the time we were granted our "license" to participate in 1976, I would estimate that 75-80% of AMSI's accident investigation clients were also insured, or clients, of our parent company. This fact was well known and discussed at the time. Today, only 15-20% of AMSI's accident investigation business is insured by or clients of our parent. Yet now the board has taken the stand to revoke our privilege and debar us from further representing our client manufacturers. This, I will repeat, is simply a reinterpretation of the same regulation that gave us the status or license in the first place. The other group that petitioned the board, as I am certain that many of you are familiar, was headed by Mr. C. O. Miller. Mr. Miller and the associates who signed the petition set forth a number of proposals which were intended to allow broader participation in aircraft accident investigations conducted by the NTSB. Mr. Miller's petition was rejected in total, every step turned down and the reasons given were much the same phraseology and in some cases, the exact wording that has been used for the past ten years in rejecting proposals of this type. In almost all cases of rejection of these proposals, the reference goes back to the Federal Aviation Act of 1958 which "set forth the responsibilities for the investigation of aircraft accidents" and further supported by the Independent Safety Act of 1974 which bans the admission of Board Reports in tort litigation.

This is where I would like to pause for a moment. The evolution of the NTSB from the CAB in the late sixties was a broad step in setting up, or should I say, separation of the investigation activities within the government. This, needless to say, included not only aircraft but marine, pipeline, railroad, and highway transportation systems. One change that did not take place to any great extent was a change in the regulations governing the investigation of these systems, specifically aviation. No one in this room would disagree that the changes in technology with reference to aviation have hardly been surpassed in the world today.

I spoke here two years ago on the subject of how important it is for manufacturers to have all the facts related to the accident and their product. The manufacturers must have these facts *now*, not only if these facts may point to his product, and that his product may have contributed to the cause, but just as importantly, that it did not. How did it hold up under certain impact conditions? With a certain number of hours on it? With a certain maintenance package, etc. A manufacturer with a knowledge of these things will make every effort to improve his product, which could in time prevent a re-occurrence of the same type of accident. These are obviously steps toward the prevention phase and a promotion of aviation safety. However, it cannot be done without all the facts, and why should the manufacturer have to wait for the submission of the facts? He should have the prerogative to be there as they're being discovered and participate in the discovery before they are lost or destroyed.

I may have drifted slightly off the subject here, but the point I'm trying to make obviously is that there *is* a need for change in the regulations, at least some of them. C. O. Miller's group not only outlined the problem, it gave viable alternatives and/or suggestions as to what could be done. As I have stated, all were rejected in a four page letter.

The regulation we're discussing is, of course, 49 CFR 831.9(C). I feel the background of this regulation is interesting. Believe me, I asked for years, "Why?", and never could get a straight answer. Most of these answers were, "That's the way it's always been", a phrase I heard many times during my ten year affiliation with the U.S. Air Force. My affiliation with the U.S. Air Force did educate me in many ways; however, one axiom I firmly believe and have seen demonstrated that it is indeed true, is, "If it's been done that way for ten years in today's world, then it's got to be wrong."

After searching high and low for a "why" for this particular regulation, I think I finally found the answer. The original regulation which prohibited representation of persons such as attorneys, insurance, representatives of claimants, etc., was originated in the mid-fifties and was expressly applicable at that time to the CAB Public Hearings, again mainly in major catastrophies. Attorneys, and probably others, were using the public hearing as a discovery tool. When the government had witnesses on the stand, all would take advantage of getting their shot in . . . which, of course, would tie up the proceedings. I am sure I can't blame the attorneys; if they had the opportunity, they certainly should take advantage of it. The CAB saw fit to draw up a regulation that would prevent this, and that regulation became the birth of what is now 831.9(C). Note that it did not expressly apply to the on-scene phases of the investigation. At the time, it merely applied to the public hearing . . . and I might add again . . . for good reason.

The revision of the CAB Rules of 1957 provided for designation of "Parties-to-the-Investigation" and its hearings. These "parties" would have the opportunity to question witnesses following questions by the board personnel. The CAB, after studying the overall reaction to these rules for sometime, approved them with only one main opposing party . . . claimant attorneys. The CAB denied these requests stating that the original purpose of parties at hearings was "not to enhance the position of these parties, but to assist the board in developing a more factual record."

The NTSB assumed the responsibility of aviation accident investigations from the CAB in 1967. They also adopted the present rules (formerly CAB Part 303) and renumbered them 431 of Title 14 of the Code of Federal Regulations (CFR).

In 1971, Part 431 was amended to include rules applicable to the field phase of the investigation and therefore, Parties-to-the-Investigation along with the Parties-to-the-Hearings, had separate distinction. Unfortunately, the rules were not changed or should I say, not adapted specifically to the hearing phase vs. the on-scene or field phase. The old prohibition of attorneys, insurance, etc. was simply applied to the field phase.

My point, again, is that a rule was written or established in the fifties for what I'll say was good reason . . . if it applies to the public hearing phase. But . . . why simply let the rules slide over to the field investigation phase when the original intent is not even applicable here; i.e. the witness interviews which I discussed earlier?

My time here is limited; however, I know that there is agreement in this audience that there have been many changes in the on-scene investigation phase over the past decade. When I started investigating—and mostly general aviation accidents—the personnel participating on scene usually included the NTSB, maybe the FAA, AMSI (representing his manufacturer client) and possibly, but not usually the airframe manufacturer. Now . . . even the same general aviation aircraft with two fatal injuries ends up with a cast of thousands (so to speak), all feeling they have a genuine interest in being there. These people are the American public, and many do indeed have an interest in being there, an interest not as prevalent a decade ago.

I'm simply advocating a change. I've heard it discussed for the past seven years . . . "We're looking at that", but petitioners are turned down year after year with the same "canned terminology" and we've seen no change to date. The fact of the entire matter is there are interested parties, be they companies or individuals, who *do* have genuine interest and rights to be there and who can indeed add to the overall investigation. The enhancement of the investigation may be in the form of expertise and deeper knowledge of a particular product; it may come in the form of financial assistance in efforts to rightfully continue an investigation and uncover more facts; or it may simply be another set of eyes, ears and knowledge to help the NTSB toward its goal.

Last Thursday night President Reagan went on public television to better clarify his new program and mentioned a few items that will definitely apply to this situation. I guess I was astounded like others, to hear that we're reaching a national debt of "one trillion dollars and the interest alone exceeds ninety-six billion per year, more that the combine total profits of all 500 companies listed in the Fortune 500." The President further discussed how he planned to curb this debt. I think every department in the United States Government with the exception of Defense and the Social Security Program was "hinted" at as a potential target for a decreased budget for the next few years.

The manning and budgeting problems of the NTSB are no secret. Formal schooling and/or training was curtailed several years ago. Even the in-field investigators have told our people that they will be expected to accomplish 3-4% more investigations next year with the same, or no increasing in, manning. I'm sure we can all help . . . but at the moment the regulation, or should I say the interpretation of the regulation, prohibits much of this voluntary assistance.

In conclusion, I will re-emphasize "If it's been done that way ten years in today's work, it's *got* to be wrong."

Remarks

Capt. Oded Abarbanell MO0593

The form and quality of air safety investigation outside of the U.S.A. is greatly influenced by the Chicago Convention (1944), its Annex 13 and its Manual of Aircraft Accident Investigation as well as all allied material to the above-mentioned documents. It should be realized that the Convention, its Annexes and all its auxiliary materials are an issue of innumerable and endless conferences, where national legislation and practice of all member-states to the Convention (there are today 156 such member-states) were thrown, in the form of verbal and written proposals, into the melting-pot, wherefrom they emerged in the form of international standards and recommended practices. The effort is, unfortunately, by far not perfect or ideal and it is no wonder that the U.S.A., though a veteran and important signatory to the Chicago Convention has wandered far and wide in its quest for better and more reliable investigative procedures.

Whilst the mighty means and ability of the U.S.A. has led her to develop, within 50 years, an awesome and amazing investigative tool which is constantly hampered by the very same ultra-democratic laws and regulations which enabled its formation—other, less mighty nations in five other continents tried to shape and model their own investigative procedures and machinery along the lines of ICAO and the NTSB, but were not always very successful.

It may shock our North American members to know that the concept of "air safety investigator" or "aircraft accident investigator" is neither known nor accepted in some African and Asian countries. That some countries do not have even one single pathologist (let alone aviation pathologist) residing within their boundaries (Swaziland; Malawi). That in some countries in Western Europe the investigation of an aircraft accident is carried out by the police (Belgium), frequently the police station next to the *loci delicti*, and that some of these police forces do not have a single properly trained aircraft accident investigator. That in many European countries whose legal system is based solely or partially on the *Code Napoleon* the investigation takes the form of a *Proces-Verbal* carried out by a public official who has no training or knowledge of air safety investigation and that in many cases this is the end as well as the beginning of the investigation. That in most Asian and African countries the fatal accident is "investigated", or more appropriately "inquired", by a public board appointed by the Minister of Transport and composed mainly of prominent citizens or public personalities, lawyers and employees of the national aeronautical authority, none of which is a trained investigator and most of whom are there for political reasons only. That in some countries it is held that the accident should be investigated by a pilot or by any two or all three of these but not by a person specifically trained and qualified to do the job of investigating an aircraft accident.

As far as the petition at hand is concerned I would like to state my bewilderment at the opening statement which mentions the "aviation community". What is an aviation community? Who is and who is not part of an, or the, aviation community, in the U.S.A., and abroad?

Personally, I am strongly for an investigator certification requirement and would like to see one not only in the U.S.A. but around the world, possibly through the good offices of ICAO. However, it should be clear to all of us that if we are aiming to get qualified and properly motivated personnel representing all affected parties into the field and hearing phases of the investigation we shall have to have personnel that were properly trained before being properly certificated.

In order to train and certificate them properly we must have a full set of good, sound and efficient criteria and standards to which these personnel shall be trained, examined and certificated.

This should not remain an American effort. The international interface should be considered. The frequent occurrence of an "international" accident should get a new, professional and efficient answer on this occasion.

Consider another Tenerife or another Armenonville type accident. Consider an accident to an aircraft manufactured in Israel, registered in Swaziland, flown by a crew of Austrian citizens holding FAA licenses and ratings, carrying passengers from Yugoslavia, Benin and Iceland and crashing withing the territorial boundaries of Upper Volta. Consider the board of investigation which will be set up, including people from all the above-mentioned countries, holding different capacities or status on the board and who were not all trained and certificated uniformly along the same standards and practices. What kind of backfeed may we expect from such an investigative Tower of Babel? What will be the benefit to future flight safety from the report of such a board? And last but not least - what kind of social justice may parties hurt in the accident expect?

Humanity is already badly divided when it comes to social justice. The children of a British subject get 10% of the compensation given to the children of a U.S. citizen although both parents were killed in the same accident. Let us not add to the confusion and injustice by letting the wide variance of investigative standards and practices continue on its blind path of trial and error.

I would like to see an international effort sponsored either by ICAO or by a major aviation power such as the U.S.A. and with the Active participation of ISASI. Possibly an international congress or conference where all ICAO member-states will be represented and ISASI will be given special member's status.

One of the most important items on the agenda of such a conference should be the standardized advanced training of the aircraft accident investigator. This training, and the following certification should be broken in two: Undergraduate training awarding a general, non-specialized, investigator's certificate and post-graduate, specialized training, awarding a specialized investigator's certificate.

Petition to Add Additional Parties to the NTSB Team—The Public Viewpoint

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The general public is concerned with safety. Safety is the primary reason for aircraft accident investigation. This assumes that during the course of the investigation all facts pertaining to the crash will be discovered and objectively studied and reported. While this may be the objective of the present procedures followed by the NTSB, some deficiencies and abuses of these procedures may detract from or prevent the accomplishment of the stated purpose.

At the outset, it should be recognized that there is a substantial difference in both quantity and quality between investigations of air carrier crashes and general aviation crashes. Without any criticism or discussion of why these differences occur, the fact is they do. This presentation will be directed toward the general aviation aircraft accident investigation.

The Problem

Under the present procedures and practices a typical accident investigating team consists of an investigator in charge from the NTSB regional office, a representative of the FAA from the local GADO office, and a representative of the aircraft manufacturer. Depending upon the circumstances, additional representatives from component part manufacturers; e.g., the engine, may also participate. Many manufacturers are represented by Aerospace Management Services International (AMSI), a subsidiary of United States Aviation Insurance Group.

While the owner/operator of the aircraft has a right to representation on the accident investigation team, such representation is rare. Either the owner/operator is not aware of this right, or does not have immediate access to qualified investigators. Cost can also be a deterrent.

In addition to the obstacles encountered by the owner/operator, representatives of the passengers would not be allowed participation with the accident investigation team, even if it were requested and a highly qualified accident investigator was tendered.

This practice does not afford the opportunity for a complete investigation and discovery of all pertinent facts, and provides an opportunity for some information which might otherwise be of value to be overlooked or minimized.

Specifically, the long recognized concept of design induced pilot error has been practically ignored in most general aviation accident investigations. Once information is developed indicating pilot error, the investigation stops. Manufacturers are all too content with establishing pilot error or inadequate maintenance as the cause of most crashes, and the NTSB investigator is all too willing to rely upon the information and opinions supplied by the manufacturer. Without the presence on the investigating team of additional expertise and funding ability, the NTSB investigator has not real choice to do otherwise.

Design induced pilot error is a fertile field for those who are truly dedicated to accident prevention—safety. Why pilots err has not been adequately pursued. The general phrase "pilot error" has been continually and readily accepted as the probable cause of most general aviation accidents. This limitation in the investigative process does not prevent accidents and adds little to aviation safety. On the other hand, the determination of why pilots err and elimination of some of these causes could make a substantial contribution to accident prevention.

The flight characteristics, performance, operational instructions and warnings in general aviation have not been pursued with any regularity under the existing NTSB procedures. The time limit on this presentation will not allow a listing of the specific areas in which such investigations might prove fruitful. The list is too long. For those interested, a partial list is included in a paper presented at the July, 1981, symposium hosted by the San Francisco Regional Chapter of ISASI and published in the Fall, 1981, issue of ***forum***.

The NTSB Reply to the Petition

The NTSB seems to take the position that an investigation "for the purpose of discovering the facts, conditions, and circumstances concerning an aircraft accident in order to determine the probable cause of the accident and to ascertain the measures which will best tend to prevent similar accidents in the future" is inconsistent with and opposed to inquiries "held for the purpose for determining the rights or liabilities of private parties" and that its mission "to promote the public interest" does not involve "the advancement of private interests."[1] These are not inconsistent objectives but are mutual. They are both dependent upon the complete, objective development of all facts. This is the purpose of the petition.

If the purpose of permitting participation in the investigation is "to assist the Board in developing a more complete factual record" in the hopes that selected parties will "contribute specific, factual information or skill which would not otherwise be supplied," and if it is the NTSB's objective to utilize "all available fact finding sources outside of the Board's own staff" as a "means of developing a complete factual record," there is little justification for excluding certain qualified aircraft accident investigators from the investigating team. The best way for all facts to be developed is to have all interests represented.

No one can criticize the Board's objective "to conduct our investigations as free as possible from the influence of pending and future litigation," but that is not what is happening in general aviation aircraft investigations. Why does the NTSB think that the general aviation manufacturers have established a team of investigators who go to the scene of every crash involving their products, participate in the investigation as a member of the team where they can have an influence on the extent and direction of the investigation? Why does the NTSB think that at the completion of the investigation the manufacturer's investigator does not file a report with his enginerring department, but sends the *only* copy of his report or the results of his investigation to the manufacturer's general counsel?

If "the Board cannot permit its statutory objective to be thwarted by the designation of persons whose interests lie beyond the legitimate scope of the accident investigation," why do they continue to allow and depend upon the manufacturer's investigators without some counterbalancing representation? Does the NTSB really believe that the general aviation manufacturers who have devised procedures to help them defend product liability actions by having one of their investigators on the NTSB investigating team, who reports directly to general counsel, do not have interests which "lie beyond the legitimate scope of the accident investigation"?

The NTSB seems to harbor some fear that its investigations may become "more adversary." What is wrong with the presentation of conflicting ideas? It is the adversary nature of a proceeding that tends to uncover all of the facts. The closed, in-house country club atmosphere tends to produce the opposite.

Let's take a look at how the present procedure and practice works. Nearly all general aviation manufacturers have designated certain of their engineers as accident investigators. In fact, the sole duty of many of these persons is accident investigation. Arrangements have been made for the manufacturer to be notified immediately each time one of its aircraft is involved in a serious accident. It then dispatches one of its investigators who oftentimes arrives ahead of the NTSB investigator in charge, or on other occasions, provides the NTSB investigator with transportation to the accident site on a company plane.

The manufacturer's investigator then obtains and documents such information as he deems appropriate. As a member of the team, he not only has an influence on the direction or the extent to which an investigation will proceed, but is called upon to supply expert information to the investigator in charge. After the investigation is complete, the manufacturer's investigator returns to the factory with his notes, memorandums and other documents evidence on the investigation's findings.

What does he do and where does he go then? One might think that in the interest of safety and in order "to ascertain the measures which will best tend to prevent similar accidents in the future" that he would make a report to someone in the engineering or flight test department. This is not the case, or at least so they claim. Instead, he prepares only one report which is then delivered to the manufacturer's general counsel solely for his use. Therefore, all notes, memorandums or other evidence of the investigator's findings, conclusions or opinions are destroyed. Other than in the memory of the investigator, the only evidence of his investigative results are in the single report carefully guarded by the general counsel.

Later, when the manufacturer's investigator's factual findings, conclusions and opinions become important in litigation in an attempt to discover all pertinent facts relating to the various causes of the crash, the manufacturer takes the position that their investigator's report is privileged and immune from discovery, since it was obtained "in anticipation of litigation" and that it constitutes the "work product" of its attorney, since his influence on the preparation of the report has been such that it contains the attorney's mental processes and legal theories.

In the past, some courts have actually condoned this practice, and from a lack of accurate information, have summarily ruled that these reports are not discoverable. Fortunately, in more recent hearings presented with a full record, including depositions outlining the true nature of the manufacturer's procedure, as opposed to the manufacturer's one-sided characterizations by affidavit, courts are now requiring production of these accident reports. But this is not accomplished without a long and time consuming fight. This same fight occurs in every case and conclusively establishes a concerted effort by the manufacturer to use its investigators for the sole purpose of enhancing its position and otherwise assisting in the defense of any litigation that may grow out of the crash of its aircraft.

With this record, and against this past history, how can the NTSB take the position that to allow qualified investigators selected by the representatives of passengers would "permit its statutory objective to be thwarted by the designation of persons whose interests lie beyond the legitimate scope of the accident investigation"? Does the NTSB really think that their present practice of admitting to the investigative team those selected by the manufacturers does not violate this objective?

Under present NTSB regulations, no party to the investigation may represent claimants or insurers. However, most general aviation manufacturers are partially self insured, or at least they conduct their legal activities for the benefit of their insurers. Is it fair to disqualify an otherwise qualified investigator because he represents a "claimant" and yet allow on the investigating team a representative of one who defends against the "claimant"? This one-sided approach is not conducive to the full, objective discovery of all pertinent facts "to ascertain the measures which will best tend to prevent similar accidents in the future."

The NTSB also attempts to excuse its denial of this petition by its statement that since the claimants "have access to the results of our investigations and they can depose our investigators, we believe that the position of litigants is adequately protected." This overlooks the main thrust of the petition. Under the present procedure, passengers' representatives are not "privy to all of the factual data uncovered during the course of the investigation" and are not provided "an opportunity . . . to express any concerns that they may have concerning the status and conduct of the investigation" until long after the investigation is over, if then.

After the investigation is closed, after the parts are destroyed or lost, after the public accident report finally becomes available, it is too late to conduct meaningful investi-

The Great Excuses

Luncheon Address
to the International Society of Air Safety Investigators
September 29, 1981

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As I look at the airline industry in 1981 and 1982, I see it is suffering from a disease I call "The Great Excuses". The symptoms for the Excuses are: "Reagonomics", airline deregulation, 1980—the safest year in the airline industry, the Air Traffic Controllers strike, and the so-called high "cost of safety". "Great Excuses" is a terminal disease if not arrested in time. Today I will suggest some simple and logical medication for this infection.

The entire airline industry has the right to boast that 1980 was by far the safest year in aviation history; but in 1981, we're seeing an assault on the safety precautions that contributed to this achievement. No air carrier, government body, Congressional Committee, union, or anyone else has the right to revoke the public or the workers' right to safety. Why was 1980 the safest year in aviation history?

We cannot stand idly by as safety programs in government, private industry, and unions are being cut back and scrapped under the guise of "Economics". To say that a dollar value should be placed on safety is a "bunch of bunk". Lest we all lose our heads and end up believing in what some of our higher government officials have tried to convince us of, we just might fall back into the old economics vs. safety trap—Watch out!

Many of you here today can influence the outcome of aircraft occupant safety now, six months from now, a year from now, and even five years from now simply by trying to understand the dangerously naive and over-confident attitude toward safety that currently exists in the airline industry.

True, the economic picture in the airline industry is not the best and it could get worse. However, we can proudly boast (and this may be the crux of our problem) about safety. Over the past ten years the government, industry, Congress, unions, and others have developed programs and procedures through meetings which have resulted in an exchange of ideas. This has led to a positive level of preventative safety—enough to allow life-saving safety features, which have also prevented many needless injuries. Certainly airline safety regulations have not been adopted to the degree that many of us would like to have seen. Although all of us shared our disagreements as to the method of change, these disagreements did not diminish the importance of change, and, we can agree that we never shirked our duty or responsibilities to our constituents, the public, our members or our companies—THAT is how we attained the 1980 Safety level.

- It didn't just happen
- It wasn't just a fluke
- It didn't just involve exclusive attention to Airworthiness
- It didn't just involve attention to Crashworthiness solely
- It didn't involve phenomenal amounts of funds allocated to Safety programs
- It didn't just involve only one fraction of the airline industry accomplishing this goal

It took:

- Years of research and development
- Years of cooperation
- Reasonable allocation of funds for each group or faction
- Interest and dedication
- And a lot of hard work

I, too, could have been infected by the latest "Great Excuses" diseas, but I've been spending most of my waking moments analyzing the situation and I have decided that we all need to "fight back". "Reaganomics", as necessary as it is in many instances, cannot be the great excuse for justifying cuts in the airline Safety field—Neither can deregulation or the Controllers strike be used to excuse the cuts in Airline Safety research and development. Most of us can go along with economy in government. We all must cut back on our spending, but we're in a sad state if we lose sight of our priorities. We might be millionaires but we also might be dead. We can become greedy and shift our money priorities to wages or airline operation, but will our companies survive if they injure or kill our employees or passengers? Once this happens we become a reactive society with respect to the airline business—and public suspicions about airline safety will again arise—with needless economic catastrophe for more than just a few carriers. A dollars' worth of preventative safety now could well save thousands or even millions of dollars later. Some officials in our government have convinced many in the airline industry that survival depends upon minimizing costs. These same officials have boldly stated that because 1980 was the safest year in the airline industry it isn't necessary to be safety conscious anymore. This is WRONG: PREVENTION—and not REACTION has been the key to our success.

It *is* necessary to trim the fat, but let's not forget central issues and don't forget our obligations to our membership, constituency, airline, or those we represent to continue to fight for, maintain, and improve airline safety. All of our lives depend on it.

gations or pursue areas of inquiry which were "overlooked". Once the opportunity is gone, it is too late. Otherwise pertinent and helpful information is no longer available.

Certification of Accident Investigators

To the extent that those presently engaged in the NTSB investigation team are qualified, this petition should create no problem to their certification. Certification would also assure that investigators representing passengers are also qualified and would be one way to reduce the number of representatives on the investigative team.

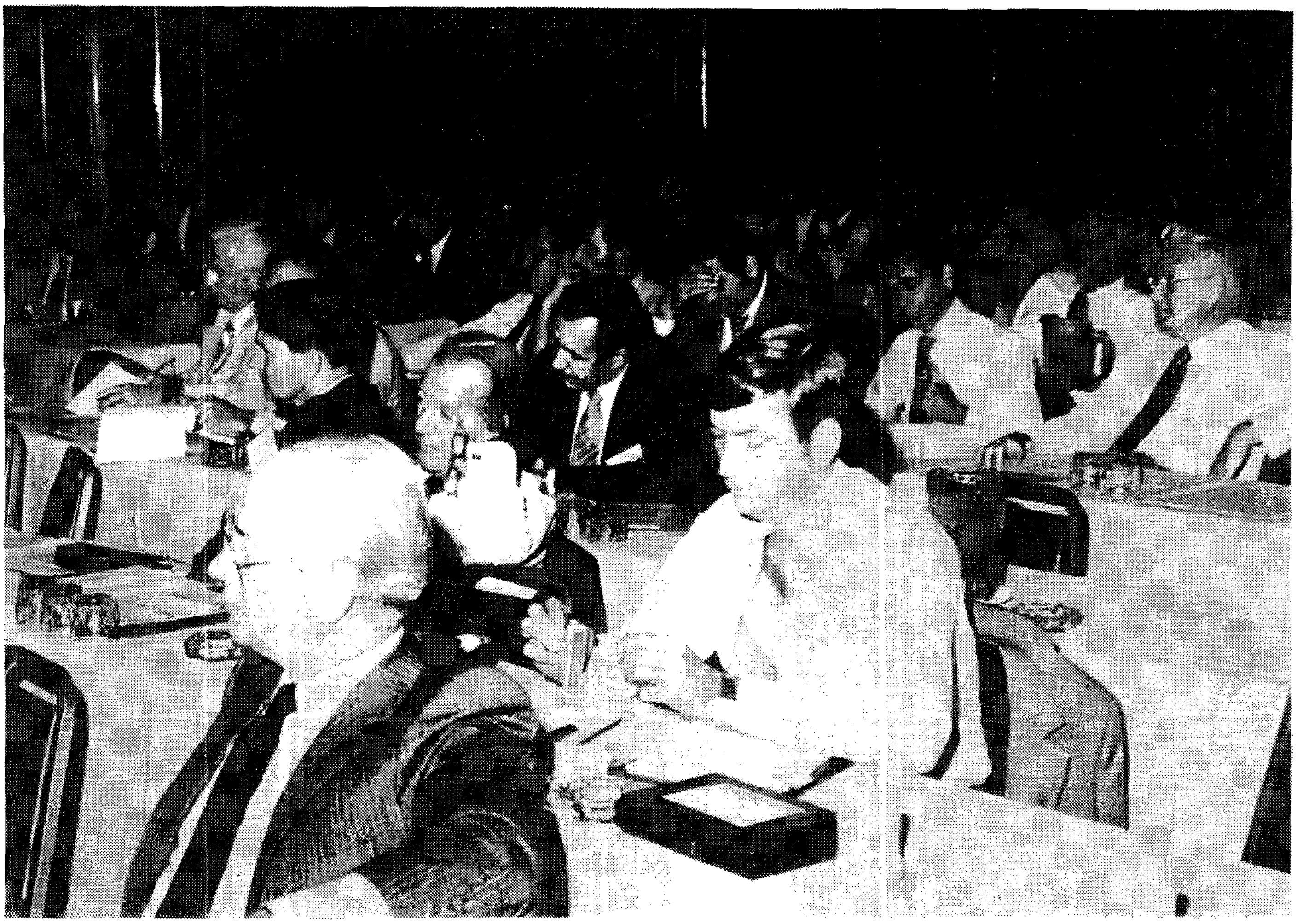
Conclusion

There is no contention that the manufacturers' investigators cannot contribute to the investigation, or that they should be excluded. It is contended, however, that the NTSB should not close their eyes to the reality of the situation and allow the one-sided investigations to continue, by claiming that they cannot admit qualified investigators representing the passengers, because they cannot allow "the designation of persons whose interests lie beyond the legitimate scope of the accident investigation." Who do they think they are fooling by allowing representation by the manufacturers, and at the same time contend that they are conducting their investigations "as free as possible from the influence of pending and future litigation"?

It is time for the NTSB to face up to the facts. While their objectives might be worthwhile, the procedures they have adopted and allowed to exist are not in keeping with their stated purpose. When all sides are represented, all facts will be discovered, and not until then.

References

1. All quotes used in this presentation are from the NTSB reply to C. O. Miller dated August 3, 1981, and published in the Fall, 1981, issue of ***forum***.



The grass roots of any organization or company wants you and me to provide them with guidelines to safe living and in our business—it's safe flying.

Public safety has to be a high priority item—we do have a responsibility to other human beings. The public has come to believe that we—the airlines—have a safe business. This perception breeds complacency among airlines and even union officials, particularly in a depressed economic situation. But think for a moment if—for whatever reason you may imagine—that the public perceives the airlines to be unsafe. Ladies and Gentlemen, in our hearts, in our honest opinion, can you, an airline representative, you a union representative, you a government official, you an airline consultant, justify a program within your structure which is enacted after the fact, rather than one which is preventative? I can't and I won't put up with it in my organization . . . and I won't watch it happen in your corner of the aviation field.

So when you, the Air Safety Investigator, are standing in the midst of this tug-of-war, just how can you help?

You represent a cross section of the aviation world: government, airlines, unions, private industry, universities, and so forth. We all share the responsibility of promoting safety programs. Many of us meet face to face at aircraft accident sites. 1850 people were injured or have lost their lives in major survivable air carrier accidents since 1970. It is our responsibility to promote programs to diminish or prevent injuries and deaths from occurring in the future. More than counting the dollars that we must spend to help avoid some or many of those 1850 injuries and deaths, our obligations should lie in knowing that we can assure the families of these accident victims that we are making an honest effort to prevent future accidents. We need to insist that outdated regulations be rewritten to adequately protect aircraft occupants. We can request that safety programs that have been scrapped or curtailed by reviewed for possible reinstatement.

The report that the National Transportation Safety Board will soon release entitled "Cabin Safety in Large Transport Aircraft" purports to illustrate, once again, the need to institute safety programs, retain safety programs, and study alternatives in an effort to make airplanes a safer place to be—Stand up for your rights and the rights of the public . . . Insist on preventative safety . . . not reactionary safety or that which is also known as "tombstone safety". Remember: Safety should not vanish at the end of the runway.

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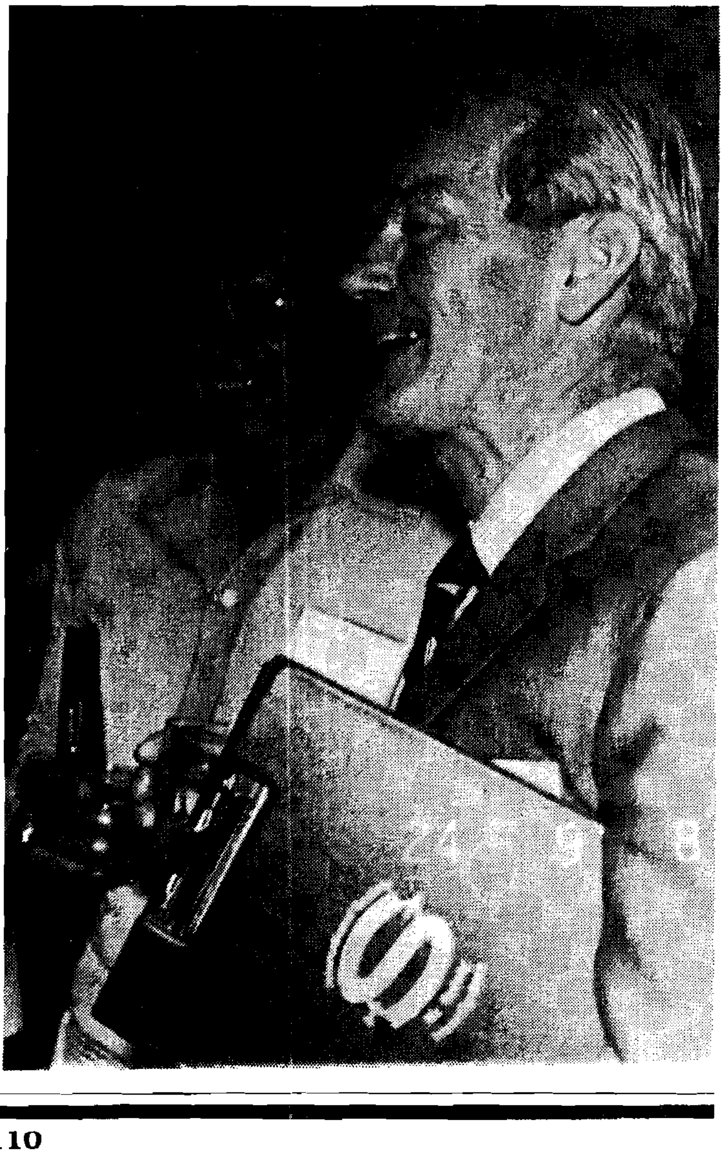

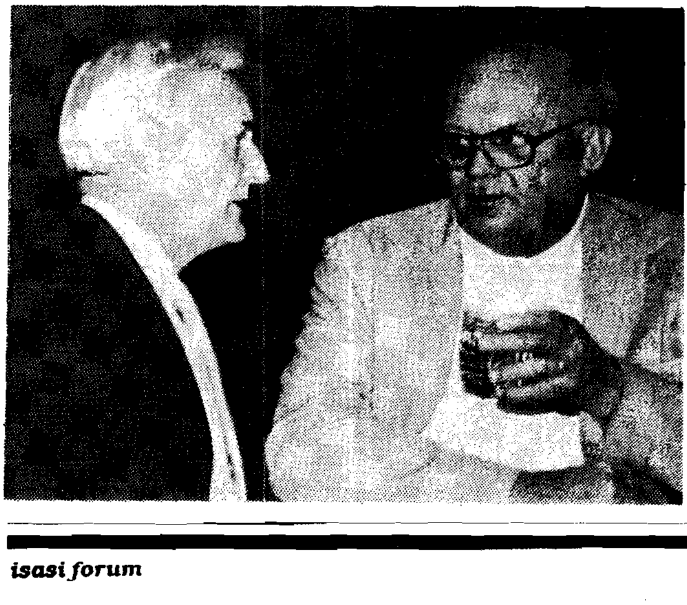

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